Science Education International
Vol. 25, Issue 1, 2014, 933-111

Beyond Nature of Science: The Case for Reconceptualising 'Science' for Science Education

SIBEL ERDURAN*

ABSTRACT: In this paper, I argue that contemporary accounts of nature of science (NoS) are limited in their depiction of 'science' and that new perspectives are needed to broaden their characterisation and appeal for science education. In particular, I refer to the role of interdisciplinary characterisations of science in informing the theory and practice of science teaching and learning. After a brief review on the reconceptualization of NoS from a range of perspectives, namely philosophy of science, socio-political accounts of science (in the context of colonial science), linguistics and anthropology, I will focus on philosophical and economical characterisation of science, drawing out some implications for science education. A predominant part of my argument will be theoretical in nature with some pedagogical applications in the context of an empirical project conducted in Istanbul, Turkey and co-funded by TUBITAK and Marie Curie Co-fund Brain Circulation Scheme. I will conclude with broader implications of interdisciplinary studies on science for science education research and practice.

KEY WORDS: nature of science, interdisciplinary, science teaching, learning

INTRODUCTION

This paper is based on a keynote lecture delivered at the IOSTE Eurasia Regional Symposium which took place at Antalya, Turkey in 2013. The conference took place at the Titanic Hotel. As a concept, the hoteliers took the original Titanic, the ship, to custom the decor and the theme of this hotel. The Titanic can also have various other interpretations from a range of perspectives. Consider for instance an engineer's rendition of the structural features of the ship. Or a historian's attempt to map out the life stories of the people who perished in the sinking disaster. One would of course also not amiss the Hollywood movie version with the iconic image of young lovers at the edge of the deck. Whichever version of the Titanic you aim to pursue will require a different approach, a nuance in interpretation. A hotelier's version will borrow some thematic elements, yet it will be different from that of an engineer's. Yet all of these interpretations rely on the approximation of a particular ship with a wealth

* University of Bristol, United Kingdom & Bogazici University, Turkey, sibel.erduran@bristol.ac.uk

of history. In this paper based on my plenary at the IOSTE conference, I will treat science in a similar vein in addressing some fundamental questions: What is science? Who should be consulted in answering the question? What should be included of science in science education? In drawing this analogy, I will appeal to the notion of multiplicity in characterisation, and approximation of a nuanced version of science for particular educational goals.

The key area of research in science education that targets the above questions is Nature of Science (NoS). I will argue that contemporary accounts of NoS are limited in their depiction of science, primarily because of their positivist undertones. Furthermore, I will argue that only do the NoS consensus view is outdated in its characterisation from a philosophical perspective on science, but also that it is limited in drawing out theoretical perspectives on science that target understanding from a range of perspective including socio-political and economical perspectives. I will make the case that what is needed for NoS studies to be more use for science education is an interdisciplinary perspective on science such that the diversity of needs and contexts of the science teaching and learning environments can be met. I will initially provide an overview of what I mean by "interdisciplinary" by briefly drawing on theoretical perspectives on science namely from philosophy of science, socio-political studies of science (e.g. colonical science), linguistics and anthropology. I will focus in on more detailed accounts from philosophical and economics perspectives to illustrate how these theoretical fields can provide input to improve not only the research but also the practice dimensions of science education. With respect to philosophical accounts, I specify how they inform domain-specificity of scientific knowledge which can provide a more nuanced take on disciplinary knowledge at the level of the classroom. In other words, I will address the question of the nature of which science? I will also mention what philosophers' work has shown us about ways of reasoning in science including argumentation which could be targeted in science teaching and learning. With respect to the economics perspectives, I will interrogate science as a financial enterprise, a notion that is practically absent in school science, which results in students not understanding that science relies heavily on economic factors for its execution.

