Exploring Secondary School Biology Teachers’ Conceptions of Explanations

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The present study explored how in-service secondary education biology teachers understand the nature of biological explanations and used a research instrument that focused on how they understand the unique explanatory features of both neo-Darwinian Biology and Newtonian physics. Newtonian physics was used as a reference point because throughout most of the twentieth century, scholars, scientists and teachers have shared the positivist idea that Newtonian physics should be acknowledged as the model for knowing and the standard for all of the other sciences. Fourteen (14) in-service secondary school biology teachers from Greece (6 males, 8 females) completed a questionnaire and were interviewed. The results show that biology teachers were unable to unravel the distinction between nomothetic and non-nomothetic natural sciences when considering the explanatory features of biology and physics. They shared a notion of time that is inconsistent with how history affects the nature of biology and they faced difficulties in understanding the historical nature of biological systems. Moreover, they were inclined to teleological explanations and encountered difficulties in stating mechanisms.

Keywords: evolutionary history; mechanisms; nature of the sciences; positivism; teleological thinking.

INTRODUCTION

Science teachers tend to engage students in accumulating and repeating descriptive information about natural phenomena without focusing on how they can help students construct and articulate scientific explanations of phenomena (Baniower, Smith, Weiss, & Pasley, 2006; Osborne & Dillon, 2008; Roth & Garnier, 2007). However, explanations are an essential feature of science teaching and provide students with an avenue to construct a deeper understanding of the content knowledge (McNeill & Krajcik, 2008). Thus, much has been written about the role of instructional explanations in science learning and the factors that influence their effectiveness (e.g. Braaten, & Windschitl, 2011; Dagher & Cossman, 1992; Treagust & Harrison, 1999; 2000; Wittwer & Renkl, 2008).

Instructional explanations are different from science explanations (Treagust & Harrison, 2000) but their quality depends on how teachers understand the explanatory frameworks that scientists use. Thus, in order for science teachers to be able to encourage students to make shifts from descriptions to explanations in science classes, they should be informed of the explanatory features or frameworks that are specific to the science they teach. While philosophers of science have long examined the structure and role of explanation in the sciences, teachers’ views of these issues have been afforded little attention in science education literature (Braaten & Windschitl, 2011). Thus, more insight into how teachers understand the discipline-specific nature of explanations is needed and this is important not only because of the role of explanations in science teaching. Science educators also argue that the teaching and learning of the structure or nature of scientific explanations may help students acquire a better understanding of science (Kampourakis & Niebert, 2018).

Therefore, the present study aims to explore how in-service secondary education biology teachers understand the main features of the biology’s explanatory framework and detect inconsistencies, flaws, deficiencies and misunderstandings.

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In order to meet our purpose we focus on how in-service secondary education biology teachers understand the unique explanatory features of both neo-Darwinian Biology and Newtonian physics. Neo-Darwinian biology originates from Modern Darwinian synthesis, which has made explicit that evolutionary biology lies at the heart of contemporary biology and plays a unified role in the articulation of most contemporary biological fields (Smocovitis, 1992). On the other hand, Newtonian physics draws its background assumptions from classical mechanics (Merchant, 2003) and embraces a host of physical scientific fields (e.g. classical mechanics, optics and electromagnetism; Baltas, 1993) that constitute much of the knowledge taught in contexts of physics instruction internationally.

Our choice to investigate how biology teachers understand the unique explanatory features of biology by focusing on neo-Darwinian Biology instead of specific biological fields, and on both neo-Darwinian Biology and Newtonian physics needs to be justified. First, instructional biological explanations are mostly grounded in the epistemological features of neo-Darwinian Biology due to the nature of biological research object (e.g. the range of phenomena that are specific to the conceptual systems of different biological fields). More specifically, interaction and context are always of essence in biology (Lewontin, 2000; Van de Vijver et al., 2003) and biological phenomena occurring at some organizational level depend on other phenomena occurring at lower and higher organizational levels. This implies that biological phenomena are fully captured when they are determined through their relations to the other phenomena and their position within the total research object of biology. Thus, the biological research object is structured and its structural composition brings all contemporary biological fields close to the ontological, methodological and epistemological features of evolutionary biology. This is evident in both aspects of biologists, philosophers of biology and science educators suggesting that biological knowledge can only be understood in the light of evolution (Dobzhansky, 2013; Mayr, 2004; Rudolph & Stewart, 1998) and contemporary international biology textbooks that interrelate aspects of biological evolution with the presentation of various biology topics (e.g., Hoefnagels, 2018; Urry et al., 2016).

