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Research Article

Bonding Nature of Science (NOS) and Nature of the Sciences (NOTSs) with Conceptual Knowledge: Introducing NOS and NOTSs Learning Objectives into the Teaching of 'Homeostasis'

Dimitrios Schizas [1*], Dimitris Psillos [2], Penelope Papadopoulou [3]

[1] Department of Primary Education, School of Humanities and Social Sciences, University of Thessaly, Volos, GREECE
[2] School of Primary Education, Aristotle University of Thessaloniki, Thessaloniki, GREECE
[3] Department of Early Childhood Education, School of Education, University of Western Macedonia, Kozani, GREECE
***Corresponding Author:** dschizas@uth.gr

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ABSTRACT

The present study aims to design an instruction that engages nature of science (NOS) and nature of the sciences (NOTSs) learning objectives with the teaching and learning of a core biological concept or 'big' idea, namely homeostasis. The design process involves choices regarding what NOS and NOTSs aspects are to be taught, while the formulation of these aspects is in accordance with science-content learning objectives, such as the understanding of definitional features of homeostasis and human thermoregulatory mechanisms, and difficulties that students face in accomplishing these objectives. Through NOS and NOTSs learning objectives, students are expected to be informed of (a) the theory-laden character of scientific knowledge, (b) the hierarchical organization of primary ontological levels, (c) a model focusing on aspects of biological causality (d) definitional and accompanying features of the notion of mechanism, and (e) how to search for finding mechanisms including the interrelation of structure and function. Moreover, students are instructed in elaborating on their causal reasoning through a model and a metaphor (e.g., air-condition) when considering human thermoregulatory mechanisms. The potential benefits of the teaching of all these items to students' understanding of homeostasis are also discussed.

Keywords: homeostasis, misconceptions, nature of science, nature of the sciences

INTRODUCTION

Although defining science is a rather difficult task, the majority of science educators would agree that nature of science (NOS) is an area of study in which students learn how science works, how knowledge is generated and tested, and how scientists do what they do (McComas & Kampourakis, 2015). An agenda that overlaps NOS recommendations for informing K-12 curriculum development, instruction and teacher education contained in eighth international science education standard documents (McComas, 1998) has also been proposed and consists of a few epistemological items. These items can be stated, as follows (e.g., Lederman et al., 2002; Mesci & Schwartz, 2017):

1. scientific knowledge is empirical, tentative, partly a product of the human imagination and creativity, theory-laden, subjective, embedded in social and cultural contexts and not obtained by a universal step-by-step scientific method and
2. scientific laws are descriptive statements about the discerned patterns of natural phenomena and differ from scientific theories, which are inferred explanations of those phenomena.

Students' understanding of NOS is an important component of scientific literacy (Cofré et al., 2019; Hodson, 2014; Lederman et al., 2002) and complements the other components, namely conceptual and procedural knowledge. However, there is limited empirical evidence that links nature of science knowledge with these components (Peters, 2012). For example, there are only a few empirical studies that have elaborated on the relation between NOS understanding and the learning of specific science content (Michel & Neumann, 2016).

Regarding these studies, Songer and Linn (1991) found that students with a dynamic view of science acquire a more integrated understanding of thermodynamics than those with a more static view. Michel and Neumann (2016) found that a more proper understanding of NOS could help students understand the nature of energy as a theoretical concept and make them more capable of learning how to relate different energy forms to each other and justifying why they can be subsumed under the term energy. And lastly, in contrast to the studies above, Schwartz (2013) found that students' conceptions of NOS and biological topics are not necessarily interrelated.

At this point, some interesting questions arise: Why is there no systematic research on the relationship between the NOS component of scientific literacy and the conceptual knowledge component? Why have studies found an association between understanding NOS and learning science content (e.g., Michel & Neumann, 2016; Songer & Linn, 1991), while other studies have not (e.g., Schwartz, 2013)?

To answer these questions, we need to focus on how the current NOS agenda is articulated and what this articulation implies for the conceptual effectiveness of the NOS field (i.e., the research avenues the field can pursue, the questions that arise and the answers the field can provide). Given the presence of heterogeneous NOS definitions within different domains such as philosophy and history of science, sociology of knowledge and sociology of science and technology (Lederman et al., 2002), NOS researchers have assumed that there may be "a reasonable consensus on many lower-level points" (Matthews, 1994, p. 8) and have proceeded to answering the question of what science or scientific knowledge is from a homogeneous and rather universal standpoint (Rudolph, 2000). Thus, NOS researchers have proposed NOS items that disregard the specificities of each natural science and the differences between the various discipline-specific epistemologies (Schizas et al., 2016). This implies that the current NOS agenda is rather context-independent; NOS items cannot be considered as parts of a unified conceptual whole (or context) like those whose structure is shaped by discipline-specific epistemologies. As a result, NOS items can hardly be engaged with how scientific-content knowledge is articulated within the context of such epistemologies and the understanding of NOS items cannot help learners comprehend conceptual knowledge. From an epistemological perspective, the NOS field cannot increase its range of conceptual effectiveness through posing and answering research questions that focus on the relationship between students' NOS understanding and their understanding of particular scientific concepts because NOS items have been articulated independently of the discipline-specific epistemologies to which scientific concepts belong.

The focus on these discipline-specific epistemologies represents an alternative approach to NOS, namely a domain-specific NOS or nature of the sciences (NOTSs) approach. This approach assumes that the criteria for what scientific knowledge is also come from the perspective of the particular scientific disciplines and thus, shifts the emphasis from similarities among disciplines to differences and unique features (Schizas et al., 2016; Schizas & Psillos, 2019).

