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(Review Article)

The foundations of the nature of science as a tool for teaching and learning scientific concepts

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Abstract

Using the Nature of Science (NoS) as a tool for teaching and learning science involves integrating the understanding of how science works into the curriculum. This approach helps students not only to construct scientific facts but also appreciate the process, methods, and values that underlie scientific knowledge. Questions about NoS have long preoccupied scientists, but recently, researchers in didactics, curriculum designers and science teachers are concerned how NoS can improve the teaching and learning of scientific concepts. While some authors have argued that science students be taught about the Nature of Science to develop their competences in science, others believe that science education should focus much more on constructing theoretical than functional knowledge. We believe that for learners to significantly improve their learning of scientific concepts, they need to understand the process of scientific thought, the Nature of Science. Thus we propose the fundamental concepts of NoS be used as a tool for knowledge constructions in the design of teaching and learning activities.

Keywords: Nature of science; Knowledge construction tool; Teaching and learning science; NOS Fundamental Concepts.

1. Introduction

Questions relating to the Nature of Science (NoS) have always preoccupied researchers (historians of science, psychologists, philosophers of science, anthropologists, etc.). According to Hansson and Yacoubian (2021), these concerns have led to various conceptualisations and limits of the NoS in recommendations for its teaching. Recently, however, the question of the Nature of Science in teaching/learning has become a central concern for didactic researchers, curriculum developers and science teachers (Hasni et al., 2020).

Some authors (Lederman et al., 1997) believe that the acquisition of concepts and the development of scientific skills by learners require an understanding of the scientific thought process. In the same vein, Reif (1995) believes that science teaching should focus much more on the construction of theoretical rather than functional knowledge. Indeed, the Programme for International Student Assessment (PISA) argues that learners should be scientifically literate and cultured, with a thorough understanding of the nature of science, its limitations and the consequences of its application.

The aim is not only to train scientists, but also to help learners acquire a scientific culture that is civic-minded (Maurines et al., 2013). Emphasis must be placed on introducing practices that help learners to better understand the image of science and scientific activity. Our hypothesis is that the use of the fundamental concepts of the NoS as a conceptual tool in the construction of teaching and learning activities in science is indispensable.

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2. Problem statement

Science has an undeniable social aspect, influencing practically every aspect of daily life. Whether we are talking about the technological development that is one of its fruits or the philosophical implications that flow from its ideas. According to Susan et al (2021), science and technology are synonymous with economic competitiveness and modernity. This encourages all countries to turn more to scientific research in order to diversify their economies. The survey conducted in France on the level of interest in science shows that it has remained virtually stable for several decades. Proof that the love of science has not waned. However, despite this strong influence, a closer analysis of the results of this survey reveals that while the people questioned are so interested in science, they have a rather confused or limited idea of how it works. They have a limited understanding of how scientific activity works. As far as science teaching/learning is concerned, Robardet's observation (1990) that pupils experience serious difficulties in truly practising the scientific approach remains valid. Very recently, the PISA survey conducted by Bret et al (2023) showed that the scientific culture of French learners was declining. Also, much other research (Lederman, 1986) has confirmed that learners' and even teachers' conceptions of the nature of science are often mixed. This non-conformity can lead, as McComas (2002) points out, to a misunderstanding of the character of science. The explanation he gives is that, at all levels of education and in science textbooks, there is a virtual absence of the process of producing scientific knowledge. As for teachers, the author mentions that they rarely have the opportunity to learn how scientific knowledge is constructed. It is therefore not surprising that they do not attach enough importance to this aspect of science for learners. Speaking of teachers, Maurines et al (2013) believe that 'one of the challenges of science teaching is epistemological in nature and that they unconsciously transmit a certain image of science to learners through their practices'. Research shows that textbooks also convey a reduced and distorted image of science through the vocabulary used and the didactic approaches employed (Gibbs & Lawson, 1992).

Moreover, even teachers for whom this dimension is important, Lederman (2007) explains that they tend not to offer learners the opportunity to reflect on the process of constructing scientific knowledge. To improve understanding of scientific activity, a number of studies have suggested placing learners in a researcher's posture (Sawyer, 2006; Allchin et al., 2014; etc.), introducing elements of the history of science into the learning process (Abd-el-khalick & Lederman, 2000; Allchin et al., 2014; etc.) and, more recently, engaging pupils in school science practices (Hasni et al., 2020). It emerges from these studies that very little research highlights the elements of NoS that can be taken into account in the teaching-learning process of scientific concepts, hence the question: what are the fundamental concepts of NoS that can be integrated into the construction of teaching-learning activities of scientific concepts? To answer this question, we first need to define what we mean by the Nature of Science.