CONTEMPORARY CONTEXTS OF NATURE OF SCIENCE RESEARCH IN SCIENCE EDUCATION

The curriculum reform contexts around the world specify goals for not just the education of the scientist but also the everyday people such that scientific literacy is achieved for informed citizenship in societies where more and more decisions rely on socio-scientific questions. Take for instances issues such as global warming, nuclear energy and genetic cloning. Science education has the challenge of coordinating goals for both the scientist-to-be and a scientifically literate citizen. Hence the public as well as the scientific community are in need of not only the relevant scientific knowledge but also the required reasoning skills and context such that they can make educated decisions on a diversity of contemporary issues. Currently the new wave of science curriculum reform in the USA, in the context of the Next Generation Science Standards (Achieve, Inc, 2013), highlight the shift from just achieving scientific literacy to acquiring scientific proficiency through students' engagement in scientific practices (National Research Council, 2017). "Scientific practices" are defined as the following:

> *Asking questions (for science) and defining problems (for engineering)*
> *Developing and using models*
> *Planning and carrying out investigations*
> *Analysing and interpreting data*
> *Using mathematics and computational thinking*
> *Constructing explanations (for science) and designing solutions (for engineering)*
> *Engaging in argument from evidence*
> *Obtaining, evaluating, and communicating information*
> (NRC, 2012, p.42).

These features of scientific practices relate to the epistemic goals of science education. NoS research literature in science education similarly has been addressing aspects of 'science' from an epistemic perspective. This line of research has a long standing presence in science education. For example in a study conducted on selected publications from 1990 to 2007, NoS emerged as a key theme in science education research (Chang, Chang, & Tseng, 2010) with considerable number of volumes dedicated to the topic (e.g. Koseoglu, Erduran & Tasar, 2010). Some researchers (e.g. Lederman et al., 2002; McComas, 1998; Lederman et al., 2002) have argued for a "consensus view" on the nature of science which have the following characteristics: *(a) Tentativeness of Scientific Knowledge, (b) Observations and Inferences, (c) Subjectivity and Objectivity in Science, (d) Creativity and Rationality in Science, (e) Social and Cultural Embeddedness in Science, (f) Scientific Theories and Laws, (g) Scientific Methods.* The references to argument, evaluation and communication of information, however seem to be a distinct emphasis in NRC that are not captured in consensus NoS accounts, at least not explicitly.

Recently some authors have been challenging the consensus view of NoS from a range of perspectives. Allchin (2011) has argued for the promotion of nature of whole science in science education, infusing in science teaching and learning a whole set of context specific accounts of science including the social aspects of science. Duschl & Grandy (2012) have pointed out that there are different approaches to the characterisation of NoS and that there has been a marked omission of a model-based view on science in science education. Irzik & Nola (2013, 2011) have outlined a "family resemblance approach" on NoS illustrating a comprehensive account on science that target a systemic consideration of the epistemic, cognitive and social systems of science.

In this climate of evaluation of NoS accounts in science education, one can also look at the very premises of the consensus view to understand its theoretical rationale. A key feature of the contemporary accounts of science is its positivist undertones. Consider the contrast in Table 1 that outlines some of the key tenets of logical positivism as it emerged in the Vienna Circle in the 1920s and 1930s through the work of Hempel, Oppenheimer, Carnap and so on, versus the contemporary consensus accounts of NoS as represented in science education research.

Table 1. Tenets of logical positivism and the consensus view of NoS.

Logical Positivist 'Science'	Consensus view of NoS
Hypothetico-deductive method of science, quantification	Scientific methods
Objectivity-subjectivity	Subjectivity and Objectivity in Science
Knower-knowledge, observer-observed dichotomies	Creativity and Rationality in Science
Data through sensory experience	Social and Cultural Embeddedness in Science
Scientific progress	Tentativeness of Scientific Knowledge Scientific Theories and Laws

The emphases in the consensus NoS accounts of some of the key aspects of logical positivism is striking. Consider however some of the more updated version of 'science' through the critiques of logical positivism. We have learned, for instance, through Thomas Kuhn's work that some key tenets like progress and method can be far from how the logical positivists envisaged them to be. With the notions of paradigms and paradigm shifts as well as incommensurability, Kuhn has pointed out that the logical positivist notion of progress can be scrutinised.

Furthermore, within the positivist accounts, as also is the case in the consensus view of NoS, the notion of neutrality of scientific claims as devoid of bias and individual subjective prejudice had led to the dichotomy of objectivity and subjectivity, and the separation of scientific fact from subjective interpretation. It is worthy to note that earlier depictions of objectivity was grounded on individually-centred accounts (e.g. Bacon) where no significance was placed on interactions among scientists. Subjectivity was based on individual psychological bias and prejudice that interfered with objectivity of science.