Second, our choice to investigate how biology teachers understand the unique explanatory features of biology by focusing on how they understand the explanatory aspects of both neo-Darwinian Biology and Newtonian physics is grounded in the fact that throughout most of the twentieth century, scholars, scientists and teachers have shared the positivist idea that Newtonian physics should be acknowledged as the model for knowing and the standard for all of the other sciences (Frodeman, 1995). Thus, the present study uses the explanatory frameworks of Newtonian physics as a reference point and tests the following scientific hypothesis: we assume that biology teachers’ views of the biological explanatory frameworks are more or less close to positivist tenets.

The nature of our scientific hypothesis enforces us to investigate how biology teachers understand the notion of time. Biological explanations are mostly historical and unavoidably include a conception of time, which is different from analogous conceptions of time in lawful sciences. For example, in biological systems there is an inherent arrow of time, while in Newtonian systems time lacks the form of an arrow and flows uniformly both to the past and the future (Ulanowicz, 2007). Thus, in order to elaborate on whether and how biology teachers understand historical aspects of the biological explanatory frameworks, we also focus on how they understand aspects of the nature of scientific predictions. This research choice helps us explore how biology teachers consider the symmetry of time and qualitative differences among the past, present, and future that the notion of historicity induces.

Additionally, our research choice to ask biology teachers answer compare and contrast questions regarding the particular epistemological features of biological and physical explanations helps us acquire a more complete picture of how biology teachers understand idiosyncratic features of biological explanatory frameworks. The unique explanatory features of biology become more meaningful when they are compared and contrasted with widely accepted reference models, such as the explanatory frameworks of Newtonian physics.

Prior to presenting the methodology and discussing the results of our empirical research, we focus on the unique epistemological features of Newtonian physics and neo-Darwinian biology and highlight how these sciences elaborate on the topics of explanations and predictions.

**Fundamental differences between Newtonian physics and Neo-Darwinian biology**

Newtonian physics is the only science whose theories are structures independently formulable within the realm of pure mathematics (e.g. vector calculus underlies classical mechanics and classical electromagnetism), as positivism requires (Baltas, 1993). Thus, the relations among the interdependent concepts that compose the conceptual systems of physical theories are mathematical and form the laws that are particular to each theory.

Physical laws are universal regularities that apply to general physical phenomena. However, the domain of their applicability is extended to the concrete empirical phenomena that Newtonian physics studies, because the latter have no qualities related to their identity and history. They are reduced to apriori mathematical sets of well-defined variables, parameters and conditions, initial and boundary, and always represent a general phenomenon (Baltas, 2004).

Contrary to physical phenomena, biological phenomena are not simply representatives of general phenomena and cannot be subordinated to universalities and deductive-
nomological reasoning. The complex, heterogeneous and foremost historical nature of biological systems (Sober, 1993) enforces biologists to focus on how entities with specific identities behave in specific spatio-temporal environments and elaborate on unique events associated with their advent (Potochnik, 2013). Thus, neo-Darwinian biology establishes a "way of looking" the world, which is different from the one of positivism and Newtonian physics. This way is mostly based on the techniques of hermeneutics and historical sciences (Mayr, 2004; Stamou, 2012).

Scientific explanations

When Newtonian physicists attempt to grasp an empirical phenomenon, they primarily focus on subordinating this phenomenon to a universal law. This implies that Newtonian explanations comply with the standards of the deductive-nomological model.

According to this model, a scientific explanation is a deductive argument ( Brigandt, 2013). A phenomenon is explained by a set of true premises from which the phenomenon’s description can be derived. These premises contain at least one law of nature and information about particular facts, such as the initial conditions of the phenomenon ( Potochnik, 2013).