3. What is the Nature of Science?

Introducing learners to the process of producing scientific knowledge has become an essential part of science education in recent years. Numerous expressions have been used in research to designate this introduction to the way scientific knowledge is produced, including Ideas about science developed by Osborne et al. (2003); how science works in the work of (McComas, 2017). However, as Hasni et al (2020) point out, it is the concept of the nature of science NoS that has come to designate this initiation. This is due to the consensus on its theoretical foundations and characteristics. According to McComas (2002), the most encompassing expression to describe the scientific enterprise is the 'nature of science' (NoS). According to Sumranwanich and Yuenyong (2014), it is a complex concept and difficult to define for experts and students alike. People interested in NoS come from a wide variety of fields. To better understand it, they ask questions such as: 'What distinguishes science from other human activities?

Are scientific ideas discovered or invented? And how does the scientific community reach consensus?' (McComas, 2002, p. 4). The nature of science is therefore a mixed field that combines aspects of various social studies of science, namely history, sociology, psychology and the philosophy of science

It is the intersection of issues addressed by the philosophy, history, sociology and psychology of science (McComas, 2002). Thus, it is at the intersection of the various social studies of science that the richest vision emerges. NoS can thus be defined as the description of how science works from these multiple points of view (historical, philosophical, psychological and social). To understand the NoS properly, it is necessary to grasp its characteristics.

4. Characteristics of the NoS

A number of studies (Lederman et al., 2002; McComas, 2017; etc.) have identified the various characteristics of the NoS. These characteristics have not always been unanimously accepted by the scientific community.

4.1. Consensus on the characteristics of NoS

The work on NoS carried out by (Lederman & Abd-el-khalick, 2002; Deng et al., 2011; etc.) has led to a consensual vision. This vision makes it possible to define seven characteristics of the NoS: the empirical nature of science; scientific laws and theories; creativity and imagination; the place of theories and the subjectivity of scientists; the social and cultural attachment of science; the myth of the scientific method and the incidental nature of scientific knowledge. Other research (Summers et al., 2019) using this conceptualisation went beyond this vision by completing this list to 12 characteristics. Subsequently, Hasni et al. (2020) readapted them to the study of (Summers et al., 2019) by grouping them into two dimensions:

- The cognitive and epistemic dimension including the tentative nature of science; the myth of a scientific method; creativity and imagination; the empirical character of science; observations and inferences; laws and theories and the subjective character of scientific knowledge.

- The institutional dimension, which brings together the institutional nature of scientific knowledge and the social and cultural roots of science.

4.2. Criticisms of the consensus view of the NoS

Despite the proven contributions of the consensus view of the characteristics of NoS, several criticisms of this conceptualisation have been recorded: Dagher and Erduran (2016) and Matthews (2012) describe the consensus on the characteristics of NoS as 'limited'. According to them, this consensus does not reflect the complexity of scientific activity and is incompatible with the development of its culture (Allchin et al., 2014). In addition, other studies (Dagher & Erduran, 2016; Hodson & Wong, 2017; etc.) point out that this consensus does not take into account scientists' views of their practices and disciplinary specificities. Moreover, it is essentially based on the work of the philosophy, history and sociology of science. On the other hand, Romero-Maltrana et al (2019) add that the consensus on NoS gives the feeling that its characteristics make science only a myth, as it has no precise method and is not based on solid evidence. As a result, it is provisional like other forms of knowledge. Indeed, for Hodson and Wong (2017), observations in science are not merely perceptual, but rest on theoretical foundations that make it possible to explain them. Thus, as Hodson and Wong (2017) show, the observation of a phenomenon in science is not limited solely to its visual perception, but is based on a reflective reading of the phenomenon observed. Similarly, (Dagher & Erduran, 2016) argue that the provisional nature of scientific knowledge casts doubt on science's ability to understand the natural world objectively. In the teaching/learning process, Dagher and Erduran, (2016) point out that the main limitation on this consensus on NoS is the fact that the characteristics that describe it offer little guidance for developing curricula and guiding teaching practices in science. On the other hand, Matthews (2012) points out that this list has long been used in classrooms as 'commandments' rather than being used to lead learners to develop understanding of scientific activity.

