An Alternative Conceptualization of the Nature of Science for Science and Technology Education

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Abstract

Since years the conceptualization about what to teach about the nature of science and technology (NoS&T) in science and technology education has been controversial, due to the domination of close lists of NoS&T aspects (the "consensus view"). Functional scientific (and technological) literacy in the service of citizens (to engage them in science or to help them on daily life decision making), which is currently the aim and context for teaching and learning NoS&T, leads to a broader view of NoS&T (assumptions, gathering and interpreting data, reliability of claims, internal and external relationships between science, technology and society, environmental and socio-scientific issues). Within this broader view, Erduran and Dagher (2014) have proposed a reconceptualization of NoS in terms of two interactive dimensions (cognitive-epistemic and social-institutional) on the basis of the family resemblance approach model. This paper assumes the broader view criticisms and presents another conceptualization of NoS&T, which is alternative to the consensus view and to Erduran and Dagher's reconceptualization (EDR). It starts from Popper's three world model and naturally develops the interactions and relationships among the worlds, which allows generating and justifying a four-dimension conceptualization for NoS&T and multiple specific categories within dimensions. Summing up, the new conceptualization shares the criticisms to the consensus view and many aspects of EDR, which appears as a particular case of it; further, it develops a powerful, explicit, straightforward, and clear tool for justifying the complexity of the broader NoS&T, which simultaneously avoids some of semantic problems in the assignation of categories and aspects to EDR dimensions.

Keywords: Science and Technology Education; Nature of Science and Technology; Teaching and Learning Conceptualization.

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Introduction

This paper presents an alternative conceptualization of the nature of science (NoS) for science and technology education (ST-Education). Thus, the paper's central question is what to teach and learn about NoS.

The conceptualization presented here is alternative, on the one hand to the so called "consensus view", and on the other hand, to the recent reconceptualization of NoS for science education by Erduran and Dagher (2014) (EDR hereafter). Specifically, this paper assumes the general criticisms on the consensus view that have been raised along years in the literature, and suggests an alternative model and conceptualization to EDR proposal by choosing a different model-base for developing the conceptualization that does yield more dimensions and categories than EDR did.

Further, the paper assumes the integration of the current science and technology in the concept of techno-science, so that the concept of NoS could be extended to encompass also technology (Echeverría, 2010; Tala, 2009). Therefore, NoS will be onward referred to as nature of science and technology (NoS&T), which also allows addressing ST-Education in a natural way (scientific and engineering practices).

Scientific and Technological Literacy and Nature of Science and Technology

NoS&T refers to the history, philosophy, and sociology of scientific and technological knowledge and practices. This general demarcation defines NoS&T as a complex (interdisciplinary realities and contributions), dialectical (change is essential), multifaceted (including multiple perspectives of analysis beyond science), controversial (underscoring its argumentative nature) and contested research territory (scholars disagree on its teaching contents). Further, this complex profile makes its teaching and learning in science and technological education a difficult, multidimensional, and innovative challenge for teachers (Millar, 2006).

On the other hand, teaching and learning NoS&T is considered a central component of scientific (and technological) literacy (ST-Literacy) for all citizens (not just for scientists or engineers), with close unanimity of the specialists. Scholars view two main components for ST-Literacy: the traditional understanding "of" science (concepts, laws, models and theories and processes) and the understanding "about" science (NoS&T). Summing up, the ST-Literacy is the actual context for teaching NoS&T in ST-Education (Hodson, 2008).

The need of teaching NoS&T has been justified for many reasons: socio-economic (S&T foster economic and social development), cultural (S&T is a culture), autonomy (S&T facilitate autonomy), utility (S&T help personal and social decision-making and quality of life), democratic (S&T impact on public and social interests and participation), and ethical (scientists and technicians are responsible for the management of techno-scientific affairs) (Sjøberg, 1997)

The lack of meaning in ST-Education often alienates and disaffects many students from meaningless science and technology, which does not meet their interests, needs, or self-image (i.e. many women are uncomfortable learning science and increasing numbers of students reject S&T in their future careers and jobs). The pedagogy practiced in traditional science classrooms (i.e., memorization to learn laws) oppose to the values of science that the NoS&T tries to advocate (Aikenhead, 2006). The absence of NoS&T in the classroom contributes to those deviations, whereas their active presence provides a global sense of coherence to the ST-Literacy, so teaching NoS&T constitute the source of values that justify learning ST-Literacy (Duschl, Maeng, and Sezen, 2011; Erduran and Dagher, 2014). Thus, another essential and relevant educational reason to teach NoS&T in ST-Education stems from the assignation of global sense or meaning making to teaching and learning contents in the context of ST-Literacy for all students: pedagogy and contents must be coherent with NoS&T features (Bennássar, Vázquez, Manassero, and García-Carmona, 2010).

