Can the history of the balance of nature-idea inform the design of narratives for highlighting general aspects of nature of science?

GEORGIOS AMPATZIDIS, MARIDA ERGAZAKI

Department of Educational Sciences
and Early Childhood Education
University of Patras
Greece
ampatzidis@upatras.gr
ergazaki@upatras.gr

ABSTRACT

The idea of the Balance of Nature (BON-idea), which implies a predetermined order and stability guaranteed by a God's will or nature itself, is much older than the science of ecology and had a remarkable influence on it. It seems that the history of the BON-idea might be used for highlighting Nature of Science (NOS). Our study concerns whether it is actually feasible to draw on the BON-idea history in order to design historical narratives that could effectively support students to reach a better understanding of general NOS aspects. In this paper, we focus on which general NOS aspects could be highlighted by the BON-idea history and how. So, we argue that the BON-idea history can offer resources for the design of narratives that outline scientific knowledge as (i) influenced by socio-cultural contexts, (ii) mediated by creativity, and (iii) subject to change.

KEYWORDS

Nature of science, history of science, balance of nature

RÉSUMÉ

L'idée de l'équilibre de la nature, qui implique un ordre et une stabilité prédéterminés garantis par la volonté de Dieu ou la nature elle-même, est beaucoup plus ancienne que la science de l'écologie et a eu une influence remarquable sur elle. Il semble que l'histoire de l'idée de l'équilibre de la nature pourrait être utilisée pour illustrer la nature de la science. Notre étude se demande s'il est possible de s'inspirer de *l'histoire de l'idée de l'équilibre de la nature afin de concevoir des récits historiques qui pourraient efficacement aider les étudiants à mieux comprendre les aspects généraux de la nature de la science. Nous soutenons que l'histoire de l'idée de l'équilibre de la nature peut offrir des ressources pour la conception de récits qui décrivent les connaissances scientifiques comme (i) influencées par des contextes socioculturels, (ii) médiatisées par la créativité et (iii) sujettes au changement.*

Mots-Clés
Nature de la science, histoire des sciences, équilibre de la nature

Introduction

The progress of science is very fast nowadays and its products can considerably affect our lives (Raved & Assaraf, 2011). In order for people to be able to participate in personal or collective decision making about challenging socio-scientific issues such as gene therapies, designer babies or climate change for instance, they need to have at least an essential understanding of science and its nature (Summers & Abd–El–Khalick, 2019; Tsoni, Ampatzidis, & Kalogiannakis, 2020). The need for informed decision making of this kind has shifted the goal of science education from training future scientists to training future, scientifically literate citizens (Tripto, Assaraf, & Amit, 2018). As a result, scientific literacy appears very often in the discussion about the objectives of education, whereas it has also become central to science education research several decades now. In fact, the term scientific literacy 'stands for what the general public ought to know about science (Durant, 1993, p. 129). More specifically, it 'commonly implies an appreciation of the nature, aims, and general limitations of science, coupled with some understanding of the more important scientific ideas' (Jenkins, 1994, p. 5345).

So, Nature of Science (NOS) is a major component of scientific literacy (Cofré et al., 2019; Lederman & Lederman, 2014), and, as such, it is also an important objective of science education and an important theme in science education research. Although it has been proven difficult to articulate a commonly accepted definition of it, NOS refers to *how* scientists work to produce knowledge, as well as to what *kind* of knowledge they produce. In other words, it refers to the Nature of Scientific Inquiry (NOSI) and the Nature of Scientific Knowledge (NOSK) as well (Dagher & Erduran, 2016; Kampourakis, 2016).

NOS seems to be a hard topic for both students and teachers (Capps & Crawford, 2013; Erduran & Dagher, 2014). A popular teaching/learning approach is the so-called 'general aspects conceptualization of NOS'. In fact, there is not a strictly defined set of NOS aspects which could in turn result in a unique 'NOS aspects list'. On the contrary, there are several such lists, which may be used in different educational contexts and serve different teaching/learning objectives (Kampourakis, 2016; Lederman & Lederman, 2014). Having in mind *students* and the need of enhancing their scientific literacy, NOS is broken down to a small number of 'pieces' that when put together they may help them build a not necessarily advanced but still helpful version of the 'NOS-puzzle' (Kampourakis, 2016; Lederman & Lederman, 2014). This approach to the teaching and learning of NOS has received criticism, according to which (a) general aspects lists may shade the differences among the various science disciplines, and (b) some of the general NOS aspects may also characterize human endeavors other than science. However, general NOS aspects lists are largely used in NOS teaching and learning in seemingly effective ways (Abd-El-Khalick, 2014; Lederman & Lederman, 2014).

