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"What Matters Is Species Richness"—High School Students' Understanding of the Components of Biodiversity

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Abstract

The definition of biodiversity stated by the Convention on Biological Diversity (CBD) in 1992 was conceived as occurring on three different organizational levels: genetic, species, and ecosystems. However, current understanding of biodiversity includes other components, such as the number, abundance, composition, and spatial distribution of species and functional groups. This paper aimed to identify high school students' frameworks of biodiversity, to assess their conceptual understanding of biodiversity against scientific definitions, and to analyze the influence of sex and school location on students' understanding of biodiversity. By administering a written questionnaire in which ten different biodiversity scenarios were presented, each consisting of two environments which differed in certain biodiversity components, we asked students ($n = 321$, 15–18 years old) to choose and argue their preference for biodiversity conservation. Students held a range of frameworks of biodiversity, with some of them being in agreement with scientific conceptualizations (idea of variance as the number of species, functional groups, and trophic relationships). However, students were strongly centered on species richness and undervalued population size, functional characters, species evenness, and alpha diversity. Biodiversity was associated with a notion of balance, by which a proportioned trophic chain prevents species extinction. Overall, students used few components of biodiversity in their argumentations, with no influence of school location or sex. We recommend that teachers fully integrate students' frameworks with more updated definitions of biodiversity than that of the CBD, conceptualizing its components in order to empower students to decide on current socioscientific issues.

Keywords Biological diversity · Conceptual framework · Food web · Balance of nature · Socioscientific issue

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Back Affiliation

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Introduction

The Convention on Biological Diversity (CBD), signed on June 5th, 1992, in Brazil, brought the issue of biodiversity to the attention of scientists, educators, policymakers, and the public worldwide (Kassas 2002). Biodiversity was defined as "the variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, such as diversity within species, between species and of ecosystems" (Convention on Biological Diversity (CBD) 1992, p. 3). Following this definition, biodiversity includes three standard components, i.e., genetic diversity, species diversity, and ecosystem diversity, which are sometimes summarized as the "biodiversity trilogy" (Kaennel 1998). Recent publications have further specified the meaning of biodiversity to include many other components, such as species evenness, species composition, functional composition, and landscape units (Díaz and Cabido 2001; Díaz et al. 2006, 2015a, b; Hooper et al. 2005; Swingland 2001). Biodiversity can thus be described in terms of the number of entities (how many genotypes, species, or ecosystems), the evenness of their distribution, the differences in their functional traits, and their interactions (see detailed discussions in Hooper et al. 2005; Swingland 2001). However, definitions of biodiversity often range from "'the number of different species occurring in some location' (= species richness) to 'all of the diversity and variability in nature' and 'the variety of life and its processes'" (Swingland 2001, p. 380).

Biodiversity in all its expressions plays an important role in ecosystem functioning that provides essential benefits to people and their well-being, such as supporting, provisioning, regulating, and cultural services (e.g., recreation, esthetic, spiritual and religious) (Díaz et al. 2015a, b). These services translate in the human access to basic material for a good life and health, good social relations, security and climate regulation, as well as freedom of choice and action (Millennium Ecosystem Assessment (MEA) 2005). In spite of the utmost importance of biodiversity in sustaining human life, biodiversity is declining at unprecedented rates (e.g., Cardinale et al. 2012). Due to the strong decline of biodiversity worldwide (Cardinale et al. 2012), measures to discourage its loss are urgently needed (MEA 2005; UNEP/CBD/COP/8/29 2014). Biodiversity has thus been recognized as an educational priority at all levels of formal education (UNESCO 2005), and it has been proposed that students should be empowered to act in ways that protect and conserve biodiversity (Lindemann-Matthies et al. 2011; Menzel and Bögeholz 2009; Nisiforou and Charalambides 2012; Van Weelie and Wals 2002).

According to the United Nations Environment Programme (UNEP) and United Nations Educational, Scientific and Cultural Organization (UNESCO), biodiversity can no longer be a scientific concept only understood by intellectuals and protected by nature conservationists (United Nations 2015). Therefore, learning about the biodiversity concept means challenging commonly held assumptions and overcoming mental obstacles in a way to empower people's decision-making. For instance, Menzel and Bögeholz (2009) pointed out that biodiversity education poses a particular challenge for learners since the term "biodiversity" (contraction of "biological diversity") is commonly understood to be a synonym for "the variety of species."