The standards of the deductive-nomological model are in agreement with ‘formal’ explanations (e.g. the ideal gas equation pV = nRT; Besson, 2010). Formal explanations correspond to the causal closure of physical systems and consist of simultaneous functional relations among quantities that describe the system and are all internal to the system. These explanations focus on relations among entities that belong to the same organizational level and, thus, they can be considered more to be descriptions rather than explanations. However, many scientists consider that a phenomenon is sufficiently and satisfactorily explained when it is well described by a certain law, in the sense that the law explains and results in the estimation of the characteristic variables (Besson, 2010).

Moreover, the Newtonian principle of decomposability, that larger units are considered to be decomposable aggregates of stable least units, which can be built up and taken apart again (Ulanowicz, 2016), gives rise to "bathygeneous" explanations (Besson, 2010; Halbwachs, 1971). Bathygeneous explanations consist of a lower-level underlying structure or a more general, deeper theory (e.g. kinetic theory explaining the behavior of gases) and presuppose that regularities at lower organisational levels explain regularities at higher organisational levels. Remarkably, when these regularities reflect mechanisms, then mechanistic explanations result. These explanations focus on how a phenomenon occurs and consist of chains of causes and effects through which the parts of the system under consideration are connected to each other (Lewontin, 2000).

On the other hand, law-like universalities are inappropriate for explaining biological phenomena because apart from being historical, biological phenomena are (a) contingent, i.e. the causal factors do not act individually and independently of other factors and a phenomenon has a tendency to occur in a particular context (Ulanowicz, 1999) and (b) causally open, i.e. the action of a causal agent is interrelated with and dependent on the effects of other causal factors, which are found not only within but also outside the borders of the biological system under study.

Nevertheless, like Newtonian physics, biology focuses on causal mechanisms and descends organizational levels to answer questions of the ‘how’ type. In contrast to Newtonian physics, however, these mechanisms are outcomes of biological evolution and do not describe invariable and universal sequences of facts. Thus, in conjunction with answering questions of the ‘how’ type ( i.e. proximate causality; Mayr, 1997), biology ascends organizational levels in order to answer questions of the ‘why’ type ( i.e. ultimate causality: Mayr, 1997). The latter explanations are evolutionary and make extensive use of narrative logic. They narrate a story and create a context that defines and gives meaning to biology research and data (Frodeman, 1995).

Scientific predictions

The specific numerical values of the characteristic variables, parameters and conditions (both initial and boundary) are the only features of natural phenomena that Newtonian physics can be informed of. If we keep in mind that these quantities can be estimated with accuracy, then we can reach the positivistic conclusion that all behavioral aspects of physical phenomena can be predicted with certainty ( Baltas, 2004). Certainly, Newtonian physics can make erroneous predictions, but this failure results from human errors and it is not an inherent feature of Newtonian physics.

On the other hand, biology cannot make certain and secure predictions mostly because of discontinuities in the behavior of biological systems, missing data resulting from their causally-open nature and the dependence of the new states of biological systems on the historical succession of their previous states ( Beatty & Desjardins, 2009).

Moreover, contrary to Newtonian systems, biological systems are irreversible and generalities holding true for the past cannot be projected into the future (Ulanowicz, 2007). Thus, contrary to Newtonian explanations in which physical laws are assumed to work the same in past and future temporal directions, biological explanations cannot be equated with predictions.
METHOD

Data collection and analysis

Data were collected through a complementary procedure that involved the administration of a questionnaire and the implementation of interview sessions. Interviews were the primary source for gathering data because they are considered to be the most appropriate methods for exploring learners’ views on the nature of science along with open-written questions (Abd-El-Khalick & Lederman, 2000; Lederman et al., 2002). Prior to interview sessions, however, each teacher was asked to complete a questionnaire consisting of 3 multiple-choice questions. Our purpose behind the administration of the questionnaire was to trigger teachers’ thinking of the nature of scientific explanations (including aspects of scientific predictions), elicit their views about these issues and create a context in which these views could be discussed. This discussion was carried out during in-depth individual interviews.

Fourteen (14) in-service secondary school biology teachers from Greece (6 males, 8 females) took part in our research and were selected out of a larger pool of biology teachers (about 108 individuals) who participated in life-long biology education seminars. These seminars were carried out by one of the authors in the Aristotle University of Thessaloniki several times and their main target group was in-service Greek biology teachers. These teachers share a strong disciplinary background having studied their discipline for four years in the Universities. Although their undergraduate studies involve very few courses on other natural sciences, Greek legislation considers them to be sufficient to teach all the natural sciences in secondary schools. Furthermore, during their undergraduate studies biology teachers have not become competent in the field of the nature of science (NOS). NOS knowledge is not included in school science curricula and this is why their further professional development as school science teachers does not involve institutional in-service courses on NOS.