What is important for the present study is that science educators have recently argued that it is time to complement the current domain-general approach to NOS with domain-specific NOS definitions or NOTSs topics (Kampourakis, 2016). In the words of a key proponent of this domain-general approach (Abd-El-Khalick's 2012a, p. 365):

> "…the two approaches are complementary and synergistic … current consensual NOS aspects serve as foundational understandings that could be further refined and nuanced through context-specific explorations…"

Thus, the present study aims to elaborate on this complementarity by presenting an instructional design that associates NOS and NOTSs items with the teaching of a biological topic, namely homeostasis. These items are presented in the form of learning objectives and their teaching aims to familiarize students with epistemological aspects of natural sciences and enhance their understanding of aspects of homeostasis.

In what follows, we first clarify epistemological and didactic aspects of the theoretical framework behind our instructional design. Next, we focus on why we chose the topic of homeostasis as our instructional content-based knowledge and offer a brief overview of the difficulties learners encounter in understanding this topic. Subsequently, we provide an outline of the Greek biology curriculum and the Greek biology textbook that presents the content-based knowledge of our instructional design. Finally, we present the intended instructional design.

THEORETICAL FRAMEWORK

The interrelation of NOS and NOTSs topics with science content-based learning integrates rather separate aspects of 'scientific literacy' and complies with certain epistemological aspects of what scientific knowledge is and how it is structured (Schizas et al., 2016). According to these aspects, scientific concepts are rendered meaningful in the interior of the specific scientific fields to which they belong (Baltas, 1988; Schizas, 2012). Scientific fields are conceptual structures consisting of relations among mutually determined concepts and background ontological, epistemological, and methodological assumptions (Baltas, 2007; Korfiatis & Stamou, 1994; Schizas, 2012). These assumptions are inextricably related to the interpretation of these conceptual structures and dictate the latent NOS and NOTSs conditions under which a scientific concept's manifest meaning makes sense (Baltas, 1988; Schizas et al., 2019b). In particular (Schizas et al., 2016), they

(a) anticipate scientific practice or impose certain styles of how to think of scientific knowledge through providing a priori answers to a multitude of ontological, methodological, epistemological and ultimately philosophical issues, such as what is an entity, how entities may be studied as scientific objects, what is causality and how it can be grasped (Schizas, 2012),

(b) articulate the component elements of a given field into a coherent and thus understandable whole (Baltas, 2007),

(c) foster certain choices (e.g., choices of taking a position from where the world is observed, choices regarding the direction they are looking at) on scientists who work in the field to see the world and study the research object (Arageorgis & Baltas, 1989), and

(d) form, in total, general descriptive or explanatory schemes of how the world is made up and operates, namely ‘scientific worldviews’ (Schizas, 2012).

Noticeably, most biological disciplines or fields comply with the background assumptions that underlie the neo-Darwinian worldview. This worldview originated from the neo-Darwinian synthesis in the middle of the twentieth century, draws its assumptions from the product of this synthesis, namely evolutionary biology, and provides a NOS understanding predominately based on the techniques of hermeneutics and historical sciences (Schizas et al., 2016).

Regarding the design of our instruction, it involves choices referring to what to teach and how to teach. While elaborating thoroughly on the latter choices is out of the primary scope of the present study, a preliminary account of how to teach NOTSs and NOS items indicates that instructions can be based on an explicit-reflective perspective, introduced, expanded and refined by Abd-El-Khalick (2012b) and coworkers. This perspective represents an efficient overarching framework to guide instruction about NOS topics and thus, it can also be used for NOTSs topics.

The label “explicit” emphasizes the need for including specific NOS and NOTSs learning objectives in content-based instructional sequences. Additionally, the label “reflective” has pedagogical implications; it calls for instructional choices that support learners to reflect on their own and others’ understanding of NOS and NOTSs aspects and consider their conceptions in the light of their experiences. Unavoidably, a successful explicit/reflective teaching perspective depends on learners’ abilities to create new knowledge from their own personal understandings of the world and prompts students to discuss and think over the activities in which they are engaged (Hrisa & Psillos, 2022; Mesci & Schwartz, 2017). Thus, our strong preference would be instructional choices that treat learners’ prior knowledge from an inclusive constructivist perspective. Such a perspective penetrates the present study and offers us the opportunity to

(a) show how the learning and teaching of conceptual knowledge can embrace the learning and teaching of NOS/NOTSs items and

(b) illuminate the necessity and usefulness of these items for students’ understanding of scientific topics.

The present study primarily focuses on choices regarding what NOTSs and NOS items are to be taught and aims to analyze how learners’ understanding of these items can enhance their understanding of homeostasis. This analysis indicates two major innovations compared to how the current NOS items have been formed. Firstly, NOS and NOTSs learning objectives are not defined in advance. The source that will supply such objectives is more the specific conceptual structure to which the teaching content-knowledge belongs and less the nature of science or the nature of some specific science, in a general or abstract form. Secondly, NOTSs and NOS learning objectives are defined through a process that focuses on the conceptual teaching knowledge from both an epistemological and didactical point of view. Students’ difficulties or misunderstandings regarding acquiring the scientific knowledge to be taught will inform the content of instructional activities and the formulation of such objectives.