Only few studies have investigated laypersons' conceptual understanding of biodiversity by using more updated definitions than that of the CBD (1992), and even fewer have focused on upper secondary students. The present study, carried out in the province of Córdoba, Argentina, aims to fill this knowledge gap. The study is of an exploratory nature and one of the first to investigate students' conceptions of biodiversity through their decisions and reasoning in simulated conservation scenarios.

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Conceptual Framework

Biodiversity Definitions in the Political and Scientific Spheres

There is a range of biological diversity definitions in the scientific literature; hence, it is useful to make a brief synthesis of the genesis of the concept and its evolution. According to Harper and Hawksworth (1994), the expression "biological diversity" was used independently in 1980 by T. Lovejoy and E. Norse and R. McManus. While for T. Lovejoy biological diversity meant primarily the number of species, E. Norse and R. McManus used it to describe both genetic (the amount of variability among individuals of a single species) and ecological diversity (the number of species in a community of organisms). These reduced and simple definitions, which embrace many different parameters, have been much elaborated and debated in the last three decades (Swingland 2001).

By 1981, the US Strategy Conference on Biological Diversity had taken place, while in 1985, W. Rosen used the contracted form "biodiversity" for planning the conference National Forum on BioDiversity, carried out in 1986 (Ghilarov 1996). In 1988, E. Wilson edited the Forum proceedings under the title "BioDiversity," and although he acknowledged Rosen's contribution ("he introduced the term biodiversity, which aptly represents, as well as any term can, the vast array of topics and perspectives covered during the Washington forum") (Wilson and Peter 1988, p. vi), Wilson is often recognized for coining the term "biodiversity."

In the late 1980s and early 1990s, the UNEP (https://www.unenvironment.org/) organized and convened special groups of experts on biodiversity to explore the need for an international convention on biological diversity, with some of the main goals being to reach a common understanding of the meaning of the conservation of biological diversity and to establish international needs. This international endeavor culminated in 1992, when official representatives of more than 50 nations signed the "Convention on Biological Diversity" (CBD, https://www.cbd.int/), which can be considered as the official recognition of the importance of biodiversity (Ghilarov 1996). In short, biodiversity was conceived as occurring on three different organizational levels: genetic diversity, species diversity, and ecosystem diversity, which is also known as "biodiversity trilogy" (Kaennel 1998). However, biodiversity is often equated to "species richness" (= number), and other components are frequently underestimated (Díaz and Cabido 2001).

By the beginning of the twenty-first century, Díaz and Cabido (2001) reviewed scientific publications and recognized a general agreement on that "biodiversity includes both number and composition of the genotypes, species, functional types and landscape units in a given system" (p. 646). Later, the report of Hooper et al. (2005) expressed the aforementioned "trilogy" as "entities" and further stated that not only the "number" but also the "evenness" of entities distribution matters. The attention of Hooper et al. (2005) to different components of biodiversity (e.g., richness, relative abundance, composition, presence/absence of key species) was based on their effects on ecosystem properties, such as productivity, carbon storage, and nutrient cycling. Hooper et al. (2005) also specified that the term "diversity" was used in their paper when discussing more general attributes of biodiversity, including differences in "relative abundance" and "composition." In a more detailed approach, Díaz et al. (2006) incorporated the "spatial dimension" and the "interactions" between the entities of biodiversity: "number, abundance, composition, spatial distribution, and interactions of genotypes, populations, species, functional types and traits, and landscape units in a given system" (p. 1300).

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Back to the political agenda, since 1994, the Conference of the Parties (COP, https://www.cbd.int/cop/), has been the governing body of the CBD, which promotes the application of the Convention through the decisions adopted by the signatory countries. In this context, the scientific and political spheres come together and produce documents and take decisions that update the CBD bodywork (CBD Technical Series, https://www.cbd.int/ts/). As another international action, the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, www.ipbes.net) was established in the framework of the United Nations in order to strengthen the science–policy interface for the conservation of biodiversity, ecosystem services, long-term human well-being, and sustainable development (Díaz et al. 2015a). IPBES' definition of biodiversity retrieves that of the CBD and further specifies that it consists of "the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part, (…) [which] includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems" (Díaz et al. 2015b, p. 12). Although it is not discussed here, it is worth mentioning that IPBES revisits the concept of cultural diversity and defines "biocultural diversity" in its conceptual framework.