The general NOS aspects may be introduced to students either *per se* or in connection with specific scientific content. In the latter case, they may be integrated, implicitly or preferably explicitly, in student-led lab inquiries, lessons based on current cases of scientific work, or lessons based on cases from the history of science (Allchin, Andersen, & Nielsen, 2014; Clough, 2011). Teaching history of science on its own is not enough to support NOS understanding; however, it seems that if, during history of science-based lessons, teachers introduce some of the general NOS aspects in an explicit, systematic way, NOS teaching becomes more effective (Abd-El-Khalick & Lederman, 2000; McComas & Kampourakis, 2015).

In fact, drawing on the history of science to explicitly introduce general NOS aspects, appears to be a quite interesting strand in NOS literature (McComas & Kampourakis, 2015). Since we have been working with challenging the idea of the Balance of Nature (BON-idea) in students' reasoning for quite some time (Ampatzidis & Ergazaki, 2014, 2016, 2017, 2018a, 2018b), we noticed that the history of this persistent idea, which is much older than ecology itself and had a remarkable influence on it (Cuddington, 2001), might be used for highlighting NOS. Thus, our research question concerns whether it is feasible to draw on the history of the BON-idea in order to design historical narratives that could effectively support university students to reach a better understanding of general NOS aspects. To address this question, we first need to focus on *which* general aspects of NOS might be highlighted by *which* aspects of the BON-idea history and how.

Methods

Finding general NOS aspects and aspects of the BON-idea history that could possibly match and so be used in our design, requires exploring (a) the general NOS aspects appearing in the lists that shape the 'general aspects NOS conceptualization', and (b) the BON-idea history.

Exploring the general NOS aspects appearing in suggested lists

One can find several independently suggested lists of general NOS aspects for educational use (Kampourakis, 2016). Some of the most popular ones are presented below.

According to Osborne et al. (2003):

- Scientific knowledge is not produced by a single method.
- Science tests ideas and hypotheses using experimental methods.
- Science involves creativity and imagination.
- Scientific knowledge is produced through a collective process which is considerably based on the cooperation of the scientific community.
- The production of scientific knowledge has a historical dimension.
- Science involves the analysis and interpretation of data.
- Making predictions and collecting empirical data to support them have a central role in the formulation of hypotheses and conclusions within science.

According to Lederman (2007):

- Scientific knowledge is subject to change.
- Scientific theories and scientific laws are not identical.
- Scientific knowledge is influenced by the socio-cultural context within which it is produced.
- Scientific knowledge is based on observations of the natural systems.
- Scientific knowledge is subjective.
- Observation and inference are not the same.
- Scientific knowledge involves imagination and creativity on behalf of the scientists.

According to McComas (2008):

- Science relies on creativity.
- Scientific knowledge is tentative and robust.
- Science and technology are not the same, but they impact each other.
- Science relies on empirical evidence.
- Scientific theories and scientific laws are distinct forms of understanding.
- Science is not in position to answer all questions.
- Science is subjective.
- Science is influenced by historical, cultural, and social factors.

According to Niaz (2009):

- Scientific observations are influenced by theoretical presuppositions.
- Scientific knowledge relies largely on observation and experiment.
- Scientific knowledge is subject to change.
- Science is based on peer review and reproducibility.
- There is no universal, step-by-step scientific method.

- Scientists often use their imagination.
- Development of scientific theories may be based on inconsistent foundations.
- Scientific advancements are achieved through competition among competing theories.
- Different scientists can interpret the same observation in different ways.
- Laws and theories are distinct forms of understanding.

As shown above, the suggested lists differ in how many and which general NOS aspects they include. However, some NOS aspects are repeated. In other words, the lists may not be identical but they are more or less similar. Their similarities concern the outline of the scientific knowledge as based on empirical evidence, mediated by scientists' creativity and of course their interpretations and their inferential reasoning, influenced by the current socio-cultural context, produced through a range of different methods, taking distinct forms like laws and theories, and, very importantly, being tentative or subject to change. In other words, the lists promote a NOS-notion that addresses common misconceptions of students (Kampourakis, 2016; Lederman & Lederman, 2014).

Exploring the history of the BON-idea

The BON-idea implies a predetermined order and stability in nature, guaranteed by a God's will or nature itself. It is an idea with a rather long history. In fact, it was already present in most ancient religions and cosmologies. Within the Chinese philosophy of yin (Earth/Female) and yang (Sky/Male) everything in the universe lies in harmony through the balance of opposite forces (Jelinski, 2005). On the other hand, the ancient Greek mythology suggests that several order-enforcing deities, such as Tethys, Gaia, Themis and Metis, ensure the balance of the universe; everything is supposed to be interconnected so that balance and stability can be preserved (Jelinski, 2005). The BON-idea continued to be dominant for many centuries. In the 13th century, Thomas Aquinas claimed that there is order and purpose in nature in his book 'Quinque viæ' (McIntosh, 1985). Throughout the Middle Ages and later on, BON was considered a proof of a wise creator, who protected all species from extinction by not allowing for randomness and unpredictability in nature (Egerton, 1973; Jelinski, 2005).