Sample size determination was guided by the criterion of saturation (Francis et al., 2010). We initially started gathering data from a small number of participants (about 8 participants). The teachers who were selected to participate in our study had a genuine interest in improving their professional profile and expressed enthusiasm for discussing their views with the interviewer who was also their seminars’ teacher. Then we continued increasing the sample size and we terminated sampling when no new information was elicited by sampling more units. During this process, sample representativeness was considered important and thus the participating teachers were intentionally selected to represent a range of individual and educational profiles. More specifically, their ages and teaching experience varied from 26 to 48 years and from 5 to 19 years respectively; twelve teachers taught in public schools and the rest in ‘private coaching’ ones; six schools were located in rural or semi-rural areas and eight in urban areas; two teachers held Masters in Biology and one of them held a PhD in Biology.

The final version of the questionnaire was derived from a revision procedure that involved a two-stage discussion among the authors, two experienced teachers who held PhDs in science education and two experienced in-service teachers (a biologist and a physician). As a result, some of the initial items were reworded and others were deleted.

Each question allowed participants to choose from bipolar agree-disagree positions coupled with several justifications (Table 1). Positions and justifications were categorized as representing non-informed (NI) or informed (I) views. There was only one informed position and justification in each item, whereas the criteria used for their categorization were drawn from the theoretical framework already discussed in a former section and presented more thoroughly in Schizas, Psillos and Stamou, 2016. Additionally, following Abd-El-Khalick and BouJaoude (1997) as well as Dogan and Abd-El-Khalick (2008), we added to each item an open-ended choice that allowed teachers to express ideas or viewpoints different from those provided in each item. Participants, however, used this choice rarely and when they used it their written responses were, in almost all cases, a combination of the standard answers provided for the various items.

Table 1. The questionnaire items.

| Question 1. A physicist tries to explain the behavior of a specific pendulum in a particular environment and a biologist tries to explain the behavior of a specific population (e.g. a change in the population size of a species) in a particular environment. Does the physicist think like the biologist? |
| Your position is The physicist thinks similarly to the biologist. |
| Justification (NI). Because the explanation in both cases is based on three things: the description of the initial conditions (what is the initial state of the population or the pendulum), the formulation of universal generalizations (generalizations that describe how each pendulum behaves or how each population changes) and the description of the environmental conditions of the pendulum and the population. |
(NI)B. because in both cases the phenomena are instances of general phenomena such as “the movement of a harmonic oscillator” or the “exponential increase in population size”.

The physicist does NOT think similarly to the biologist.

Justification
(I)C. because in biology there are no generalizations to explain or predict how each population will behave in any environment. While the biologist studies the change of a specific population in a specific environment as a separate case study, the physicist considers that the specific pendulum in the specific environment behaves like all pendulums and deviations in its behavior pertain to different environmental conditions that can easily be predicted by theory.

Question 2 (Schizas & Psillos, 2019, p.47). A physicist examines the causes of a physical phenomenon such as the expansion of metals in summer and a biologist searches for the causes of a biological phenomenon such as the migration of insectivorous birds from temperate to subtropical and tropical areas in the autumn. Does the physicist think like the biologist?

Your position is
The physicist thinks similarly to the biologist.
Justification:
(NI)A. Because the explanation in both cases concerns how these phenomena occur. Both the physicist and the biologist seek for the mechanisms that cause the phenomena and attempt to describe a sequence of events that take place in the interior of the metal and the organism, respectively.

The physicist does NOT think similarly to the biologist.

Justification:
(NI)C. Because there are types of explanations in biology that are not present in physics. These explanations ascribe intentions and purposes to organisms. For example, insectivorous birds migrate from temperate to subtropical and tropical areas in the autumn because they want to find food, to overcome severe climate conditions, to reproduce and so on.

(I)D. Because biological explanations involve not only mechanisms that cause the phenomenon under study but also narrations of historical events. Thus, apart from describing the mechanisms that underlie the behavior of migratory flight, a biologist should narrate a story in regard to how insectivorous birds have become able to manifest this behavior.