More contemporary accounts of science as represented in the work of Longino, for instance have reshaped the way that we think about objectivity and subjectivity whereby the social articulation and evaluation of scientific claims are paramount to the establishment of objectivity in science:

> "*Empirical adequacy and accuracy (treated as one or separate virtues) need further interpretation to be meaningfully applied in a context of theory choice. Those interpretations are likely to import the socio-political or practical dimensions that the search for a purely cognitive criterion seeks to escape. At the very least the burden of argument falls on those who think such an escape possible."* (Longino, 1995, p. 395)

Numerous examples exist in the literature that put into question the logical positivist accounts of objectivity in science. The 19th century notions of evolution of humans claimed skulls and posture of European races were more developed than Negroes (Gould, 1981). Persons of African descent were deemed inferior intermediaries on an evolutionary scale as 'proven' by science. Similarly, female skulls, skeletal anatomy and physiology were taken by male scientists as evidence of women's 'natural' role in society, legitimising social relations and privileging males (Schiebinger, 1990)

> "*When we detach a factor from the contexts in which it naturally occurs, we are hoping to achieve understanding of that factor's precise contribution to some process. But by taking it out of its natural context we deprive ourselves of understanding how its operation is affected by factors in the context from which it has been removed. This is, of course, a crucial aspect of experimental method. I suspect that it's not (or not always) the decontextualization that is to be deplored, but the concomitant devaluation as unimportant or ephemeral of what remains.*" (Longino, 1995, p. 395)

A further example of the contemporary frameworks that challenge the tenets of logical positivism is the socio-political contexts of science, including what is often called "colonial science". The European colonial powers in extending their ambitions around the world have used science as a point of power in making it clear to the natives what they lacked. For instance, staging science in exhibitions and museums to force acknowledgment by the natives the justness of British rule in India (Prakash, 1999). Likewise, commodification and globalisation of resources were justified from a scientific standpoint for instance in the way that botany and visual culture interacted in the Spanish enlightenment (Bleichmar, 2009). The visual imagery of plants and crops acted as a way to create a sense of global ownership. Other examples can be traced in the context of astronomy, cartography and tropical medicine. Ecology as a discipline has even been argued to be an imperial science developed by Danish, British, South African researchers (Anker, 2001). Other critiques of logical positivist accounts of science have included perspectives on culture and language. For instance, some authors (Knorr-Cetina, 1981) have argued that there has not been sufficient differentiation in the way that research papers in science are transformed from laboratory reasoning to literary reasoning. Latour and Woolgar (1979) have argued that scientific papers systematically conceal the nature of the activity which typically gives rise to research reports.

The overall lessons that we have learned from a range of critiques of logical positivism is that the many faces of science have been concealed and that further investigations are needed to provide a more authentic version of what we mean by science. In the rest of this paper, then, I will turn to issue of 'interdisciplinarity' in the characterisation of science and explore how this approach can be a fruitful in application to science education in general and in the formulation of new and more authentic perspectives on NoS in particular.

INTERDISCIPLINARY RESEARCH AND SCIENCE EDUCATION

There are various rationales (e.g. Erduran, 2013a; Erduran & Duschl, 2004) for infusing interdisciplinarity in science education. Foremost, science as an endeavour is inherently interdisciplinary: science has a history, philosophy, psychology and economics. Furthermore, education and educational research are themselves inherently interdisciplinary. Learning contexts appeal to theoretical insight on sociology of human interactions, psychology of individuals and cultural norms of practice, for example. Science Education as a research field is inherently interdisciplinary, i.e. it can be examined from a range of perspectives such as cognitive psychology, philosophy of science and sociology. Of course one would also need to be mindful of the fact that working across disciplinary boundaries can also present challenges as well as potential contributions. For instance, there might be mismatch in the intentions and disciplinary contexts, leading to misunderstandings of theoretical contexts. There can also be anxiety about interdisciplinary in traditional academic circles given the potential threat to traditionally autonomous domains, institutional and community identities and lowering of academic standards.

With some concerns in mind, it is still plausible to explore the potential of contributions from a range of disciplines to ensure that science education is not missing out on important characterisations of science. It was this spirit that led to our initiation of the “Science Studies” Section of the Wiley-published Science Education Journal in 2008 (Duschl, Erduran, Rudolph & Grady, 2008). What then can interdisciplinary perspectives offer for science education? Table 2 provides some example contributions of a range of perspectives.

Table 2. Potential contributions of interdisciplinary perspectives to science education.