Some call functional ST-Literacy the knowledge about S&T as long as it is in the service of citizens (to engage in science or to make practical decisions). Functional ST-Literacy involves understanding of aspects of the development and validation of S&T knowledge and practices: assumptions, gathering and interpreting data, reliability of claims as well as the internal and external relationships between science, technology and society (funding, communication, institutions, policy, priorities, etc.), where environmental and socio-scientific issues are prominent centres of interest. Thus, functional ST-Literacy is the context for teaching and learning NoS&T (Allchin, Andersen and Nielsen, 2014).

The Contested Consensus View

The broad view of NoS&T emerging from the functional ST-Literacy (depicted in the former paragraph) contrasts with the consensus view, which is featured by a close list of aspects of science for teaching NoS arguing that a short agreed list of NoS issues may be enough for ST-Literacy and facilitate their teaching in ST-Education. The Lederman's seven aspects may be considered a conspicuous representative of the consensus view, and includes the following list of NoS issues: empirical, theory-laden, inferential, creative, tentative, uncertain, and socially embedded (Abd-el-Khalick, 2012; Lederman, 2007). A more extended list of NoS tenets was developed by McComas (2008), whose details are included in the fifth column of the table in the appendix.

A different line of research was developed by Osborne, Collins, Ratcliffe, Millar, and Duschl (2003), who empirically elaborated a list through a Delphi study that gathered the opinions of some teachers. The categories of this list depict a new profile for NoS as they are wider than the former proposals (see its details in the fourth column of the table in the appendix).

Such short lists of declarative NoS tenets (consensus view) has been criticized as reductionist, and thus invalid for adequately portray the NoS&T. The criticisms address the confusion among the ontological, philosophical, sociological, and ethical features of science, the inaccurate depiction of the heterogeneity of scientific practices, the distortion of the historical descriptions of science, and the ignorance or devaluation of some features, such as the role of technology, and the social, verbal and communicative aspects in the construction of knowledge (Allchin, 2011; Duschl and Grandy, 2008; Matthews, 2012; van Dijk, 2012). Summing up, the critics advocate for an integral and inclusive view of NoS&T, that Allchin calls whole science, where all features related with doing science (cognitive, epistemic, and social practices, as well as material and technological contexts) are candidates to be taught to students in ST-Education.

According to this line of criticisms about the consensus view, Matthews (2012) pointed out to change the denomination from NoS to features of science (FOS) and proposed a couple of features that depict an integral and broader image of science (see details in the third column of the table in the appendix). The change from NOS to FOS involves a concern with the processes, institutions and cultural and social contexts where the knowledge is produced, and of course remains focused on the nature of scientific knowledge. Indeed, broadening the field does not mean setting high-level educational aims; rather, modest goals for FOS teaching are proposed through an appropriate pedagogy that allows elaboration, discussion and inquiry about FOS issues, rather than just learn and assess FOS.

Acevedo, Vázquez, Manassero and Acevedo (2007) empirically analysed 637 sentences of the Views on science-technology-society (VOSTS) item pool (Aikenhead and Ryan, 1992) searching the agreement of expert judges on those sentences. The criterion for agreement was set up when 2/3 of judges agreed on the sentence classification as adequate or naïve. The results showed an extensive catalogue of sentences that reached the criterion for empirical agreement: 41 sentences to be considered adequate ideas and 93 sentences as naïve ideas. Thus, this empirical analysis shows that experts are able to agree on a much larger set of different statements about NoS&T than a simple and reductionist consensus list.

Summing up, it seems also consensual that the consensus view is a reduced depiction of NoS&T. The broader view of NoS&T about authentic (whole) science not only includes and enlarges the lists of the consensus view on tenets, but also involves large amount of naive conceptions to take into account in the pedagogy. Further, the controversy on the consensus view shows that any vision of NoS&T is partial and fragmentary and a structuration of the field is needed not only in order to overcome the typical reductionism of the consensus view, but also to develop classifications that may help researchers and teachers to pinpoint their aims amid the complexity of NoS&T field.

Erduran and Dagher's Reconceptualization (EDR)

Assuming the broader view of NoS&T, Erduran and Dagher (2014) apply the Irzik and Nola's (2014) family resemblance approach model (FRA) develops the idea that the different sciences, like the members of a family, resemble and differentiate one another in some aspects. Further, the different sciences resemble and differentiate one another in some NoS aspects, thus accounting for domain general and domain specific aspects of science.