In the dawn of the 19th century, Paley and the famous watchmaker analogy in his 'Natural Theology' enhanced the BON-idea further more: if the complexity of a watch's mechanism is a proof of a skillful watchmaker, then the extremely delicate BON has to be a proof of a wise creator (Jelinski, 2005). The BON-related idea that species are fixed was challenged by Charles Darwin. While visiting the Galapagos Islands, Darwin noticed that the species living there were more similar to the species living on the closest mainland than with each other. In order to explain this, he suggested that, at some point, species from the mainland inhabited the islands and, once there, they evolved. Such a claim was incompatible with nature's predetermined harmony, as this was represented in Paley's watch (McComas, 1997).

Although Darwin challenged the BON-idea in one way, he also contributed to it in another. As the science of ecology emerged, the predetermined order and stability implied by the BON-idea was rather transferred into a Darwinian context. Ecologists of early times attributed populations' equilibrium size at certain points, to an evolutionary control (Cooper, 2001). In the 20th century, the BON-idea was not always in the foreground but it *did* remain influential for the most part (Egerton, 1973). For instance, it kept manifesting itself through creative analogies. This was the case with the theory of ecological succession (i.e. the predetermined course of juvenile plant communities towards the maturity and stability of their adulthood), or, more generally, with the holistic view (nature is an organism-like, self-controlled, homeostatic entity that teleologically preserves its order and stability), and finally the cybernetic one (nature is a machine-like entity with strong regulatory mechanisms that always restore its balance by acting inversely). Deterministic ideas linked with these views were criticized from early on (Westra, 2008). However, it was *not* until the 1970s that equilibrium ecology was successfully challenged by new findings, interpretations and arguments, and the modern, BON-free ecological view of the resilient nature and its contingency took over (Ampatzidis & Ergazaki, 2018b).

Findings

Considering the above, the BON-idea history can be used to highlight the general NOS aspects that follow.

Scientific knowledge is influenced by socio-cultural contexts: the God-/order-bound BON-idea

The BON-idea, which emerged from strong religious assumptions of a divinely created stability in nature, had a significant influence on ecological knowledge. As cited in Jelinski (2005), Glacken, a great contributor to environmental history, in his 1967 masterpiece *Traces on the Rhodian Shore*, argues that 'modern ecological theory (…) owes its origin to the design argument' (p. 243), and it is not a coincidence that it 'has become the basic concept for a holistic view of nature, [having] behind it a long preoccupation in Western civilization with (…) trying to see [earthly environments] as (…) manifestations of order' (p. 706). The socio-culturally originated BON-idea was so powerful within ecology that had a long and huge impact on its progress. Interpreting data through a socio-cultural, rather distorting BON-lens, kept shaping scientific knowledge accordingly (Egerton, 1973).

This aspect of the BON-idea history is not the only one that can allow us shape historical narratives for highlighting the link between scientific knowledge and society's culture. This link may also be introduced by drawing on specific scientists who were involved in the history of the BON-idea. Darwin, for instance, had been developing his theory since 1839 but he hesitated to publish it, in part because he was afraid that it would be considered as an attack to the prevailing view of a world of harmony, stability and fixed species (Kampourakis & McComas, 2010). The first book discussing evolutionary issues, the 'Vestiges of the Natural History of Creation', was published anonymously by Robert Chambers in 1844 and caused rather strong objections. Darwin was worried that if he published his ideas, they wouldn't be more welcome than those of Chamber's (McComas & Kampourakis, 2015). Furthermore, Darwin was worried that his views would hurt his marriage, since his wife, Emma Wedgwood, was a deeply religious woman who, as most religious people of the time, would think that species' evolution was in conflict with Christian beliefs (Kampourakis & Gripiotis, 2015). In sum, we suggest that the history of the BON-idea can offer several opportunities for creating narratives with the aim at helping students enhance their understanding about the social embeddedness of science.

Scientific knowledge is mediated by scientists' creativity: BON-inspired analogies

The BON-idea history includes inspired analogies that seem appropriate for shedding light on the role of creativity in science. For instance, trying to argue *for* the BON-idea, Clements (1916) devised an analogy between the life-cycle of an individual organism and the life-cycle of a plant community. He viewed plant communities as super-organisms, which, in analogy with individual organisms, (a) go through a predetermined course of progressive shifts from their immature juvenile stages to their more mature ones, and finally (b) reach their totally predictable and stable adulthood, i.e. the equilibrium-conformed climax. In Clements (1916) own words:

> The climax formation is an organic entity. As an organism, the formation arises, grows, matures and dies. (…) The climax formation is the adult organism, the fully developed community, of which all initial and medial stages are but stages of development. Succession is the process of the reproduction of a formation, and this reproductive process can no more fail to terminate in the adult form in vegetation than it can in the case of the individual plant (pp. 124-125).