Apart from following constructivist guidelines, our method of defining NOTSs and NOS learning objectives needs to be embedded in real didactic situations. Teaching in Greek school environments, particularly in upper high school, is mainly traditional and textbook-centric; students are mostly asked to learn and understand the content knowledge of their textbooks (Schizas et al., 2018). Thus, our method on defining NOTSs and NOS learning objectives is also based on how a Greek biology textbook, namely the Greek biology textbook (Adamantiadou et al., 2013) utilized in the 12th grade presents the concept of homeostasis. In conclusion, we will identify NOS and NOTSs learning objectives through a process that

(a) focuses, in the beginning, on the content-knowledge learning objectives that are described in the textbook mentioned above to form a narrative line for instruction and to be informed of the content-based knowledge to which students’ difficulties and misunderstandings are attached and then

(b) detects these difficulties and misunderstandings in science education literature and reflects on them from an epistemological point of view (finding for example misconceived general ideas behind how students understand a multitude of ontological, methodological, epistemological, and ultimately philosophical issues, such as what is causality, what is a biological entity, what is mechanism etc.) to form NOS and NOTSs learning objectives.

Relevant instructional activities and measurement tasks concerning students’ conceptual and NOS/NOTs evaluation will be based on the intersection of (a) and (b) through the above-described process.

THE TOPIC OF HOMEOSTASIS

‘Homeostasis’ was chosen as an exemplar for associating concept-based knowledge with NOS and NOTSs learning objectives for three main reasons. First, homeostasis is an abstract and complex concept indicating an inclination towards a balanced state on the one hand and a perpetual process on the other (Mor & Zion, 2021). Thus, it is loaded with a heavy theoretical and epistemological burden ranging from definitional features of many concepts that emerge from the description and definition of homeostasis (e.g., dynamic equilibrium, thermal balance, regulation, and terms in different organizational levels) to contradictions, such as that a constant state changes, and complex causal reasoning (Zion & Klein, 2015). Therefore, the teaching of homeostasis can easily relate to various NOS and NOTSs aspects.

Second, homeostasis has a continued pride of place within secondary school curricula throughout the world and most science educators consider it to be a core concept or a ‘big’ idea (McFarland et al., 2016; Michael et al., 2017; Modell et al., 2015). Big ideas are important ideas central to some disciplines and are considered the building blocks from which meaningful patterns are constructed, connecting concepts within this discipline (McFarland & Michael, 2020; Wiggins & McTighe, 2005). Epistemological assumptions, such as what causality is, what mechanism is and so on, implicitly underlie these patterns (Schizas et al., 2019a) and form the invisible ‘glue’ by which different concepts are connected, thereby allowing the conceptual systems within a discipline to be deeply understood (Baltas, 2007). Thus, the use of homeostasis as a teaching concept-based knowledge into which NOS and NOTSs learning objectives are introduced, can help us elaborate on NOS and NOTSs items that recur in the learning of biology and lay the foundations for the understanding of a broad range of biological phenomena.

Third, 'homeostasis' has been referred to in several research papers as a complicated and difficult topic for students (Klein & Zion, 2015; Mor & Zion, 2021; Westbrook & Marek, 1992; Zion & Klein, 2015). Students' difficulties in understanding homeostasis pertain to multiple aspects of homeostasis, such as a range of phenomena concerning the complexity of the organisms' body, the view of homeostasis as a dynamic process and the study of homeostatic processes through sequential steps that involve entities belonging to different organizational levels (Klein & Zion, 2015). Thus, the complexity of homeostasis and the variety of difficulties that learners face in understanding this science content-based topic would also help us offer a more complete view of how the teaching of NOTSs and NOS items can enhance learners' understanding of scientific knowledge and direct their attention from simple rote memorization of conceptual knowledge to deep and meaningful learning (McFarland et al., 2017).

Remarkably, many of such difficulties have been discussed from a viewpoint that complies with the epistemological features of biology, namely the one of 'cognitive construals' (e.g., Coley & Tanner, 2012). Cognitive construals, such as essentialist, anthropocentric and teleological thinking, are informal, intuitive ways of thinking about the world. They may give rise to many biology learners' misunderstandings because biology's fundamental epistemological underpinnings are far away from the assumptions underlying these construals (Schizas et al., 2016). Regarding homeostasis, scholars have classified many learners' misunderstandings concerning the constancy of body features (e.g., that temperature change is only related to illness and that homeostasis maintains the body in a constant invariant state; Westbrook & Marek, 1992; Zion & Klein, 2015) into the category of essentialist thinking. Essentialist thinking refers to a set of assumptions that learners make about concepts such as that an entity's category membership (e.g., being an organism) is ultimately based on the presence or lack of an essential property and the outward characteristics exhibited by members of this category should be relatively uniform, static, and predictable. Needless to say, our instructional design will focus on the presence or absence of this thinking on the part of students.

Greek Biology Curriculum and Greek Biology Textbooks That Present the Topic of Homeostasis

The topic of 'homeostasis' is a part of the Greek biology curriculum in both junior and high schools. In junior secondary school, one of the curriculum's general objectives is students to become familiar with biological processes occurring in themselves (human bodies). Thus, they learn about definitional features of homeostasis and the function of homeostatic mechanisms. In higher secondary school one of the curriculum's general objectives is students to be able to interpret phenomena that they experience as parts of the natural and human environment. Thus, they learn about the mechanisms that ensure the dynamic equilibrium of biological systems and the maintenance of life, both at organismic (homeostatic mechanisms) and ecosystem level (self-regulating mechanisms).