FRA model reconceptualises science in terms of two interactive dimensions that unify the many fragmentary aspects into meaningful wholes: cognitive-epistemic and social-institutional. The cognitive-epistemic dimension includes four categories: scientific practices, aims and values, methods and methodological rules, and scientific knowledge. The social-institutional dimension contains the following categories: professional activities, scientific ethos, social certification, social values, and organizational, political, and financial aspects of science, though just four of them appear later on. Further, the reconceptualization provides holistic views and disciplinary variations through some specific aspects that are assigned to the categories (classification, observation, experimentation, epistemological issues relevant for science education, disciplinary similarities and domain-specificity, etc.), which are modelled trough the science eye and the heuristic rings (table 1).

All in all, Erduran and Dagher's reconceptualization structures the field according to an integrative view of scientific knowledge and practices and other family categories, though the proposal might be improvable and the aim of this communication is to display an alternative reconceptualization of NoS&T assuming the criticisms to the consensus view to go beyond the reductionist lists of NoS&T tenets, and sharing the same integrative background on NoS&T.

The Three World Conceptualization

Popper's analogy of the three worlds, which draws on Plato's philosophy, is assumed as the model base for the 3-World/VOSTS proposal. The physical world of material objects is the first world (W1), while the second world (W2) refers to the world of human thoughts (cognitions and mental states that are the object of the psychology). The cognitive and mental activity through the human consciousness and perception on W1 creates new independent and tangible products of mind (ideas, scientific theories, artwork, problems, arguments, books, papers, etc.) that constitute the World 3 (W3), the world of created (objective) knowledge. Later on, Hodson (2008) called W2 the "world of scientific practice" (subjective thinking of scientists who investigate W1) and W3 the "world of scientific and technological knowledge" (artefacts, ideas, and technological and scientific theories), and dismissed objectivity as a property of W3.

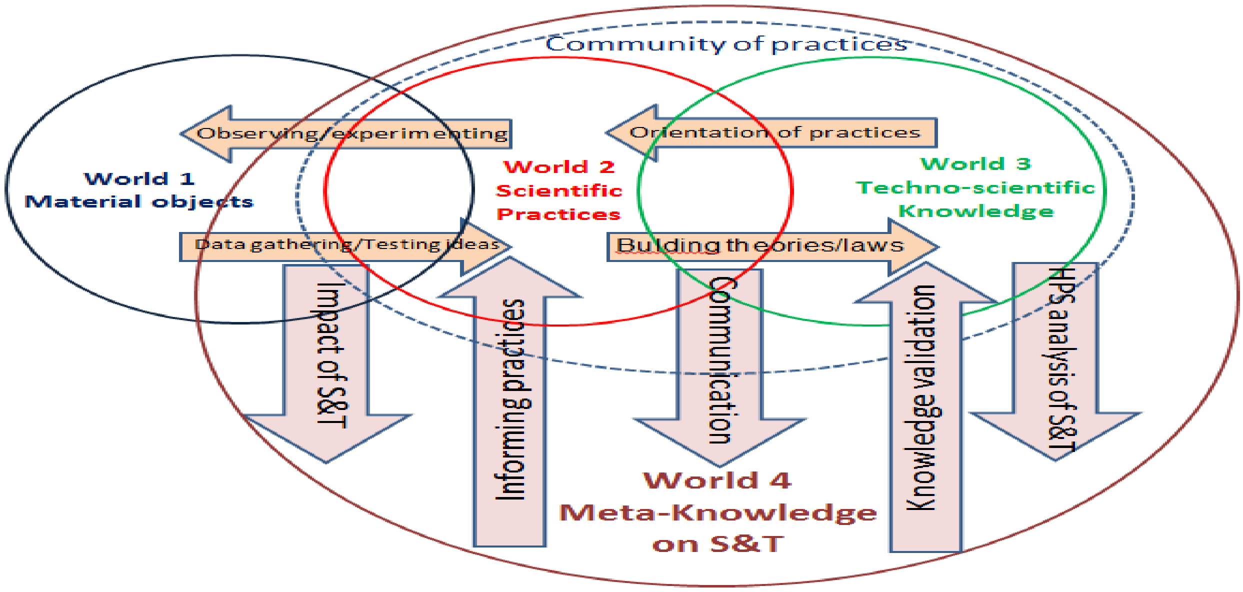

Figure 1 - Meta-theoretical model, based on the Popper's three worlds, which reconceptualises NoS&T as a multidisciplinary meta-knowledge that is produced from the study of interactions within the community of scientific practices (World 4).