Question 3 (Schizas & Psillos, 2019, p.47). Can natural sciences make certain and secure predictions?

Your position is
Natural sciences can make certain and secure predictions
Justification:
(NI)A. Because in each case prediction is based on explanation. For example, if we can explain how a physical or biological system behaves then we can predict how this system will behave in the future with certainty and security.

(NI)B. Because in each case the behavior of physical and biological systems is subordinated to physical and biological laws. If we know the initial state of these systems we can use these laws to predict their future states with certainty and security.

Natural sciences CANNOT make certain and secure predictions
Justification:
(NI)C. Because in both classical (Newtonian) physics and biology non-predictable events can occur that change the predictive outcome.

(I)D. It depends. For example, classical (Newtonian) physics can make certain and secure conditions because it knows everything concerning the physical system under study. Biology, however, cannot make certain and secure predictions because non-predictable and new events can occur in both the environment of the biological system and the biological system itself. Apparently, these events change the predictive outcome.
Interviews lasted approximately 30 minutes each. All participants were encouraged to explain their responses to the questionnaire's items and exemplify their choices. Follow-up and probing questions were used to clarify vague or obscure statements and allowed us to further examine the respondents' lines of thought.

All interviews were recorded on an audiotape and the resulting interview transcripts were subsumed to content-analysis. Content analysis is beneficial in analyzing interviews (Devetak & Vogrinc, 2013) and helped us acquire descriptive data on participants' views of the explanatory frameworks of neo-Darwinian biology and Newtonian physics, and detect participants' misunderstandings, missing information, inconsistencies and inaccurate statements.

Within the framework of content analysis, the formation of categories is a crucial feature. In our study, the categories were similar to the ones used in Schizas and Psillos (2019) and were used as columns in tables of contents. These categories were the following: "Subject" entitled the studied text material; "Text" included the participants' responses to the questionnaire and the interviewer's questions; "Vocabulary" referred to how participants defined epistemological concepts; and "Ideas" included participants' assumptions concerning philosophical or epistemological categories (e.g., the category of causation, the category of time, etc.) that underlie the epistemological issues discussed in the interview session. The elements of all of the previous categories merged in the column "Worldview", which referred to the participants' affinity to positivistic ideas or the neo-Darwinian worldview.

Each participant was treated as a separate case and the answers of each participant to every questionnaire item were determined as unit of analysis (i.e., the fragment of message that was analyzed each time). Our choice reflected the fact that each item helped us discuss a central theme or particular aspects of this central theme with participants during the interview session.

Finally, we checked the inter-rater reliability of our analysis by asking all authors to analyze a 20% random sample of the textual material during each of two rounds of analysis. This process yielded a 91% mean of reliability coefficient during the second round. The rest of the analysis was conducted by one of the authors.

RESULTS AND DISCUSSION

The content analysis of interview transcripts led to the following results:

Scientific explanations

Question 1. A physicist tries to explain the behavior of a specific pendulum in a particular environment and a biologist tries to explain the behavior of a specific population (e.g. a change in the population size of a species) in a particular environment. Does the physicist think like the biologist?

Four (P2, P3, P7 and P8) out of fourteen participants agree with the questionnaire’s non-informed position and justification that physicists think like biologists because scientific explanation in both cases is based on the mathematical description of (a) initial conditions (i.e. the description of the initial state of population or pendulum), (b) universal generalizations (i.e. generalizations that describe how a pendulum behaves or a population size changes) and (c) boundary conditions (i.e. the conditions of the environment of the pendulum and the population). When these participants are asked to elaborate on their choices in the interview session, they focus on positivistic tenets. For example, P7 mentions that “both physicists and biologists use mathematical equations to explain the behavior of the pendulum and the population”, P2 argues that explanatory universal generalizations are important and apply to both cases, while P3 states that the basic way of approaching a scientific problem is common to all natural sciences...it is the mathematical logic...this is the way the universe works.