Junior school students are introduced to homeostatic topics in chapter 4 of the 8th grade biology compulsory textbook (Mavrikaki et al., 2007), written by science educators and experienced biology teachers and published by the Greek Ministry of Education, Lifelong Learning, and Religious Affairs. This chapter is entitled 'diseases and factors that cause their presence', while the involved homeostatic issues concern some defining and accompanying features (e.g. examples of organs and organic systems that participate in that process) of homeostasis along with preliminary and generic accounts of homeostatic mechanisms and factors that may influence homeostasis.

High school students are asked to elaborate more on homeostatic topics through the 12th grade biology compulsory textbook (Adamantiadou et al., 2013), written by experienced biology teachers and published by the Greek Ministry of Education, Lifelong Learning, and Religious Affairs. Homeostasis is included in the introductory section of the first chapter entitled as 'human and health'. By studying this section, students are mostly expected to be able to define features of homeostasis and describe the homeostatic mechanisms through which humans regulate their body temperature.

NOS knowledge has not yet been included in school science curricula and the attention given to the nature of science topics in science classrooms is sparse. In addition, the scientific training of Greek biology/science teachers has not provided them with much understanding of the nature of science and their NOS/NOTSs conceptions are often naive or limited (Schizas & Psillos, 2019). Thus, it is necessary to support biology/science teachers with appropriate materials and effective teaching strategies to acquire a basic understanding of NOS/NOTSs aspects and implement them in their classrooms. Furthermore, biology/science teachers normally adapt their teaching objectives to the scientific content of textbooks. We consider that associating NOS/NOTSs aspects with the content of a textbook offers teachers and students a feasible opportunity to come into close contact with relevant and intriguing NOS/NOTSs aspects.

Our aim to associate NOS and NOTSs learning objectives with conceptual learning objectives drawn from how the 12th grade Greek textbook presents the topic of homeostasis puts constraints on our choices regarding what NOS and NOTSs topics are to be taught. For example, the textbook avoids of presenting the notion of 'negative feedback' and thus, NOS and mostly NOTSs aspects related to this notion, such as those focusing on the nature of circular causality as opposed to linear causality (Barbas & Psillos, 1997), are not examined.

Introducing NOTSs and NOS Learning Objectives into the Teaching of Homeostasis

Definition of homeostasis

The textbook starts by presenting definitional features of homeostasis and the first conceptual objective is students to understand that homeostasis is the ability of organisms to maintain their internal environment stable despite external environmental variations (Adamantiadou et al., 2013).

This objective can be achieved by focusing on students' everyday experiences with physical phenomena and motivating them to involve themselves in their own learning actively. Thus, the following first activity (for an overview of our designed instruction, see **Table 1**) is suggested to be assigned to students: Touch the desk (wood) and the floor (marble) with your palm. What do you feel and what do you infer about their temperature?

Several students are expected to answer this question spontaneously and argue that wood has a higher temperature than marble. This is a widespread alternative conception (Douglas & Doris, 2004) and its possible presence in students' minds demonstrates that students, even at the 12th grade level, may still face difficulties understanding that all physical bodies tend to acquire the temperature of their environment (i.e., the physical phenomenon of thermal equilibrium). Possibly students respond erroneously because they experience wood as warmer than marble and similar to high school students in other countries (Bektas & Geban, 2010), they encounter problems in understanding that the scientific world is different from the empirical world they experience.

Our instruction may help students cope with these rather naive conceptions of the relation between scientific and daily observations if we focus on the NOS view that spontaneous experience is not the right path toward building or acquiring scientific knowledge. This implies that we can widen the scope of the first activity towards helping students understand that scientific knowledge can be based on observations of the natural world, but these observations are almost always mediated by a host of scientific concepts (e.g., heat conductivity) and theories (i.e., wood is experienced as warmer than marble because it is less of a heat conductor than marble and there is a slower heat transfer to wood from our hands).

Thus, the first suggested **NOS L**earning **O**bjective (NOS L.O.1) is students to learn that scientific observations are theory-laden (Lederman et al., 2013). This objective can make students realize that 'thermal equilibrium' is a theoretical concept and could make it easier for them to understand related concepts (i.e., concepts that underlie homeostatic processes such as 'heat transfer') and phenomena that cannot easily be sensed (Michel & Neumann, 2016).

In the second didactical activity, students are asked questions that can facilitate their understanding of definitional features of homeostasis. Such questions are the following: What is usually the temperature of the human body? If the ambient temperature is 45°C or -8°C, what happens to the temperature of the human body? Do we have any change? What is the difference in the response to temperature changes among wood, marble, and all other physical objects in your classroom, on the one hand, and human bodies or biological organisms, on the other hand? What can you infer? Can you conclude that biological entities possess a property that physical entities do not share? How is this property known?

Throughout these sequential questions, students are expected to construct a definition of homeostasis similar to the textbook-based definition and perceive homeostasis as a biological property or phenomenon. Contrasting homeostasis and biological entities with thermal equilibrium and physical entities respectively, help us stress the biological character of homeostasis (i.e., that living organisms maintain an autonomous internal environment different from their surrounding external environment; Mor & Zion, 2021) while highlighting a common for all entities process (e.g., heat transfer) occurring because of differences among internal and external temperatures. The latter is important because homeostasis is grounded in a reciprocal relationship between an internal and an external environment (Zion & Klein, 2015) and heat transfer between entities and their environment is a precondition for learners' understanding of homeostasis and thermoregulation as a perpetual process. Noticeably, misconceptions concerning the conceptual understanding of physical topics often make it hard for students to understand biological topics (Alkhawaldeh, 2007). Thus, the possible appearance of misunderstandings related to these phenomena on the part of students needs to be further examined. We will explore this in further detail in the following section.