The human and mental activity (W2) through observation, classification and experimentation on W1 generates data and positive and negative tests of ideas. Again, the human and mental activity (W2) on data and tests (through reasoning, argumentation, contradiction, self-criticisms, peer review, etc.) builds laws, models and theories (W3) about W1. Further, W3 and W1 feedback innovative practices for W2: the validated scientific and technological knowledge of W3 may suggest innovative orientations for new or replicating practices (theory-laden observations and experiments), and the data and tests results drawn from W1 influence new organization of practices in W2 (evolutions or revolutions) and new developments and refinements of scientific and technological knowledge (W3).

In fact, W2 and W3 hold profound, permanent, and dialectic interactions that make difficult to separate them. In addition to the subjective mental states of scientists, W2 contains a whole world of complex special interactions among scientists and between the scientific community and the whole society, so that the distinction between objective knowledge (W3) and subjective knowledge (W2) is diffuse.

The former elaboration leads to the theoretical proposal for NoS&T. The integration of W2 and W3 conforms a new entity (the community of practices), which combines both knowledge and mental states, individual and collective actors, weaving a complex system on a dense network of mutual relationships and interactions between actors and knowledge. The meta-analysis of the scientific and technological knowledge (W3), the activities in W2, the impact on W1 and the W2-W3 interactions within the community of practices from different disciplines (philosophy, sociology, history, psychology, politics, economy, etc.) generates a meta-knowledge (about knowledge, mental states and actors of science and technology), which form a new World 4 (meta-knowledge on S&T) that is known as the NoS&T. This meta-knowledge is a new form of critical and dialectic knowledge that is fed back, informed, influenced and transformed by the continuous activities within the community of practices (Figure 1).

ST-Education can be considered a subsystem within this community of practices. World 4 feeds back an innovative proposal: the inclusion of its meta-knowledge as teaching contents in school science curriculum as the features of the NoS&T. The contents of the thick arrows in Figure 1 summarize the different meta-knowledge on NoS&T that didactic research has contributed to characterize for teaching (see details in the table in the appendix).

Summing up, the 3-World/VOSTS proposal develops the mutual interactions between the three worlds to display the complex, multifaceted, and controversial contents and structures that feature science and technology. In particular, the interdisciplinary meta-knowledge of World 4 created through the study of contents and structures of Worlds 1, 2, and 3 constitute the core of NoS&T (Vázquez, 2014).

The complexities of the meta-knowledge of NoS&T, which are generated in the W4, are summarized using a taxonomic framework elaborated by the authors from the proposal of Aikenhead and Ryan (1992). The taxonomy involves nine topics that are grouped in four strands (Table 1): (I) Definitions (1-Science and technology), (II) External sociology of S&T (encompassing 2-Influences of society on S&T, 3-Triadic influences, 4-Influences of S&T on society, 5-Influences of school science on society), (III) Internal sociology of S&T (encompassing 6-Characteristics of scientists, 7-Social construction of scientific knowledge, and 8-Social construction of technology), and (IV) Epistemology (9-Nature of scientific knowledge). The contents of the strands I and IV are epistemic, while the strands II and III gather the many facets of the social relationships of S&T. Further, each topic is flexibly developed in several open categories (see the first column of the appendix), which help the taxonomy to accurately accomplish its function of detailed classification for all NoS&T issues.

The proposed conceptualization based on the three-world model and the VOSTS taxonomy allows demonstrating that the dimensions and categories of EDR are a special case of the former.

3-WORLD/VOSTS TOPICS	EDR DIMENSIONS	EDR CATEGORIES
DEFINITIONS *1. Science and Technology* *EPISTEMOLOGY* *9. Nature of the scientific knowledge*	*Epistemic and cognitive system*	*Aims and values* *Scientific practices* *Methodological rules* *Scientific knowledge (theories, laws and models)*
EXTERNAL SOCIOLOGY 2. Influences of Society on Science / Technology 3.Triadic influences 4. Influences of Science / Technology on Society 5. Influences of the school science on Society INTERNAL SOCIOLOGY OF SCIENCE 6. Characteristics of scientists 7. Social construction of the scientific knowledge 8. Social construction of Technology	Social-institutional system	Organizational, political, and financial Social values Social certification and dissemination Scientific ethos Professional activities

Table 1. Comparison between the dimensions and categories of EDR and the multi-dimension VOSTS taxonomy proposed here for conceptualizing the features of the NoS&T that show the coincidences and the differences between both proposals.