Ten out of fourteen participants agree with the questionnaire’s informed position and justification that physicists think differently from biologists because in contrast to physics, there are no biological generalizations capable of explaining how biological entities (e.g. a population) behave in different environments. Responding to our request of justifying their choice, P6 focuses on both the internal and external sources of biological causality, namely the nature of both entities and environment, stating: “biological generalities cannot be universal because of specificities of the entities under study and the complex nature of the environment which these entities live in”. However, partial considerations of these sources are frequent. For example, P5 overlooks the nature of biological entities and focuses only on environmental complexity and stochasticity. In particular, P5 states: “general explanations are impossible because the environment which biological systems live in consists of many ever-changing factors”.

In the interview session, only four (P4, P6, P12, P13) participants explicitly focus on the interplay of both the internal and external causal factors that influence biological systems by stressing the role of evolution. More specifically, P12 states: “unlike physical phenomena, biological phenomena involve evolutionary processes. Bacteria of the same species would behave differently if they evolved over time”. Moreover, responding to our request of elaborating on why she did not support the first position-justification choice regarding the use of the deductive-nomological model in biological explanations, P12 mentions: “in biology we do not apply a pre-defined mathematical equation to a biological system...
observe the system, we find that the system changes due to certain parameters and then we put these parameters into a mathematical equation… the equation is the result of our research.” Obviously, this response takes into account unique epistemological features of biology that favor inductive reasoning over deductive-nomological reasoning.

Question 2: A physicist examines the causes of a physical phenomenon such as the expansion of metals in summer and a biologist searches for the causes of a biological phenomenon such as the migration of insectivorous birds from temperate to subtropical and tropical areas in the autumn. Does the physicist think like the biologist?

Three (P3, P7 and P8) out of fourteen participants agree with the questionnaire’s non-informed position and justification that physicists think like biologists because explanations focus on how something occurs. In the interview session, thus, we expect from these participants to focus on mechanisms when answering the question of how insectivorous birds migrate. However, all of these participants encounter difficulties in stating mechanisms. For example, P7 and P8 direct their attention to environmental factors rather than the interior of insectivorous birds’ body where a mechanism can be found. P8 states that the required mechanism is the season, whereas P7 holds that the birds migrate because of temperature.

These statements are in accordance with the views of other participants (P2, P10, P11 and P14) who accept the questionnaire’s informed position and non-informed justification that physical and biological thinking are different because in biology there are explanations not found in physics such as those based on intentions and goals. For example, the views of P7 and P8 are consistent with the views of P2 who holds that the cause for the migration of insectivorous birds to subtropical or tropical areas in the autumn is to find food, to avoid severe winter conditions and to reproduce. Thus, there are participants who identify teleological thinking as a unique feature of biological explanations and participants who focus on ‘how’ type questions, but fail to state mechanisms and resort to teleological thinking.

Probably all the above mentioned participants encounter difficulties in understanding that the operation of mechanisms rather than the necessity of the function itself is what determines if a given function will be performed. Thus, they confuse teleological purpose with mechanisms of action in considering body functions and cannot develop their mechanistic reasoning (Richardson, 1990). Moreover, this way of looking at biological explanations addresses the future rather than the past, i.e. the historical character of a given function, and shifts participants’ thinking from biological explanations that are grounded in evolution.

The appeal to evolutionary explanations is evident in the majority of participants. Most participants (P1, P4, P5, P6, P9, P12 and P13) agree with the questionnaire’s informed position and justification that physical and biological thinking is different because evolutionary explanations in biology should be provided in parallel with mechanistic explanations. However, while these participants are able to apply evolutionary schemes to the phenomenon of insectivorous birds’ migration, such as the scheme consisting of mutations, population variation, inheritance and natural selection, and integrate this phenomenon into a structured whole that can likely render a kind of historical narrative (van Dijk & Kattmann, 2009), they find it hard to focus on the mechanisms that lie behind birds’ behavior of migratory flight. In particular, they cannot grasp the ontological openness of biological systems and face problems in associating phenotype with genotype (Duncan & Reiser, 2007; Duncan & Tseng, 2011) and reducing the distance that separates lower (genotype) from higher (phenotype) organizational levels. Thus, they cannot direct their attention to sequences of events from setup conditions through intermediate stages to termination conditions that occur in the interior of biological entities and underlie mechanistic explanations (Russ et al., 2008). Indeed, in participants’ responses to the follow-up question of how the genes that are responsible for migratory flight cause this individual behavior, no reference is made to hormonal and other metabolic phenomena that are induced through environmental stimuli, such as the length of the daytime period.