The wide range in biodiversity conceptualizations indicates that biodiversity does not have a universally agreed on definition and it is often redefined on each occasion according to the context and purpose of the author (Swingland 2001). In this study, biodiversity is interpreted as genetic, functional group and species richness (local and among habitats), as well as evenness, range in functional traits, species interactions, and population size.

Laypersons' Understanding of and Attitudes Toward Biodiversity

A range of studies has investigated how laypersons conceive biodiversity (e.g., Buijs et al. 2008; Fischer and Young 2007; Fischer et al. 2011; Lindemann-Matthies and Bose 2008). The Flash Eurobarometer survey, for instance, asked European citizens in 27 states about their familiarity with biodiversity (almost 26,000 respondents). About 44% of respondents had heard of the term "biodiversity" and could briefly describe what it means (European Commission 2013). However, how informed respondents felt about the loss of biodiversity was strongly and positively related to education. Overall, 75% of respondents agreed that more information about the importance of biodiversity is urgently needed.

In Switzerland, the general public most frequently referred to the diversity of species when defining biodiversity but also quite often believed that biodiversity has something to do with ecological concepts such as the equilibrium between all the components of nature (Lindemann-Matthies and Bose 2008). During focus group discussions in the Netherlands, Germany, and Scotland, biodiversity was occasionally defined as the variety of species, sometimes including habitats and, more rarely, genes (Buijs et al. 2008). However, laypersons more often used broader definitions, including the number and quality of habitats as well as the number of species. They regarded biodiversity as the basis of human life and as providing and ensuring balance in nature. In a study by Fischer and Young (2007), laypersons in the UK expressed rich mental concepts of biodiversity, which included notions of balance, food chains, and human–nature interactions. In the USA, the most common public understanding of the concept of biodiversity centered on the quantity and variety of life, with a few people also including the range of habitats where the species live. Dissecting the term "biodiversity" allowed many respondents to craft a simple, but partly correct definition (Hunter and Brehm 2003).

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Little is known about the different components of biodiversity that (upper) secondary students know about and consider important for conservation. In a study from Turkey, secondary school students often referred to biodiversity as the diversity of living organisms (Kilinc et al. 2013). Students understood diversity as both the number of species and the number of living organisms, thus confounding species richness with abundance and population sizes. Similar results were found by Menzel and Bögeholz (2009) with a sample of 16- to 18-year-old Chilean and German students, who mostly attributed the terms for "biodiversity" to the variety of plants and animals. In both studies, genetic diversity was neglected as an integral part of biodiversity and students were often unable to explain the differences between species diversity and genetic diversity.

Nisiforou and Charalambides (2012) investigated university students' knowledge of and attitudes toward biodiversity in Cyprus. While knowledge of second-year students was higher than that of first-year students, no differences were found in their attitudes toward biodiversity. Moreover, although all students had positive attitudes toward biodiversity, they were, most of the time, unwilling to engage in environmental behavior. In a study by Grace and Ratcliffe (2002), 15- to16-year-old students from the UK used utilitarian, esthetic, or economic rather than ecological arguments for the conservation of biodiversity, indicating a need to discuss a range of conservation scenarios in order to maximize students' understanding of the complexities involved. What is more, Greek university students found it very likely for a disturbed ecosystem to fully recover its initial state, showing a strong belief in an extremely resilient "balance of nature" (Ergazaki and Ampatzidis 2012). Moreover, most of the students believed that if human protected, an ecosystem will be in a continuous balanced state.

Implications of Gender and Urban/Rural Settlement for People's Knowledge of Biodiversity

One important sociocultural-related issue influencing differential knowledge construction is gender (Youdell 2005). Regardless of people's biological sex (based on sexual chromosomes), societies define gender roles and stereotypes by assigning certain tasks and expectations to either boys or girls (Keller 1995). For instance, male identity encourages to go outside public places, to take risks, and to participate in outdoor activities, while the female identity leads to the inner, private, and invisible things (Bourdieu 2000). Similarly, Loughland et al. (2003) point out that girls are often socialized into being more caring and nurturing than boys.