Homeostasis as a Dynamic Process

The second textbook-suggested conceptual objective refers to the mechanism of thermoregulation; students are expected to understand how thermoregulation is accomplished when humans are situated in environments with higher temperatures than their bodies.

Biology teachers will likely face difficulty teaching 'thermoregulation' through a constructivist approach because 'thermoregulation' contains the difficult notion of 'mechanism' (Trujillo et al., 2016) and refers to entities and relations that are not tangible or visible. Thus, shifting our learning objectives from what students learn to how they learn may enhance their thinking. This shift can be done in a variety of ways but before viewing one of them, which includes models and metaphors, we need to examine whether students understand thermal equilibrium and heat transfer between entities and their environment as a starting point in homeostatic processes. Conceptual problems with this understanding may lie behind or trigger those misunderstandings of homeostasis that can be classified into essentialist thinking (Coley & Tanner, 2012). According to these misunderstandings, students

(a) consider temperature to be a variable that only changes because of illness (Westbrook & Marek, 1992),

(b) take constancy of their body temperature for granted assuming that a constant body temperature is due to body (Buddingh, 1996) and

(c) consider homeostasis to be a static state (Zion & Klein, 2015) or a process that keeps the body static and unchanging (Coley & Tanner, 2012).

Table 1. Overview of our instructional design

Science-content L.O. Students need to know:	**Learners' difficulties & misunderstandings**	**Some of the suggested didactic activities**	**NOS L.O. Students need to know:**	**NOTSs L.O. Students need to know:**
Definitional features of homeostasis				
Homeostasis is the ability of organisms to maintain their internal environments stable despite of external environmental variations Homeostasis is a property of the biological world.	Misconceived views of heat transfer and thermal equilibrium. Naïve conceptions of the relation between scientific and daily observations	Students compare the temperature of wood to the one of marble. Students construct definitional features of homeostasis throughout sequential questions.	1. Observation is theory-laden (scientific observations are different from daily observations)	
Homeostasis as a dynamic process				
The starting point of thermoregulation is that all biological entities tend to acquire the temperature of their environment. How and why human bodies keep their temperature constant.	Misconceived views of homeostasis pertaining to essentialism. Possible misunderstandings of physical processes occurring in biological entities Inappropriate use of the deductive-nomological reasoning. Difficulties in distinguishing 'how' and 'why' question types in biology. Inappropriate universalist views of thermoregulation rather resulting from essentialist thinking.	A diagnostic tool is used to uncover students' misunderstandings Students reflect on the types of explanations in biology	2. Hierarchical organization of matter; phenomena occurring at a higher level (e.g., biological) can never change or violate the laws or principles of a lower level (e.g., physical)	1. Biologists employ mechanistic and evolutionary explanations. 2. Biological generalities including biological mechanisms do not apply to all organisms in all places and times; they are the outcomes of biological evolution.
What is a 'mechanism' and how scientists proceed to investigating mechanisms?				
Defining and accompanying features of the concept of mechanism. Aspects of scientific inquiry regarding the study of mechanisms.	Difficulties in understanding the notion of mechanism.	Students reflect on the intentional meaning of the concept of 'mechanism'. Use of a metaphor in posing questions that exemplify the downward analytic and the synthetic phase.	3. A mechanism is a sequence of causal steps and reflects structural aspects of phenomena involving different and multiple processes that serve a function. 4. The formulation of mechanisms involves a downward analytic and a synthetic phase.	3. Behind each biological function there is a well-organized material structure consisting of material entities and relations among these entities.
The homeostatic thermoregulatory mechanism				
Sequences of processes that compose the thermoregulatory mechanism: ▪ when humans are situated in environments with higher temperature than that of their bodies. ▪ when humans are situated in environments with lower temperature than that of their bodies.	Difficulties in understanding that homeostatic mechanisms are composed of sequential steps *and occur under control and regulation.* Students often hold a fragmentary causal reasoning and encounter difficulties in elaborating on the causal chain of effects underlying a biological phenomenon.	A metaphor and a model are employed to trigger students' thinking and deepen their understanding. Application of new knowledge.		4. In biology there are mechanisms within mechanisms (the human thermoregulatory mechanism involves sub-mechanisms)

To explore the presence of the above-discussed misunderstandings in students' minds, we can examine how students understand what happens to the human body when it is situated in environments with higher than human body temperatures. Thus, we suggest a third didactical activity, which is articulated around a diagnostic tool:

Four students discuss why their body temperature does not change and remains 36.6°C even when the external environmental temperature is 45°C. This is what they said:

> **Nick:** Our temperature does not change because we are not sick.

> **Aphrodite:** Our temperature does not change because our bodies' temperature is always 36.6°C.
>
> **George:** Our temperature does not change because heat cannot pass from the external environment to the interior of our body.
>
> **Malena:** Our temperature does not change because the human body prevents the temperature increase that heat provokes when passing inside from the external environment.

Which student do you most agree with? Justify your answer.