Remarkably, teleological thinking is also present in those participants who focus on evolutionary explanations and impedes them from elaborating on mechanistic reasoning. For example, P13 applies a generalized evolutionary scheme to the birds’ behavior of migratory flight but when being asked to suggest a mechanism, she claims: “The mechanism is probably the absence of food…” Moreover, P5 makes the need to search for mechanisms and aspects of “proximate causality” (Mayr, 2004) redundant when mentioning: “the birds learnt to behave this way… learning is heritable… there is a survival mechanism… a kind of internal will that allow the species to survive…”

All participants are more or less susceptible to teleological thinking and this is discouraging. Learners’ teleological thinking has been discussed as being a “cognitive construal” (e.g. Coley & Tanner, 2012), namely an informal and intuitive way of learners’ thinking about the world that gives rise to a number of misunderstandings regarding biological topics. Thus, it is questionable whether participants can guide their students to struggle with this cognitive construal when considering biological phenomena.

More to this point, cognitive construals may not be simply informal, intuitive ways of thinking about the world that are a priori attached to learners. Teleological thinking may be also a “side effect” of the existential nature of biological
science. Biological entities exist rather than “are” in particular environments and they struggle for existence exhibiting functions or properties that serve particular goals (e.g. their well being) (Walsh, 2008). Thus, biological phenomena do not simply happen. They have an innate purpose and this purpose is the survival and reproduction of biological entities. Therefore, participants cannot avoid making references to the survival needs of the organisms and thus, they become susceptible to teleological thinking due to the epistemological specificities and unique features of biological science (Evans & Rosengren, 2018).

Teleological thinking however is not acceptable in biology and the main reason is that biological entities cannot be equated with humans who exhibit a purposeful behavior. Biological explanations, focusing on “why” type questions, derive from the past and not from the future. They are primarily historical explanations and, thus, biology teachers need to be more informed of the notion of historicity and how it penetrates into biological explanations if the shift from purpose-based teleological explanations to the purposeless natural selection is to be accomplished on the part of their students (Lennox & Kampourakis, 2013).

The question of whether participants possess non-informed views of the historical nature of biological systems or not, needs further elaboration and this can be done with the examination of participants views of the nature of biological predictions.

**Scientific predictions**

**Question 3.** Can natural sciences make certain and secure predictions?

Three (P3, P4 and P7) out of fourteen participants respond in the affirmative. P7 agrees with the questionnaire’s non-informed justification that in every case the behavior of physical and biological systems is subject to physical and biological laws respectively and if we know the initial state of these systems, we can use these laws to predict their future state with certainty and security. P3 and P4 prefer the other non-informed justification that, in any case, predictions are based on explanations and, thus, if we explain how a system behaves, then we can safely predict how it will behave in the near or distant future. Thus, their questionnaire’s choices indicate their affinity to the idea that time is more the neutral background on which timeless generalities unfold and less what became after Darwin, the relational sequence of unique and past events (Kwa, 2010). Unavoidably, positivistic tenets that advance predictability as an essential feature of natural sciences are brought to the fore. In P3’s own words: “I cannot imagine a natural science without predictability... the nature of biological phenomena is not different from the nature of physical phenomena ... only there are more variables and the final prediction is difficult ...”

A few participants (P6, P11 and P14) agree with the questionnaire’s informed position but non-informed justification that natural sciences cannot make secure and safe predictions, due to the occurrence of unpredictable events that can change the outcome of prediction. Moreover, responding to our question of whether biology and physics share the same predictability problems or not, they disregard the historical character of biology and state obscure generalities stemming from uniform nature of the sciences views. For example, P6 mentions: “[m]ostly biology I believe ... but also physics... I was thinking the same thing at the time I tried to answer this question…. there may be some other particles, which are currently unknown and may influence the phenomenon under study or affect the final outcome ...science will never reach at the level of making certain predictions because the human mind is finite and we cannot have all the data to know everything that happens in nature”.