Families influence children's scientific literacy according to their sex well before formal education begins, by differentiating their discourse and children's activities. In a study conducted by Crowley et al. (2001), parents were willing to explain science more often to boys than to girls. Tenenbaum and Leaper (2003) also found that US fathers used more cognitively demanding speech regarding science topics with sons than with daughters. This social contribution to a gender gap of the children impacts on their conceptions of the environment (Loughland et al. 2003) and their perception of species diversity (species number and composition): girls seem to appreciate plants more (Prokop et al. 2007), and express a tighter emotional attachment to animals than boys (Pointon 2014). Related to this, in a study performed in Argentina, Campos et al. (2012) found that girls mentioned more ornamental plants, whereas boys were more familiar with wild plants. Although educational studies have tackled gender differences for the "species" component of biodiversity, other components of biodiversity still need to be addressed.

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In relation to the nature–culture relationship, people's place of residence is only the physical dimension of where culture makes sense of the world, and then it could be an indicator of the sociocultural-founded knowledge of the environment (Bang 2015; Eberbach and Crowley 2009; Pointon 2014; Villarroel et al. 2018). Although students' knowledge of biodiversity has already been compared among countries (see revision in Patrick and Tunnicliffe 2011), studies on students' differences between rural–urban environments are sparse. Related to this, rural boys in Argentina were more familiar with birds, reptiles, amphibians, fish, and wild plants than rural and urban girls (Campos et al. 2012). Similarly, children from Spain who live in rural settlements tended to draw more plants (flowers, trees, etc.) and abiotic factors (the sun, soil, rainfall, etc.) than the kids from urban settings. In addition, English rural girls were likely to express an esthetic appreciation and an intrinsic value of nature, while rural boys were more likely than urban students (girls and boys) to disregard nature (Pointon 2014).

In spite of the gender differential knowledge of environmental topics held by students, studies on adult laypersons' perception of biodiversity revealed contrasting findings. For instance, a study across Europe on mental representations of different types of species (mammal, spider, and plant) concluded that rurality/urbanity had no significant influence on adults' beliefs (Fischer et al. 2011).

The Loss of Biodiversity in Córdoba, Argentina

With regard to the environmental context of the current study, the Chaco forest—the geographically most extended seasonally dry forest in South America—has been experiencing profound land cover changes in the last few decades (Conti et al. 2016). Within this region, biodiversity in the province of Córdoba (Argentina) is strongly declining, mainly due to deforestation, a process largely driven by soy bean cultivation (Cáceres 2015). The accelerated habitat fragmentation rate is accompanied by social narratives that associate crops with progress and societal benefits, and native vegetation with poverty (Cáceres et al. 2016). In addition, Córdoba mountainous areas are subject to an incipient spread of woody alien species (e.g., *Gleditsia triacanthos*, *Ligustrum lucidum*, *Pinus elliottii*) from lower altitudes (Giorgis and Tecco 2014), negatively influencing ecosystem processes and structure (Furey et al. 2014).

With respect to animals, mammal introductions in southern South America have a long history. Many introductions were associated with the early European colonial period and with economic activities in the mi-twentieth century. The animals were brought from other parts of the world to "improve" local ecosystems and, in consequence, often more valued than native species (Anderson and Valenzuela 2014). However, introduced consumers in general, and mammalian herbivores in particular, can modify the structure of entire networks of interacting species and have strong impacts on ecosystems they invade (Vázquez and Simberloff 2003). As an illustrative example of the negative consequences of animal introductions to Argentina, the European hare (*Lepus europaeus*) is strongly outcompeting the native Patagonian mara (*Dolichotis patagonum*) (Novillo and Ojeda 2008). Moreover, the presence of cattle was found to strongly affect the structure of plant–pollinator interaction networks in Argentinean forests (Vázquez and Simberloff 2003).