This diagnostic tool is mostly based on respective tools employed in a series of NSTA books published under the general title "uncovering student ideas in science" (Keeley et al., 2005). Behind the misconceptions of Nick, Aphrodite, and George, we consider that there are specific epistemological perspectives that impede students from understanding biological phenomena. More specifically, behind the perceptions of Nick and Aphrodite there are essentialist perceptions of biological entities that favor the conceptualization of biological phenomena as static states rather than dynamic processes. Moreover, Aphrodite's misconceived response may also result from an approach to biological entities that misidentifies the explanation of a biological phenomenon with the description of events taking place at the organizational level to which the phenomenon is manifested. This approach complies with the deductive-nomological (explanatory) model, which fosters 'formal' explanations in physics, but it is inappropriate to provide explanations in biology (Schizas & Psillos, 2019). Finally, in the case of George, the opposite phenomenon is evident: biological entities are understood as radically different from physical entities, which further implies the non-informed epistemological view that natural laws and principles (e.g., the transfer of heat through temperature gradients and the resulting phenomenon of thermal equilibrium) cannot apply to biological entities.

The scientifically informed response is the one of Malena and includes two parts that require further instructional treatment. The first part refers to the statement that the temperature of the human body tends to increase in a 45° C environment because heat is transferred from the external environment to the interior of the body. This statement opposes to the other students' responses and can become understandable under certain aspects of the nature of biological and physical entities that pertain to the hierarchical organization of primary ontological levels.

The ontology of primary levels (sociological, psychological, biological, and physic-chemical) is a long-lasting debate in the philosophy of science. It is not our intention to elaborate on this matter through this paper. For pragmatic reasons, we can agree with Emmeche et al. (1997), who argue that the relationship between ontological levels is inclusive. This relationship indicates that students need to comprehend the following NOS knowledge (L.O. NOS 2):

(a) higher levels of matter organization are built upon lower levels and higher-level entities consist of lower level entities;

(b) higher-level entities possess emergent properties (e.g., biological entities possess the emergent property of life) and their behavior cannot be explained by regularities occurring at the lower level; and

(c) phenomena occurring at one level can never change or violate the laws or principles of a lower level. Regarding our case, the latter implies that physical laws and principles apply to biological entities and thus all biological entities tend to acquire the temperature of their environment.

However, some of these entities, such as "heterotherms", obtain the temperature of their environment in the end, while others, namely "homeotherms" resist this tendency and keep their temperature constant.

The second part concerns how the human body works and why it works the way it works. To help students start elaborating on these issues, we suggest the fourth activity where students are asked to compare 'how' and 'why' biological questions and infer their definitional features. The following set of questions can be posed: Can you compare the question of how the human body keeps the temperature constant with the question of why the human body keeps the temperature constant? Which question refers to the causes behind homeostasis? If the answer is both, do the terms 'how' and 'why' direct your attention toward searching for similar causes? Are the causes pertaining to the how type questions universal? Do all organisms have the ability to keep their temperature constant? If not, how do they get this ability?

Here, we assume that to answer these questions students need to know the possible types of explanations in biology. This necessity leads us to introduce informed conceptions of the nature of biology and elaborate on the first NOTSs learning objective (L.O. NOTSs 1). Students need to be informed that biologists are trying to answer two types of questions (Mayr, 2004): "how" type questions whose answers call for mechanistic explanations and 'why' type questions (for example, why there are heterotherms and homeotherm organisms or why some organisms have thermoregulatory mechanisms and some others do not) whose answers call for evolutionary explanations.

According to the knowledge presented in the school textbook, the desirable answer we seek belongs to the first type. Before however, proceeding to instructionally elaborating on this topic, we would like to highlight that students often avoid providing mechanistic explanations when explaining "how" biological phenomena occur and instead resort to 'ultimate causes' (Mayr, 2004) by explaining "why" phenomena occur (Abrams & Southerland, 2001). Thus, the suggested activity discussed above may help students distinguish between these two types of biological explanations and overcome such misunderstandings.

Furthermore, the value of the 'why' type of biological explanations cannot be overemphasized. Students often draw unconsciously epistemological perspectives from the science of physics and erroneously apply them to biological entities (e.g., Bishop & Anderson, 1990; Van Dijk & Reydon, 2010). In our case, many students may assume that thermoregulation is essential in all organisms, and similar to what holds true for physical mechanisms, they may consider biological thermoregulatory mechanisms to be universal. Thus, the value of the "why" type questions lead us to introduce the second NOTSs learning objective (L.O. NOTSs 2): biological generalities do not apply to all organisms in all places and times (Schizas & Psillos, 2019). Biological generalities including biological mechanisms are the outcomes of biological evolution, which in turn means that biological entities, in contrast to physical entities, are evolutionary products.

What is a 'mechanism' and how do scientists investigate mechanisms?

During the previous fourth activity, students were motivated to reexamine the possible presence of the essentialist cognitive construal in their minds. They were also informed that the answer to the question of how human bodies keep their temperature constant needs a biological thermoregulatory mechanism to be stated. Do students possess fundamental knowledge to answer 'how' type questions? Are they familiar with the meaning of 'mechanism' and the relevant biological inquiry?

Because of learners' difficulties in understanding the notion of 'mechanism' (Trujillo et al., 2016) and their tendency to confuse mechanisms with simple processes (Schizas, 2019a), the answer is probably negative. Thus, students may find it hard to elaborate on the fifth activity, which is based on the following questions: Can you recall and describe a mechanism you have already learned (e.g., the self-regulatory mechanism of a prey-predator ecological system)? Does this mechanism possess peculiar characteristics? Can you think of differences between this mechanism and a single biological process (e.g., predation)?