Similarly, Allee et al. (1949) discussed an analogy between the self-regulation of an individual organism and the self-regulation of an animal community. They viewed animal communities as super-organisms, which, in analogy with individual organisms, undergo homeostatic self-regulation, and thus enhance further the BON-idea. The idea that animal communities form a 'super-organism', which demonstrates an evolutionary-driven balance, is evident in their book 'Principles of animal ecology':

> The evolution of division of labor and integration between species results in a biotic system that may appropriately be called an interspecies supraorganism. The incorporation and control of the physical habitat by the interspecies supraorganism produces a unitary ecosystem. Homeostatic equilibrium within the ecosystem (balance of nature) is in large part the result of evolution (pp. 728-729).

Scientific knowledge is subject to change: from 'BON-bound' views of nature to a 'BON-free' one

Designing historical narratives about the tentativeness of scientific knowledge does not seem very hard, since the history of science is full of instances in which scientists elaborate, reconsider or reject previous ideas. The whole timeline of the shift from a predictable, one-state balanced nature to a contingent, multiple-state resilient one, can be used to address the aspect of tentativeness, and possibly along with the other two aspects since all three are actually intertwined within the historical context.

To give an example, we note the case of Clements. A decade after shaping his analogy about plant communities as super-organisms, Clements appeared to downgrade it in the light of criticisms raised by his colleagues (Egerton, 1973). Cooper (1926), for instance, pointed out that a mature plant community may end up as a community with shrubs and low vegetation after many months of overgrazing; and this would constitute a 'reverse development', i.e. a transition from a higher to a lower stage. According to Cooper (1926), since a single organism can never develop backwards, the idea of plant communities as super-organisms should not be accepted. On the other hand, Tansley (1935) also challenged Clements' idea based on the fact that two plant communities that are initially very different from each other (one grows in a swamp and the other grows on dry soil, for instance) is possible to develop into the same climax community (the same forest). According to Tansley (1935), since organisms who share similar adult stages, they also share similar early stages, plant communities shouldn't be considered as super-organisms. Even more erratically, Gleason (1926) suggested that plant communities have no natural boundaries, are assembled with species that *happen* to be together in a particular time and area and give a false balance-impression because of our snapshot-like insights to them. Gleason did not accept the existence of climax communities suggesting that the plant species existing in an area are constantly changing (Egerton, 1973).

Discussion

Drawing on the history of science to explicitly introduce general NOS aspects seems to be an interesting strand in NOS literature (McComas & Kampourakis, 2015), whereas it seems to be quite effective as well (Abd-El-Khalick & Lederman, 2000). Historical narratives are engaging, they help illustrate abstract concepts, and motivate the learners (Klassen, 2010). (Noddings & Witherell, 1991) note that:

> We learn from stories. More important, we come to understand—ourselves, others, and even the subjects we teach and learn. Stories engage us.… Stories can help us to understand by making the abstract concrete and accessible. What is only dimly perceived at the level of principle may become vivid and powerful in the concrete. Further, stories motivate us. Even that which we understand at the abstract level may not move us to action, whereas a story often does (pp. 279-280).

As already shown, the BON-idea history can offer resources for the design of narratives that outline scientific knowledge as (i) influenced by socio-cultural contexts, (ii) mediated by creativity, and (iii) subject to change. We think that, after managing to describe into detail how our narrative(s) will be unfold, it would be interesting to explore whether and how they could be integrated into an anti-BON learning environment like the one we have already developed and tested within a three-cycle design research (Ampatzidis & Ergazaki, 2017; Ampatzidis & Ergazaki, 2018a). Our learning environment aims at highlighting ecosystems' contingent behaviour to non-biology students, by engaging them in exploring simulations of more than one possible trajectory of disturbed or protected ecosystems. In fact, it is a purely ecology-oriented learning environment and it seems to us worth exploring whether and how it could be transformed into an 'ecology/NOS'-oriented one, by integrating narratives based on BON-idea's impact on ecological thought over time. Drawing on the history of ecology to bring ecological knowledge and NOS aspects together in ways that could make sense for non-biology students, might be a meaningful contribution to the modern quest of scientific literacy for all.

Acknowledgements

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Reinforcement of Post-doctoral Researchers - 2nd Cycle" (MIS-5033021), implemented by the State Scholarships Foundation (IKY).

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