The Education System and Curricular Standards in Argentina

The Argentinean education system is regulated by the National Law of Education, which was enacted in 2006 (Cofré et al. 2015). The system consists of four levels: preschool, elementary,

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secondary and upper secondary education (Arriassecq and Rivarosa 2014). Students in upper secondary education are usually between 15 and 18 years old. They can specialize, for instance, in natural or social sciences, but biology is always a mandatory subject (Cofré et al. 2015). A set of national standards (called priority learning guidelines) direct the development of curriculum guidelines within each state (Ministerio de Educación de la Nación 2005). However, with regard to ecology or environmental education, the national standards are rather vague, and it is up to the school and the individual teacher to decide upon the teaching content and the depth of its transmission (Bermudez et al. 2018). This may result in many different approaches to biodiversity and, in consequence, in strong differences between classes and schools (Bermudez et al. 2018; Cervini 2009).

Dimensions in the Documentation of Conceptual Frameworks and the Current Study

According to Driver and Erickson (1983), "mental frameworks" are constructed by a child as a result of numerous encounters with the environment, a process which is mediated and reinforced by a rich linguistic input from other people. In children's attempt to conceptualize their experience of the physical world, they may develop autonomous frameworks, which are termed "alternative frameworks" after Driver and Easley (1978). Although there is a distinction between the terms "alternative frameworks" and "alternative conceptions," with the latter being derived from something like a minitheory, it is important to acknowledge that the conceptions elicited from students could be "more than an idiosyncratic response to a particular task, they may be general notions applied to a range of situations" (Driver 1983, p. 7), and then they constitute "personal conceptual frameworks." It is also possible to imagine that students hold "manifold conceptions" that actually derive from several alternative personal conceptual frameworks "rather than distinct mini-theories, each having a restricted range of application" (Taber 2009, p. 253).

At school, students' frameworks could interact with academic knowledge in the need to respond to problem settings, especially when students' frameworks are partially or completely contrary to the target curriculum. In fact, Driver and Easley (1978) acknowledged that students' "intuitive ideas are not necessarily reorganized as a result of instruction; the pre-instructional ideas may remain with classroom words imposed, or the new and old ideas may co-exist" (p. 78). In addition, Driver and Erickson (1983) highlight that the construct "conceptual framework" means the "mental organization imposed by an individual on sensory inputs as indicated by regularities in an individual' responses to particular problem settings" (p. 39), and hence, the reporting of conceptual frameworks "is significant because it shows that students can have extensive, theory-like, personal conceptual frameworks that are 'alternative' to curriculum science and occur in the domain of scientific knowledge" (Taber 2009, p. 249).

There are different methodological approaches to investigate science learners' understandings. The seminal papers of Driver and Easley (1978) and Driver and Erickson (1983) introduced two dimensions that have been widely used in science education. The first one relates to the analysis of students' responses and consists of the "nomothetic–ideographic" dimension. On the one hand, in nomothetic research, the individual case is used as the basis for developing generalizations, and then, the educational phenomena are described in terms of norms or general laws (Taber 2009, 2014). For instance, when students' understanding is assessed in terms of the congruence of their responses with "accepted" scientific ideas, such a

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study is nomothetic in character (Driver and Easley 1978; Wiske 1998; Wiske et al. 2001). On the other hand, “an idiographic study explores the individual for its own sake” (Taber 2009, p. 75), and thus, students’ conceptualizations are explored and analyzed without the assessment against an externally defined system (Driver and Easley 1978).

The second dimension, stated by Driver and Erickson (1983), is about the design of diagnostic questions. This “conceptual–phenomenological” dimension defines the extent to which the situations are framed; i.e., contextual constraints (provided by a physical situation) and conceptual constraints (where concepts are presented). Driver and Erickson (1983) recognized “that students’ responses may differ significantly depending on whether they are investigated using a technique which is conceptually framed or one based on an actual event or phenomenon” (p. 43). While the former elicits propositional knowledge, the latter evokes knowledge-in-action (how a student conceptualizes and answers specifically designed phenomena).

The aim of the current study is threefold. Firstly, it attempts (1) to identify and describe high school students’ conceptual frameworks of biological diversity. Secondly, it seeks (2) to assess high school students’ conceptual understanding against scientific conceptualizations of biodiversity that are more updated than the one settled by CBD (species, functional group and genetic richness, evenness, range in functional traits, species interactions, population size, species richness among habitats) and (3) to explain whether school location (urban, rural) and sex influence students’ level of biodiversity understanding of an updated definition of biodiversity.