Regarding this activity, the third NOS learning objective (L.O. NOS 3) is students to

(a) consider mechanisms as sequences of causal steps or processes starting with an initial state and ending in a final state and

(b) understand that mechanisms reflect structural aspects of phenomena involving different and multiple processes or relations among entities that in total serve a function or a common end.

This objective may help students become more familiar with questions of the 'how' type and acquire appropriate epistemological knowledge for enhancing their mechanistic (causal) reasoning.

We also suggest the sixth activity focusing on how scientists investigate mechanisms. This activity is articulated around the following crucial question**:** If we measure the temperature of a human body with a thermometer at different ambient temperatures, we observe that it remains constant. What should we do if we aim to find out how this happens, i.e., to find a mechanism?

To answer this question, students need to know that the formulation of mechanisms follows a reductionist approach to studying entities that involves two stages (Lewontin, 2000). This necessity leads us to formulate the fourth NOS learning objective (L.O. NOS 4), an objective that refers to guiding principles for scientific inquiry and thus, could also be considered a nature of scientific inquiry learning objective (Schwartz et al., 2008): students need to be informed that scientists begin with a downward analytic process that breaks the whole into its constituent parts and then follow a synthetic phase in which causal pathways among the parts are clarified.

To exemplify these two stages, we can use a metaphor from everyday life. We can ask: how does a mechanical clock function? What can we do to find the mechanism behind this function? If human organisms are viewed as if they were mechanical clocks, what should we do?

Focusing on the cross-cutting concepts of structure and function is very important here. Thus, another NOTSs learning objective (L.O. NOTSs 3) is students to understand that is the so-called biological structuralism governs biological science (Schizas et al., 2016). Behind each function there is a well-organized material structure. As examples, we could mention the vision-eye pair, the hearing-ear pair, and so on.

Deepening the former two learning objectives (i.e., L.O. NOS 4 and L.O. NOTSs 3) is necessary because students need to be familiar with aspects of the notion of 'organizational level' and predict the entities that may form the thermoregulation structure. In particular, we should remind students of some definitional features of biological organizational levels that may help them understand that

(a) organisms are considered wholes consisting of many organizational levels,

(b) the downward analytic process dissects organisms into biological entities that belong to different organizational levels, and

(c) the subsequent synthetic phase can uncover the kind of causal connections between those entities that result in the homeostatic property of organisms.

Overall, the question of how thermoregulation is accomplished in humans conceals many epistemological ideas with which, if students became familiar, they would direct their attention towards searching for a mechanism. Their focus now can be directed to biological structures and interrelated processes, i.e., entities within the human organism and relationships among these entities that serve a common function, such as thermoregulation.

The Homeostatic Thermoregulatory Mechanism

Most likely, students are not yet able to formulate the homeostatic thermoregulatory mechanism on their own. To trigger their thinking and facilitate their understanding of homeostatic mechanisms, we can employ a metaphor and a model.

This model can be grounded on a machine of everyday life, namely air-conditioning. Thus, students can be actively involved in discussing the following questions during the seventh activity: Have you ever seen an air-conditioning machine? What are its parts? If warm air enters a room, then how does the air-condition function?

By discussing these matters with students, our attention is to formulate a mechanism such as the following:

1. **Initial state:** The room temperature tends to rise above the set point.
2. The thermometer (sensor) detects the change.

3. The thermometer sends a signal to the thermostat (control center).
4. The thermostat sends a signal to the outdoor unit to produce cold air (effector).
5. **Final state:** The room temperature is reduced to the set point (homeostasis).

The resulting conceptual model can be formulated using the terms found in brackets (sensor, control center, effector; Modell et al., 2015) and comprises a proper elaboration of textbook's conceptual learning objectives. The sensor, control center, and effectors may be physically far from each other in the body and represent the components of a typical control system (Chirillo et al., 2021). Students can use these terms to think about how the human body remains constant despite the higher environmental temperature. For example, they could state that the skin is the sensor that detects environmental temperature changes. The brain is the control center that guides other organs and sweat is the response (thus, sweat glands are the effectors or response organs). Also, using this model, students may become able to

a. build those cognitive nodes around which the rest of the knowledge presented in the school textbook can be articulated (knowledge that students cannot acquire on their own), such as how these sensors are called, what are the exact parts of the brain involved in thermoregulation, etc., and
b. unpack other homeostatic mechanisms different from the thermoregulatory one (the names for the components of these mechanisms may differ, but the generic labels are useful as they convey the homeostatic system function that is being described; Michael et al., 2017).

However, the teaching of the thermoregulatory mechanism does not stop here. An activity is suggested, based on a number of questions. The crucial question during this eighth activity is the following: how does the secretion of sweat cause a decrease in body temperature? We are also looking for a mechanism to this question as it is important for students not to have knowledge gaps between the sweat secretion and temperature fall. These gaps often occur due to students' difficulties in identifying all the entities or activities that participate in a mechanism and unraveling their causal thinking in a step-by-step order (Mor & Zion, 2021; Russ et al., 2008). However, we may overcome these difficulties by introducing another NOTSs learning objective (L.O. NOTSs 4): students need to know that there are usually mechanisms within biological mechanisms. Thus, the required mechanism can be stated now, as follows:

Sweat secretion→sweat evaporation→heat dissipation→skin temperature decrease

The formulation of this mechanism by students is not an easy task since it requires knowledge drawn from the science of physics. Many of these difficulties, however, may be overcome if we posed a sequence of questions that would help students identify the entities (e.g., water and heat) and events involved in the required chaining: in hot summers, we drop water in our yard. Why do we do that? What happens to the water on the ground in our yard? If we measure the ground temperature, what will we find out? What is being carried to the atmosphere? Is it only water vapor?