In response to these criticisms, some research has proposed a reconceptualisation of the NoS:

- placing the actual practices of scientists at the heart of understanding how science works. For Hodson and Wong (2017), learners will be able to take part in the scientific activities of researchers;

- other research (Dagher & Erduran, 2016,) proposes comparing scientific disciplines in order to highlight their similarities and specificities, in terms of methodology, theory, values, etc. ;

- talk about the characteristics of science instead of the nature of science. For Matthews (2012), it will encompass more inclusive ideas about science than those re-held by the NoS vision.

These characteristics include, among others, experimentation, models, mathematisation, technology, socio-scientific issues, values, and so on.

In view of the criticisms levelled at previous conceptualisations, we believe that it is necessary to define the fundamental concepts of the NoS that can be used as tools in the construction of teaching activities learning about scientific concepts.

5. Fundamental concepts of the NoS for constructing teaching and learning activities for scientific concepts?

One of the main responsibilities of science teachers is to provide a description of scientific activity and to engage their learners in argumentative exchanges of their point of view. In the absence of consensus in teaching, as recommended by McComas (2002), the science teacher must present a plurality of viewpoints in the sense that science teaching is not indoctrination, but the exchange of reasons for accepting a divergence of viewpoint (Matthews, 1997). On the basis of the characteristics, criticisms and reconceptualisation of the NoS, we present the fundamental concepts of the NoS that we consider essential to integrate into the construction of teaching/learning activities for scientific concepts.

5.1. The creative and imaginative nature of science

Science requires creativity not just in experiments but also to develop new theories and models. There is therefore the need for teachers to encourage students to think creatively in designing experiments or solving problems. Designing classroom activities should incorporate creativity.

Science is not an entirely rational or systematic activity (Hasni et al., 2020). Its nature as defined by Rubba and Anderson (1978) is a creative and imaginative activity (Bohm & Peat, 1987). Scientists do not work solely with data and well-developed theories. They often have only provisional hypotheses about the explanation of certain phenomena. Some scientific discoveries are unexpected or even accidental. But it usually takes knowledge and creative thinking to recognise the significance of the unexpected. Creativity is involved at all stages of scientific investigation and allows us to ask original and interesting questions. It is through creative thinking that scientists build models that enable them to understand or explain the phenomena they are studying. Although scientists use a great deal of imagination and thought to formulate hypotheses and theories, sooner or later they have to be tested.

5.2. Empirical nature

Although scientific knowledge relies more on imagination and creativity, it also relies on observation, experimental evidence, rational argument and scepticism (Rubba & Anderson, 1978). Teachers should design activities in their lessons plans that will encourage students to engage in experiments where they collect data and draw conclusions based on that data. The validity of scientific assertions is established by reference to observations of phenomena. Scientific explanations must be based on evidence. This evidence is obtained either through experiments in situations ranging from the natural environment to totally artificial situations such as laboratories. To make observations, scientists use their own senses and instruments. In certain circumstances, scientists can deliberately and precisely control experimental conditions in order to obtain evidence. Scientific knowledge is durable, but it is also provisional and subject to change.

5.3. The provisional and dynamic nature of science

Teachers should use historical case studies to demonstrate the shift and evolution of scientific knowledge (e.g. shift from geocentricism to heliocentrism in the Copernican Revolution in astronomy; the discovery of the structure of DNA in biology; the Germ theory of disease in Medicine; the theory of Evolution by Natural selection in biology; etc.) to teach students that scientific knowledge is not absolute but can change with new empirical evidence.

The evolution of science is inevitable in the sense that new observations can call existing theories into question. No matter how good a theory is at explaining a set of phenomena, it is possible that another theory will fit just as well, or even better, or that it will fit an even wider range of observations. Moreover, they recognise their limitations and cannot answer all questions or explain all natural phenomena. So the evolution of knowledge is inevitable, because new observations can call into question the dominant theories. Science is therefore an evolutionary process, in that scientific knowledge is constantly being questioned, modified and improved as new evidence and new discoveries become available. In this way, science is able to revise and update existing theories in the light of new information.

5.4. Observation in science

The promotion of inquiry based learning in the curriculum where students ask questions, conduct experiments and draw conclusion is very essential.

This process mirrors the scientific process and helps students understand how scientific knowledge is constructed. If the teachers engages students in reflective discussions about how their activities reflected the nature of science, this will further deepens their understanding of science.

Observation in science is not limited to perception, but is based above all on a reading informed by the knowledge already acquired (Hodson and Wong (2017). In this sense, Hasni et al (2020) mention that there is a big difference between observations and scientific inferences. Observations are descriptive statements about phenomena that can be perceived through the senses or observation instruments, whereas inferences are statements about phenomena that are not directly accessible to the senses. As Abd-el-khalick and Lederman (2000) point out, scientists simply describe and measure things as they perceive them. These observations depend above all on their knowledge, beliefs and vision of the world. This is what we call the integrated model of the scientist. It is this integrated model of the scientist that enables him, using the rules of logic and induction, to formulate hypotheses or develop theories that provide explanations for phenomena.