According to the dimensions in the investigation of science learners’ understandings (Driver and Easley 1978; Driver and Erickson 1983), the current study has a strong phenomenological aspect, since “biodiversity scenarios” were created to explore students’ understanding of the components of biodiversity by the analysis of their choices and argumentations. Also, the present study is nurtured by both ends of the “nomothetic–ideographic” dimension, since it firstly aims to identify and describe students’ conceptual frameworks of biodiversity by the analysis of students’ argumentations in a decision-making task (ideographic study, objective 1), and then, it seeks to assess students’ understanding against current scientific definitions and to explain the role of sociodemographic variables (school location, students’ sex) on students’ understandings (objectives 2 and 3, nomothetic study). According to Taber (2014), the ideographic study performs a qualitative analysis, while the nomothetic approach uses quantitative data and analysis.

The analysis of high school students’ choices and argumentations in the presented scenarios allows the identification of students’ conceptual frameworks of biodiversity in the context of accepted scientific conceptualizations that followed the one settled by CBD in 1992 (Hooper et al. 2005; Díaz et al. 2006, 2015a, b). Also, this study provides baseline data for science education and social science research related to biodiversity conservation. Moreover, it contributes to international research on students’ understanding of the concept of biodiversity (e.g., Dikmenli 2010; Fiebelkorn and Menzel 2013; Kilinc et al. 2013) and their decision-making processes regarding biodiversity conservation (e.g., Eggert and Bögeholz 2010; Grace 2009; Hermann and Menzel 2013; Menzel and Bögeholz 2010).

Results of the present study could be of use for future curriculum planning and for preservice and in-service teacher education. Also, the characterization of students’ conceptual frameworks about biodiversity will support the development of learning environments that

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challenge biodiversity alternate frameworks and the current biodiversity definitions in teaching materials, textbooks, and conservation campaigns (Bermudez et al. 2014; Fonseca 2007; Pérez-Mesa 2013; United Nations 2015).

Methods

Survey Administration and Sampling

We conducted a questionnaire-based survey aimed at understanding students' conceptual understanding of biodiversity. To begin with, 13 high school teachers were selected with the help of a nonprofit organization that provides a network for biology teachers and an institution that provides a master course in science education. Selection criteria were that teachers had not only taught about biodiversity in the year of study, but were also representing different school locations (urban and rural).

All questionnaires were personally administered by author 1, and students (58% girls) had 25 min to complete the tasks. Overall, 321 students of the last 3 years of the Argentinean mandatory system (15–18 years old) from 13 schools (always one class per school and participating teacher) filled-in the questionnaire. Seven schools were located in an urban environment. The last three grades of Argentine secondary education (4th, 5th, and 6th) are equivalent to grades 10, 11, and 12 of the US education system.

The Questionnaire

We used a "scenario approach" to represent different components of biodiversity. A scenario consists of a plausible alternative situation based on a particular set of assumptions, which projects the impact of management decisions on biodiversity (Díaz et al. 2015b). In the questionnaire, ten different biodiversity scenarios were randomly presented to the students (Online Resource 1). In each scenario, two environments were depicted which differed in certain biodiversity components. For each scenario, participants had to judge which of the two environments should be chosen for biodiversity conservation. According to our operational definition of biodiversity, the environments differed in species richness in and among habitats (alpha and beta diversity), genetic and functional group richness, evenness, range in functional traits, species interactions, and population size (Table 1).

Students were introduced to a problem-solving task as follows: "If you were hired by the government in order to create a new national park for biodiversity conservation, and the following schemes were shown to you (of which a and b represent different environments that are available to conserve), which one would you choose?". Students were also provided with two more answers ("c" and "d") in case they thought that both environments were equally important to protect (option "c"), or in case the depicted features were not considered to be related to biodiversity and no decision could be made (option "d"). Students were also asked to provide a reason for each of their choices ("a"—"d") with the aim to interpret their conceptual understanding of biodiversity and limit the effect of chance. From here on, the order of presentation and analysis of biodiversity scenarios is organized in biodiversity components rather than following the sequence numbering of the questionnaire (Online Resource 1).