Furthermore, the temperature decrease of the skin surface cannot be equated with the overall body temperature decrease. Thus, we can pose a second sequential set of questions (ninth didactic activity): the fall in temperature occurs on the surface or near the surface of the human body, i.e., the human skin. However, we are searching for a total fall in the temperature of the human body, and thus we are searching for a fall in the temperature of the interior of the human body. How can this happen? What is this 'something' that circulates within the human body and can address heat exchanges? Which human organs are related to this 'something'? What should happen to these organs for large amounts of heat to escape towards the skin's surface that has been cooled?

Again, according to the textbook's suggestions, the conceptual learning objective is students to understand a mechanism. This mechanism can be stated as follows:

Vessel expansion→large amounts of blood come to the surface→this blood dissipates heat as the surface of the skin has cooled→this blood is cooled and circulates inside the body→the increase of human body temperature is prevented.

The application of the constructive model to the teaching of thermoregulation mechanisms does not stop here either. The stages of application and assessment of knowledge follow. For example, to check whether students really understood what homeostasis is and how thermoregulation is accomplished we can pose the following question during a tenth didactic activity: How do humans perform thermoregulation when situated in environments with lower temperatures than their bodies? Here, students are expected to apply their knowledge to a different situation from the one they have so far encountered. Intended re-contextualization would hardly succeed if teaching was teacher-centered and did not involve NOS and NOTS knowledge along with models of activation and orientation of their thought. At this phase, however, students are informed of (**Table 1**)

a. how to answer questions of the "how" type in biology,
b. definitional features of the notion of mechanism and how to search for finding mechanisms,
c. guiding their homeostatic thinking towards identifying structural elements that compose mechanisms, and
d. focusing on the sequential causal order of these structural elements.

In closing this section, it is essential to highlight that students' informed responses to the question of how thermoregulation is achieved when humans are situated in temperature-lower environments than their bodies presuppose informed answers to the question of what will happen to the human body if it is exposed to colder environments. This question is quite similar to the question of what will happen to the human body if it is exposed to high temperature external environments. Thus, students' responses will allow us to examine whether they have understood the initial role of heat transfer between the human body and environment in homeostatic processes and whether they have eventually escaped from erroneous biological perspectives such as essentialism.

CONCLUSIONS

The present study brings to light an innovative teaching strategy. The novelties involve the complementation of the current NOS agenda with NOTSs topics and the introduction of NOS and NOTSs learning objectives into the teaching of homeostasis. The assumption of our study is well-grounded on a theoretical/epistemological level and can be stated as follows: learners' understanding of NOS and NOTSs topics can be beneficially related to their understanding of scientific concepts. Students who are informed about NOS and NOTSs aspects when they are taught scientific concepts may become able to escape from naïve empiricism or realism and abandon erroneous epistemological perspectives that induce several misunderstandings in comprehending scientific entities, processes, and phenomena (Michel & Neumann, 2016).

The present study also identified NOS and NOTSs items that can associate the teaching/learning of homeostasis by means of a process that intertwined the epistemological analysis of homeostasis with the didactic transformation of homeostasis from a scientific object to an object to be taught relying mainly on how a textbook presents a scientific topic. Certainly, the presentation of homeostasis in the Greek textbook has limited our choices and further theoretical and empirical research is needed to further elucidate the methodology for identifying NOS and NOTSs learning objectives. This finding is important because the implications of our study for science education are interesting.

First, our innovative teaching strategy could be expanded to learners' understanding of other core scientific concepts. Thus, its beneficial impact should also apply as students advance from course to course in the biology curriculum. Students are expected to explore new topics and master them at a deeper level, because core concepts, once mastered, are always applicable to the new systems they are learning (Michael et al., 2017). Noticeably, by understanding core concepts and the underlying epistemological knowledge (NOS and NOTSs) that permeate these concepts students may acquire a crucial scaffolding for all their future learning about biology, whenever and wherever that learning occurs. They may become able to build more proper foundations for understanding the specificities of biological knowledge and develop reasoning skills, such as their ability to elaborate on the notion of mechanism sufficiently.

Second, our study points to a new perspective for considering scientific literacy. While the nature of science is regarded as an important component of scientific literacy, it has not yet been intrinsically related to the other components. However, our study opposes this dissociation or separation of the components of scientific literacy and attempts to integrate NOS with declarative knowledge. This may have a lot of positive results. For example, similar or analogous studies may not only shed more light on the interactions between NOS/NOTSs instruction and science content learning but may also inform teachers about the importance of fostering NOS (and NOTSs) understanding in school educational settings in order to promote student learning. This goal is of great importance in many countries, where NOS is not yet an explicit part of curricula and educational standards (Michel & Neumann, 2014).

Third, synergies between NOS and NOTSs knowledge and the intertwining of this knowledge with the content of scientific knowledge are expected to increase the heuristic power or the range of conceptual effectiveness of the NOS field itself. Our study can be fruitfully used for widening the space of inquiry of the NOS field; core concepts can be used as 'entry points', that is, points at which a NOTSs or domain-specific approach to NOS can enter the curriculum and offer valuable insights toward the direction of a more nuanced refinement, expansion and even revision of the current NOS agenda. This complementary relationship between the two agendas is expected to open new avenues of research (e.g., new questions will be asked, and new answers will be given) and create a novel vantage point from where the current state of NOS investigation can be viewed rather anew.

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