Disciplinary orientation	Application in science education
Physical and natural sciences	Domain context and reasoning in science
Linguistics	Features of scientific language, talk
Philosophy of science	Content and quality of models, explanations etc.
Communication studies	Social interaction, perspective taking
Anthropology	Cultures, norms and organisations of science
Economics	Commercialisation and commodification of scientific knowledge

The theoretical perspectives from different disciplines will highlight nuances in the characterisation of science. Let me turn to some concrete examples to illustrate this idea. I will focus on three examples that rely on perspectives from philosophy of science and economics of science. The first two perspectives draw on philosophical accounts of scientific knowledge and reasoning, namely on perspectives from (a) philosophy of chemistry on the domain specific aspects of chemical laws (e.g. Christie, 1994), (b) philosophical study of arguments, drawing on the work of Stephen Toulmin (1958). The third perspective concerns the study of science in its economical context (Nowotny, Scott, & Gibbons, 2001). In each case, I will draw out some implications and applications for science teaching and learning.

Case 1: Philosophical perspectives on nature of scientific knowledge

Philosophy of science has traditionally been dominated by physics as the exemplar science, a stance that has been questioned by a contemporary philosophers of science (Scerri & McIntyre, 1997; van Brakel, 2000). Since the 1990s, there been a growing interest, for instance, in studying chemistry in its distinct epistemological context. This view has recently been picked up by chemical educators exploring the implications of the growing field of "philosophy of chemistry" in chemical education research and practice (e.g. Erduran, 2013b; Erduran & Scerri, 2002). The work in this line of research implicitly questions the very definition of NoS. In other words, the growing literature in this area makes us question the nature of which science we are proposing as features of science for teaching and learning.

Consider the example of laws in different domains of science. Some philosophers of chemistry are trying to understand the nature of laws within a particular science like chemistry.

> *"The laws that interest chemists involve such things as how and why the behaviour of substance X might be analogous to that of substance Y. The laws indicate the connections and analogies between properties of different substances. Many of them are non-universal. A few are imprecise."* (Christie, 1994, p.629)

We are learning from philosophers that some features of scientific knowledge such as laws are not universal.

> *"Some laws are approximations while others are exact; and some laws are purely formal but not all of them. But on a more revolutionary note, many quite respectable laws of science are non-universal, and there are a few that cannot be formulated as precise propositions"* (Christie, 1994, p.613)

Yet, the nuances in the way that laws are addressed in physics versus chemistry are not generally dealt with in teaching and learning. If students are to understand the nature of chemistry, they need to understand what makes chemical knowledge what it is, and in particular, in relation to other domains of science.

Erduran (2007) has used the following instructional approach based on argumentation strategies (e.g. Erduran & Jimenez-Aleixandre, 2012; Erduran, 2012; Murphy & Erduran, 2013; Castells, Erduran & Konstantinidou, 2010) to foster students' questioning and awareness of the different nature of laws in chemistry versus physics. The example is a concrete way of instantiating how grant philosophical ideas can be transformed for pedagogical purposes at the level of the classroom. In this example, there are two claims about the nature of laws in chemistry versus physics, in the context of periodicity and gravitation.

Claim 1: The periodic law and the law of gravitation are similar in nature/All laws are deterministic in nature.
Claim 2: The periodic law and the law of gravitation are different in nature/All laws are not deterministic in nature.

Students are then provided with statements that can be used as evidence to support one claim or the other, both or neither. These statements could be as follows: "A law is a generalization", "The periodic law cannot be expressed in an algebraic form while the law of gravitation can be" and so on. The task environment, then, would provide the students with the opportunity to scrutinise the nature of chemical knowledge and how it is similar or different from knowledge in other branches of science.

Case 2: Philosophical perspectives on scientific argumentation

Argumentation has emerged as a key area of research in science education in recent years (Erduran and Jimenez-Aleixandre, 2012, 2008; Jimenez et al. 2000; Kelly & Takao, 2002). The philosophical and cognitive foundations (Erduran & Garcia-Mila, 2014) of argumentation have played a central role in the justification of research in argumentation in science education including its inclusion in the science curriculum (Erduran & Msimanga, 2014) and its wider coherence with goals of attaining scientific literacy (e.g. Erduran & Wong, 2013; Kelly, 2011).

Through his well-known book titled The Uses of Argument, Stephen Toulmin has made a significant impact on how science educators have defined and used argument (Toulmin 1958). Toulmin's definition of argument (as a system of claims, data, warrants, backings, rebuttals and qualifiers) has been applied as a methodological tool (e.g. Jimenez-Aleixandre, Rodriguez & Duschl, 2000) as well as a framework for design of activities to support argumentation (Erduran, 2007). In our work (e.g. Erduran, Simon & Osborne, 2004) we have developed frameworks based on Toulmin's framework that facilitated classroom discussion.