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Table 1 Target components of biodiversity in the ten biodiversity scenarios

No.	Scenario biodiversity components[a]	Scheme	No. of species	Evenness	No. of functional groups	Correct choices
1	Same species richness, same evenness	a	4	1.28	3	c
		b	4	1.28	3	
7	Same species richness, different evenness	a	3	1.10	2	a
		b	3	0.85	2	
2	Same species richness, different number of functional groups	a	4	1.39	1	b
		b	4	1.39	3	
4	Different species richness, different number of functional groups	a	5	1.61	3	a
		b	3	1.05	2	
5	Different species richness at local scale, same diversity among habitats	a	3	1.04	2	b
		b	3	1.04	2	
6	Same species richness, different range in canopy structure	a	3	0.94	1	b
		b	3	0.94	1	
8		a	5	1.61	1	b
		b	5	1.61	1	
9	Same species richness, different number of interactions in food webs	a	10	2.30	4	a
		b	10	2.30	4	
3	Same species richness, different population sizes	a	3	1.10	2	b
		b	3	1.08	2	
10	Different genetic compositions	a	–	–	–	b
		b	–	–	–	

[a] Biodiversity scenarios numbering is organized in biodiversity components and differs from the sequence numbering of the questionnaire

According to the conceptual–phenomenological dimension in the elicitation of students' conceptual frameworks (Driver and Erickson 1983), the conceptual aspect of the current study was the design of the scenarios. Based on our operational definition of biodiversity, justifications for the scenarios and the correct choices from a scientific point of view were as follows:

- Scenario 1 (same species richness, same evenness): The relationship between biodiversity and key ecosystem processes depends, among other components, on species richness and evenness (Chapin III et al. 2002; MEA 2005). Consequently, as species richness and evenness were the same in both environments in scenario 1, the correct answer would be "c" (equal importance for biodiversity conservation).
- Scenario 7 (same species richness, different evenness): In an environment, most species are rare, while only few species are abundant. A more even distribution of individuals of species in an environment contributes more to ecosystem stability than a less even distribution, because dominant species account for most of the energy and nutrient flow through an ecosystem (Chapin III et al. 2002). Moreover, rare species are more likely to vanish after disturbances (Mulder et al. 2004). Hence, the correct answer to scenario 7 would be "a."
- Scenario 2 and scenario 4 (same or different species richness, different number of functional groups): Species can be grouped into functional groups (e.g., trees, herbs, legumes). For a given ecosystem, functionally diverse communities are more likely to adapt to climate change and climate variability than impoverished ones and to provide more ecosystem services (Secretariat of the Convention on Biological Diversity 2003). The higher the number of functional groups in an environment is, the lower the chance

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that the disturbances affect ecosystem functioning (Chapin III et al. 2002). Consequently, the correct answer to scenario 2 would be "b," and to scenario 4 would be "a."

- Scenario 5 (different species richness at local scale, same richness among habitats): A basic measure of species richness is alpha diversity, i.e., the number of species found at given localities or single samples (3 point samples, options "a" and "b"). Alpha diversity does not necessarily co-vary with beta diversity, or diversity among habitats or along an environmental gradient (Seidler and Bawa 2013). However, alpha and beta diversity increase from polar to tropical regions is one of the most important and well-documented macroecological patterns of biodiversity (Enquist et al. 2001). Also, alpha diversity measures the number of potentially interacting species, which may influence beta diversity in the context of environmental changes (Schneider 2001). Consequently, alpha diversity is higher in option "b" (correct answer), while beta diversity is equal in both scenarios.
- Scenario 6 and scenario 8 (same species richness, different diversity in canopy structure): The value and range of functional traits (functional diversity) determine ecosystem functioning more strongly than species numbers per se (Díaz and Cabido 2001). Diversity within a functional group (e.g., within trees) and a functional trait (e.g., canopy structure) increases the probability that natural and human-made disturbances can be buffered (Chapin III et al. 2002). Consequently, option "b" would be the correct answer for both scenarios.
- Scenario 9 (same species richness, different number of interactions): The wider meaning of biodiversity (Díaz et al. 2006) includes the interactions among species. The more complex and rich these interactions are, the more likely disturbances can be buffered (Chapin III et al. 2002; Hellmann 2013). Consequently, the correct answer to scenario 9 would be "a."
- Scenario 3 (same species richness, different population sizes): Abundance matters more for ecosystem services than the presence or range of genetic varieties, species, and ecosystem types (MEA 2005). The probability of population bottlenecks due to environmental events or human activities is smaller in large populations than in small ones (Zedler and Lindig-Cisneros 2013). Consequently, the correct answer to scenario 3 would be "b."
- Scenario 10 (different genetic compositions of corn): Genetic diversity is an important component of biodiversity (Hamilton 2005; Pingali and Smale 2013). Genetic diversity in a population of corn, for instance, increases the chance that at least some of their members can cope with changing environmental conditions such as drought. Consequently, the correct answer to scenario 10 would be "b."