The main coincidence between both proposals is the overall integral picture including two big topics about epistemic and social aspects, whose correspondence among both systems is fairly evidenced in table 1. However, the epistemic and cognitive dimension of the EDR system is more developed than the social-institutional dimension, and specially the category on scientific practices. This over-development leads to reflect on some issues that might be better social than epistemic. This might be the case of the development of models, explanations, critical argumentations, evaluations and reflections on practice, and the analysis of dis / advantages and risks of scientific and technological developments. This reflection may also be extended to the EDR system proposal about the consideration of organizational, political, and financial aspects of science, which is not developed specifically, which may correspond to the many subtopics of the 3-World/VOSTS system within the social topics that lack an equivalent in the EDR system (check first and second columns of the appendix).

Some minor differences refer to the lack of consideration in the EDR dimensions of the explicit account for technology, as an important companion of current science, and a reference to the aspects of external sociology of science, which is generic in EDR and detailed in 3-world/VOSTS. Further, the EDR system uses different labels refers to values (aims and values, social values and scientific ethos) and to practices (scientific practices and professional practices). This multiplicity of labels seems unnecessary as it may break the integral picture depicted for NoS in EDR and lead to confusion.

The 3-world/VOSTS model provides a powerful representation for conceptualising the NoS&T for ST- Education, as the dimensions and categories of NoS&T arise naturally from the interactions and relationships between the three worlds, as shown in Figure 1. Further, the 3-world/VOSTS taxonomy for classifying the NoS&T features is wide and flexible enough to easily include any issue within its framework. In fact, all issues proposed for NoS by the authors cited in this paper can be assigned to one of the VOSTS subtopics, and especially the issues put forward by Erduran and Dagher (2014), as the table in the appendix shows (and many of them lack any correspondent issue yet). Further, the 3-world/VOSTS model is detailed enough to facilitate teachers the explicit plan for teaching any NoS&T issue, helping teachers to situate NoS&T issues within the curriculum, plan them to be taught, understand their importance for S&T education and develop heuristics for lessons.

Conclusion

This paper presents a conceptualization of the NoS&T for science and technology education (3-World model and VOSTS taxonomy), an alternative proposal to the consensus view, and to that presented by Erduran and Dagher (2014). Both conceptualizations stem from the criticisms to the consensus view and propose a wide set of similar specific categories for NoS&T. However, the EDR is based on FRA heuristics while the 3-World/VOSTS proposal draws its conceptualization from the Popper's three world model of science. The NoS&T categories are much straightforward justified through the powerful three world model, while the FRA heuristics does not fully allow making so explicit this justification.

Obviously, the EDR taxonomic system goes beyond the consensus lists, yet its configuration raises some questions. On the one hand, EDR appeals to a basic common sense heuristic (Irzik and Nola's FRA) without much wider prospective scope; on the other hand, some caveats can be pointed out from EDR analysis. For instance, some kind of imbalance might be perceived between the two big dimensions (epistemic and social), as the social and institutional dimension seems to be developed in a lesser extent than the cognitive–epistemic system. Moreover, a category of aims and values in science is attributed to both dimensions (epistemic and social) so that its role is embedded with mystification and controversy between the cognitive–epistemic and social systems, and again the category is less developed in the social system.

Further, some categories of the social-institutional dimension appear a bit confusing. For instance, the repetition of several categories involving values is not much justified (scientific ethos against social values); and different or new categories (i.e. scientific ethos, organizational, political, and financial aspects of science, scientific critique) appear/disappear in some parts of the proposal; finally, the assignation of some aspects to a specific category is also contentious, due to their apparent overlapping across categories (i.e. peer-review might be assigned to social certification or to professional activities).

Beyond caveats, both proposals agree about a holistic account for the representation of science and technology that try to overcome the reductionist visions of the consensus views, through integrating and enlarging contents, methods (teaching, learning, researching…) and the creation of dynamic and interactive developmental tools. The theoretical rationale of the new approach must be developed for empirical validation, and testing for the effectiveness of applied teaching strategies through the work of policy makers, curriculum developers, researchers, science educators, etc.

All in all, the prospective of this 3-World/VOSTS conceptualization involves testing its effectiveness for developing educational curriculum and programs, and especially for coping with S&T teacher education as a main target group. Within this prospective, much research (i.e. socio-scientific-issues literature and others) is insistently starting to point out that the lack of high-level thinking abilities (critical thinking abilities, critical reflection, argumentation, reasoning, decision-making,…) impedes understanding NoS&T; the detailed 3-World/VOSTS may also contribute to the systematical inclusion and development in education of those abilities that may be the "critical" holy grail of NoS&T teaching and learning.

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