Most participants (P1, P2, P5, P8, P9, P10, P12 and P13) agree with the questionnaire’s informed position and justification that physics can make certain and secure predictions, but biology cannot make such predictions because unpredictable events change the outcome of prediction. In our request, however, of defining these unpredictable events, they focus more on the complex nature of biological systems, environmental stochasticity and the behavior of biological organisms and less on historical events and evolutionary schemes that combine random changes of biological systems with environmental stochasticity. P8’s views, for example, are consistent with the views of P2 who states that predictability is difficult in biology because of the host of factors that influence biological phenomena, while P5 mentions that the environment of biological systems does not remain stable but changes and because of these unpredictable changes we cannot predict how a biological system will behave. Respectively, P9 states: “in physics you know what will happen when you throw a ball, where the ball will go… ball movement has rules... in biology [however] when zebras and elephants start their movement... when they search for water... you cannot predict their behavior”.

In conclusion, all participants fail to perceive how historicity is related to predictability issues. Indicative of this failure are also responses of some participants (P2, P8, P10, P11) that stress the tentativeness of biology. These participants argue that the ability of biology to predict future events will be improved over time due to the accumulation of scientific facts and the finding of new research tools.

**CONCLUSIONS**

Most participants are unable to unravel the crucial differences between neo-Darwinian biology and Newtonian physics when considering their explanatory and predictive features. For example, there are participants who accept positivistic tenets, such as that
biological and physical explanations comply with mathematical explanatory patterns (e.g. the one of the deductive-nomological model) and others who define predictability as a common and essential feature of natural sciences.

Even in cases where participants stress differences between biology and physics, they face difficulties in understanding the most important feature of biological systems, namely their historical nature. All of the participants can hardly capture the states of biological systems as representing unique and non-repeatable sequences of events. Remarkably, this unfamiliarity of participants with the notion of historicity may explain why their focus on differences between physics and biology is primarily directed to the complexity of biological systems and the stochasticity of the environments which these systems live in.

The main reason behind their ahistorical approach to biology is their affinity to a notion of time, which is inconsistent with how history affects the nature of biology. This notion is time reversibility and their affinity to this notion is explicitly evident in participants who make an appeal to the deductive-nomological model when considering the nature of biological explanations and predictions (e.g. deductive-nomological explanations refer to both the past and the future in the same manner). It is also implicitly evident in the cases where participants do not associate nonreversible and historical notions of time with predictability and share the positivist (mis)conception that biology will improve its predictability in the future because of accumulating scientific facts or developing more advanced techniques and methods.

The difficulties that participants face in understanding the historical nature of biology and associating this feature with biological causality accompany other difficulties. When participants are asked to state mechanisms, they focus on environmental factors or simple processes rather than interrelated entities or processes that compose sequences of events serving a common function in the interior of biological entities, namely mechanisms. These difficulties also trigger or even result from misunderstandings that indicate a pre-Darwinian type of biological thinking. Although participants can apply non-Lamarckian and Neo-Darwinian evolutionary schemes to biological phenomena, they also manifest the tendency to capture aspects of these phenomena from a teleological viewpoint.

Teleological thinking gives rise to a number of misunderstandings regarding biological topics and learners need to overcome this type of thinking. This is possible if they become more familiar with the notion of historicity. Historicity shifts biology learners’ thinking from a perspective that looks at the future to a perspective that looks at the past.

However, making biology teachers familiar with the notion of historicity is not an easy task for science educators. Historicity is a complex concept and its understanding presupposes the difficult notion of time irreversibility and the decisive role of narrative logic. Historical narratives do not explain an event by subordinating it to a generalization. They integrate it into a structured whole, which involves not only internal or external to entities events, such as mutations and changes in abiotic/biotic environmental conditions, respectively, but also a complex interplay of both of them under an evolutionary framework.

Overall, most biology teachers fail to unravel the distinction between nomothetic and non-nomothetic natural sciences when considering the explanatory features of biology and physics. This failure induces misunderstandings in regard to how they conceive the explanatory framework of biology and may have repercussions on how they transform scientific explanations into instructional explanations in science classes. Yet, further research on this kind of transformation is needed to reveal how their aspects of the nature of biological explanations influence instructional explanations and thereby informing biology teachers of how to help students struggle with their own explanatory inconsistencies, flaws and deficiencies.

REFERENCES


Dagher, Z., & Cossman, G. (1992). Verbal explanations given by science teachers: Their nature and


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