Figure 1 illustrates the Toulmin framework as applied to an example we have used in our research (Erduran et al., 2004). This framework has served several purposes in our work. First, it guided the development of instructional materials where students' writing could be supported in producing arguments. For example, students were given writing frames that included sentence statements such as "My idea is…My reasons are that…I believe my reasons because…Ideas against my idea are…I would convince someone who doesn't believe me by…". Second, the framework was adapted for coding of verbal transcripts from classroom conversations.

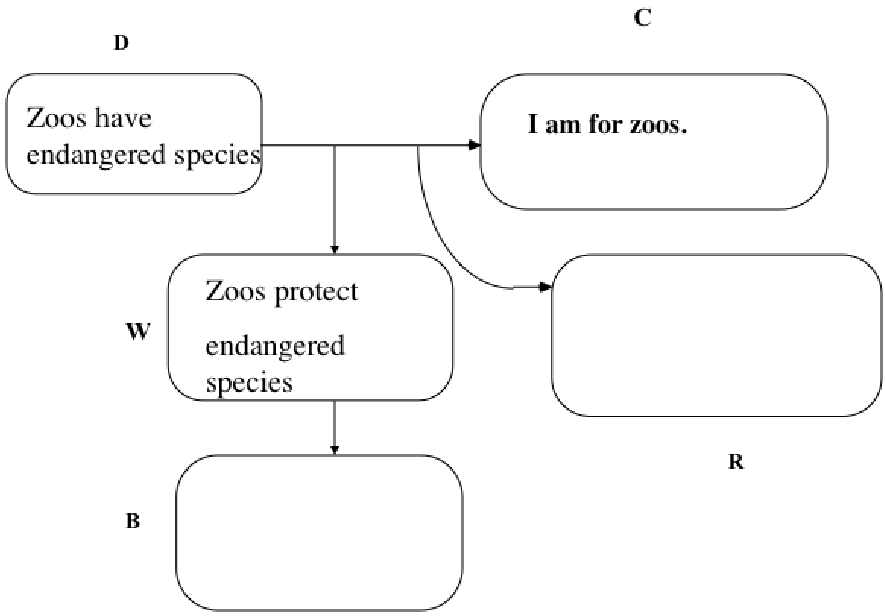


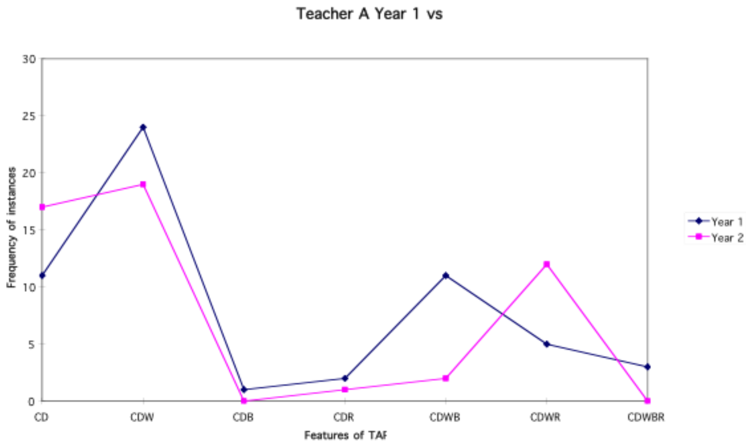
Figure 1. Toulmin's Argument Pattern applied to an example.

The following example illustrates how we traced the presence of a claim, data and warrant in conversation as captured in Figure 1.

Teacher	Yeah. Can you think of any others for?
Student	The zoo has like endangered species
Teacher	Yes, if they are becoming extinct or endangered then it becomes a way of protecting endangered species doesn't it?

Our coding of conversations in this fashion led to the quantitative measure of argument quality (Erduran et al., 2004) across two years for a group of teachers whereby we could also trace any statistically significant improvement in argumentation in classroom conversations (Figure 2).

In summary, a philosopher's framework on argument has facilitated our approach to making argumentation a reality at the level of the classroom. The transformation of Toulmin's framework into instructional and methodological resources was possible through several iterations and discussions among the research teams.



Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: developments in the use of Toulmin's Argument Pattern for studying science discourse. *Science Education*, 88(6), pp.915-933.

Figure 2. Distribution of arguments coded using Toulmin's Argument Pattern in class conversations across two years.

Case 3: Economics of science in science education

There is a body of literature focusing on the financial and economic dimensions of science (e.g. Diamond, 2008; Nowotny, Scott & Gibbons, 2001; Wibble, 1998). The topic has also found interest in the philosophy of science and science education communities (e.g. Irzik, 2013). A key notion in this line of research is that

> *"Science (can) no longer be regarded as an autonomous space clearly demarcated from the 'others' of society, culture and economy. Instead, all these domains have become so internally heterogeneous and externally interdependent, even transgressive, that they cease to be distinctive and distinguishable."* (Nowotny et al., 2002; p.1)

We have recently began to explore the implications for science education of the commodification and commercialisation of science (Erduran & Mugaloglu, 2013). We have, for instance, used the case study of the Harvard oncomouse to generate an instructional resource that can begin to address some of the issues and dilemmas about the financial context of science in science teaching and learning. Tables 3 and 4 illustrate some of the proposed activities from our work (Erduran & Mugaloglu, 2013). In these activities, students are presented with two alternative claims and provided with some statements that would help build up each claim or to refute the alternative claim. Students can be encouraged to generate their own statements and/or research information to further support their claims.

Table 3. Example student activity focusing on economic aspects of science (from Erduran & Mugaloglu, 2013).

Student Activity:
Oncomouse: To patent or not?

Consider the following competing claims about a genetically modified mouse that was produced at Harvard University. The oncomouse was designed to be susceptible to cancer and it is intended to help scientists understand cancer. In your groups, discuss each claim and use the evidence statements to build up support for your claims. Some of the evidence may be relevant for one claim or the other at the same time. Some evidence may be irrelevant and some may only be relevant for one claim. Make sure that you justify why you think that the evidence goes with your claim.
Claim 1: The oncomouse is a genetically modified animal that has been invented. It has to be patented with due financial rewards granted to its inventors.
Claim 2: The oncomouse belongs to all humanity and science; it cannot be patented to particular individuals.

Evidence Statements

Genes are made of DNA whether they are produced in the laboratory or exist naturally.	Scientists deserve to patent the important discoveries and inventions they work hard at achieving.	Genetically modified genes that cause cancer are not the same as naturally existing genes that cause cancer.
The oncomouse will help us become more productive in dealing with human fatality due to cancer.	Modified genes are discoveries about how genes can behave in different circumstances..	If we patent the oncomouse, this will help scientists to be competitive in the market and produce better discoveries.
There is no use in researching cancer in mice to help humans.	An invention is something that does not occur naturally.	All citizens in a democratic country have the right to own property.
Cancer is a disease with a market.	Everything comes with a price in life.	There is great demand for the treatment of cancer.
Modified genes are not the same as naturally existing genes.	The oncomouse may have modified genes but it is still an animal.	The mice and human beings are very different genetically
Patents are for commerce, not for science.	Science belongs to all humanity and help cure diseases.	If you want to be treated of cancer, you need to pay for it.
It is unrealistic to expect that science is free from commercialization in this day and age.	Scientists are human beings who have to survive and need money to live.	All governments should have policies to control scientists and what they do.

Such example activities will exploit the emergence of the key concepts in the classroom such that the economic dimensions of the issues are highlighted in ways that are not typically done in science classrooms. They can be complemented with key concept cards (Table 4) that provide further and deeper understanding of the issues.

Table 4. Key concepts to complement the oncomouse activity (from Erduran & Mugaloglu, 2013).

Key concepts	
Markets: are the systems, institutions, procedures and social relations by which people exchange goods.	Commercialisation: is the process of introducing a new product or process into the market.
Supply: is the amount of product that is available to customers.	Demand: is the desire to own something and pay for it.
Growth: is increase in quantity over time. Productivity: is a measure of the efficiency of production. It is a ratio of production output to input.	Commodity: is an item that can be produced to satisfy the needs and wants of a market.

In short, the theoretical literature on economics of science has guided our generation of these activities for instructional purposes.