5.5. The myth of a single scientific method.

Scientific research is not easy to describe outside its particular context. As McComas et al (2002) point out, there is no single way of doing science; in other words, there is simply no fixed set of steps that scientists always follow, no single path that infallibly leads them to scientific knowledge. There are, however, certain characteristics of science that give it a distinctive character as a mode of inquiry. Although these characteristics are mainly specific to the work of professional scientists, anyone can exercise them by thinking scientifically about many subjects of interest in everyday life.

5.6. Scientific laws and theories.

According to McComas et al (2002), laws and theories play different roles in science, which is why learners should clearly differentiate between them. There is a relationship between laws and theories. A law predicts what will happen and a theory explains why and how. However, one does not become the other, regardless of the relevance of accumulated empirical evidence.

Laws are generalisations, principles or models and theories are explanations of these generalisations. According to Hasni et al (2020), scientific laws are descriptive statements of the relationships and generalisations observed between the quantities describing a phenomenon.

As for theories, Vorms (2013) indicates that they are the result of investigation or meticulous observation of certain phenomena and make it possible to predict their behaviour by deduction.

5.7. Subjectivity in science.

Although considered to be objective, scientific activity is a human activity and always contains traces of subjectivity. The values, ideology and personal knowledge of scientists have a huge impact on the observations and proposals they formulate based on the phenomena they study. Engaging students in discussion on different scientific theories and how they were developed will enable learners understand the subjective nature of science, as they will discover how scientists' background, experience and perspectives can influence their interpretations of data.

5.8. The social and cultural roots of scientific knowledge.

Scientific activity involves many people from all over the world. People from all cultures contribute to science. As a social activity, science inevitably reflects social values and viewpoints. According to Hasni et al (2020), all scientific activity is influenced by the social and cultural context in which it takes place. The direction of scientific research is affected by the prevailing scientific paradigm and/or by political, religious and economic influences.

If teachers introduce case studies of scientific developments in different cultures in the lessons, this will enable students understand how science is influenced by the society and culture in which it is practiced.

5.9. Institutionalisation and ethics in the production of scientific knowledge.

Scientific knowledge is most often established institutionally, since it is subject to communication, criticism and validation by the scientific community (Hasni et al., 2020). For this reason, new knowledge must be communicated clearly and openly for peer review. This ensures its reproducibility. Most scientific research is conducted according to the ethical standards of science. The well-established postures of gathering accurate information and replicating results, reinforced by critical peer review, enable the vast majority of scientists to remain within the bounds of ethical professional behaviour.

5.10. The relationship between science and technology.

Science and technology influence each other. The development of information technologies affects all sciences. These technologies speed up the collection, compilation and analysis of data, making new types of analysis practical and shortening the time taken to process data.

5.11. Science is organised into disciplines.

From an organisational point of view, science can be considered as a set of different scientific fields or disciplines. From anthropology to zoology, there are dozens of scientific disciplines. They differ from one another in terms of the phenomena studied, the techniques and language used, and the types of results desired. According to Matson and Parsons (2002), scientific disciplines have no fixed boundaries. Physics is often confused with chemistry, astronomy with geology, chemistry with biology and so on. New scientific disciplines (astrophysics, socio-biology, neuroscience, etc) are being built on the borders of other disciplines. Some disciplines develop and divide into sub-disciplines, which in turn become disciplines in their own right.

There is the need for teachers to use cross disciplinary connections to link science learning with other disciplines, such as history, philosophy, and ethics, to show how scientific knowledge connects with other fields. For example, discussion on the ethical considerations in scientific research, the impact of scientific discoveries on society, and how societal needs can drive human inquiry is very crucial in constructing scientific knowledge.

6. Conclusion

The aim of this research was to present the fundamental concepts of the NoS necessary for the construction of teaching and learning activities in science. After developing the various conceptions of the NoS and presenting the various criticisms of its conceptual aspects, we defined eleven concepts that could serve as a basis for a better understanding of the image of science by learners and as conceptual tools for better didactic transposition by teachers. These fundamental concepts take account of the cognitive, epistemological, social and institutional dimensions of science. Integrating NoS into teaching and learning with enable learners not only to appropriate scientific concepts but also to develop a deeper understanding of how science work. This will better equip them to critically think and engage with controversial socio-scientific issues in society.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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