INFUSING INTERDISCIPLINARY PERSPECTIVES IN TEACHER EDUCATION

My review so far briefly touches on work that I and my colleagues have conducted for various purposes at different times. A key common thread across these various studies is that they are underpinned by interdisciplinary theoretical accounts including from philosophy of science and economics of science. In a recent fellowship project co-funded by TUBITAK and EU Marie Curie Brain Circulation Cofund Scheme, I have begun to explore the empirical dimensions of these ideas in the context of teacher education. In the project entitled "*Revisiting Scientific Inquiry in the Classroom: Towards an Interdisciplinary Framework in Teaching and Learning*" we have been addressing the following key research questions that call for interdisciplinary accounts on science to be infused in teacher education:

How can "scientific inquiry" be conceptualised from an interdisciplinary framework?
How can "scientific inquiry" informed by interdisciplinarity frameworks be taught in schools?

> *What impact do strategies and resources designed for interdisciplinary characterisations of science have on pre-service teachers and their pupils?*

At the time of the IOSTE conference, we had been implementing a pre-service teachers' professional development intervention at Bogazici University in Istanbul, Turkey. The intervention is based on three 3-hour workshops each emphasising a particular aspect of teaching and learning of scientific inquiry from an interdisciplinary perspective. We have generated a framework on the notion of "scientific practices" based on the cognitive, epistemic and social accounts of science (Erduran & Dagher, 2013) due to appear in a Springer book which has been informing the content of the workshops. The intervention agenda includes the goals of building on the participants' understanding and skills through peer discussions, collaborative investigations and reflection, strategies suggested by teacher education literature to be effective in promoting teachers' learning (e.g. Darling-Hammond, 2006). We will be in a position to report on the qualitative and quantitative measures of the impact of the intervention in due course.

CONCLUSIONS AND IMPLICATIONS

In this paper, I have argued that conventional depictions of NoS in science education are not sufficient in capturing authentic science and provides students with an outdated philosophical account of science. I have put forward the position that interdisciplinary accounts of science ranging from philosophy of science to economics of science have much potential to develop a more authentic version of science for science education. Improved representation of 'science' will inevitably expose the many often ignored 'faces' of science which, we as science educators, may not be very comfortable with. For instance, the legacy of colonialism in history of science is not an easy task for a science teacher to deal with at the level of the classroom. However, the alternative distorted version of history of science does not do any justice to learners and does not instil in learners the lessons that should be learned about ethical conduct of science. Incorporating an interdisciplinary perspective on science to characterise and embody NoS in science education is likely to contribute to teachers' and learners' interest in this approach to teaching and learning science. Given the wide range of issues being called for in an interdisciplinary characterisation (e.g. social, cultural, historical, economical) it is likely that more students' will be motivated to study science.

It is worthy to note that much of our work in this area has so far been theoretical in nature with the exception of the new TUBITAK/Marie Curie

Fellowship that I have been conducting in recent times. The empirical validation of the theoretical arguments will provide insight into how teaching and learning of NoS can be improved. Much work remains to be done in science teacher education to revisit how NoS is taught and how best to facilitate teachers' learning to teach NoS from a broader and revised perspective. I should state that a significant deal of creativity is called upon science educators in drawing on perspectives from other disciplines. As I outlined in the transformation of the Toulmin's framework, for instance, for instructional and methodological tools, we have had to not only understand the ideas in situ (ie. philosophical arguments) but also exercised much effort in making these ideas meaningful for science educators. The particular disciplinary perspectives from sociology, economics, anthropology and so on, will not present an obvious link and purpose to science education. It is out task as science educators to improve our own understanding of science from a wider perspective so that we can provide some useful recommendations for practitioners. Understanding science from one perspective, however, does not necessarily translate to the undermining of science from another. Learning about the colonial legacy of science does not devalue the rationality of science. One can learn about ethical conduct of science and at the same time engage in rationality and evidence-based reasoning. As with the case of Titanic I referred at the beginning of the paper, the various faces of science can be exposed to understand this complex domain from a range of perspectives that can be useful for science education. It is through such a nuanced and diverse disciplinary lens to NoS that students will 'sail' to authentic science.

ACKNOWLEDGMENT

The work in this paper has been supported by TUBITAK and European Union Marie Curie Co-Fund Brain Circulation Scheme Fellowship (291762/2236) to the author who held a visiting professorship at Bogazici University, Istanbul, Turkey leading a project entitled "*Revisiting Scientific Inquiry in the Classroom: Towards and Interdisciplinary Framework for Science Teaching and Learning.*" The views expressed reflect only the author's and no inferences should be drawn about the funders' input into the intellectual agenda of the paper.

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