Questionnaire Validity

In order to assess the content validity of the tasks, a draft version of the questionnaire was shown to one senior university lecturer in ecology and to another one in science education. Revisions were carried out based on their comments and suggestions. Later, the draft version was pilot-tested with a sample of ten last-year high school students and five first-year biology students. This allowed to reconfigure the options of the multiple choice tasks and to understand if students interpreted the scenarios correctly. After amendments, the last version of the questionnaire was reviewed and accepted by a science education and a social science expert.

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Data Analysis

Idiographic Study (Objective 1)

To identify and describe high school students' conceptual frameworks of biological diversity, we first performed a content analysis. This process was inductive in nature since themes were allowed to emerge from the data as the authors constructed meaning from students' responses without imposing predeveloped categories onto the data (Patton 2014; Taber et al. 2011). From the first reading of students' argumentations for each scenario, core concepts (codes) were identified. These initial codes were revised after a second reading, and after that, we wrote down some notes (such as short phrases, concepts, and ideas) in order to thought out the organization of the data. We constructed mind maps using these code words. We grouped similar codes, looked for redundant codes, and eliminated redundant categories. The process of constructing categories was first independently performed and then reaching consensus between the authors, which provided a degree of triangulation that resulted in the identification of students' conceptual frameworks (Pointon 2014). Codes and categories from the actors' perspective (native categories) were quoted and italicized, while those of the researchers were only italicized.

Nomothetic Study (Objectives 2 and 3)

Students' choices for each scenario and respective explanations were separately and jointly analyzed in order to identify their levels of biodiversity understanding. The students' choices (options a–d) were counted, expressed as proportions (%), and categorized into "correct" (= "1") or "incorrect" (= "0") (Tables 1 and 2) according to our operational definition of biodiversity. The answers to the open question (explanations for the choice of options a–d) were content-analyzed in terms of the types of reasons given and coded into categories (Driver and Erickson 1983).

Coding was discussed in the research group and reliability judged by comparing their coding. To test for reliability, the authors transcribed the students' answers of a random subset of questionnaires (30%) and independently coded them. After that, the authors discussed the codes and the most common students' phrases that accurately described the "correct" model answer for each of the biodiversity scenario. The authors agreed upon the following: (a) when students say "species variety," this was interpreted to mean "species number" (richness); (b) "diversity" and "biodiversity" were considered to be synonyms; (c) "species diversity" was interpreted to mean "species number" (richness); (d) "number of plants"" was considered to refer to "number of individuals" (population size); (e) "types of plants" was interpreted to mean "functional groups"; and (f) "proportion of" and "balance among" species were considered to refer to "species evenness." The authors then reexamined the subset of questionnaires, compared their codings, and achieved an agreement higher than 90% throughout the questionnaire. The authors also resolved through discussion the coding of students' understanding of biodiversity for the entirety of questionnaires when a student's answer differed from the previously agreed system.

The agreed "correct" model answers for each scenario are the following: "correct" answers to scenarios 1 and 7 acknowledge that the number of species is equal in schemes "a" and "b" (possibly giving richness values), but that the proportion of individuals among the species is different: while evenness is the same in scenario 1, it is different in scenario 7 (possibly counting

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Table 2 Students' reasons to biodiversity scenarios 1 and 7, and coding scheme from a scientific point of view (nomothetic study)

No. of scenario	Picking options	Coding of students' picking	Examples of students' reasons	Coding of students' reasons[a]	Coding of students' understanding
1	a	Incorrect [0]	"It is 'a' because the other has no relationship with diversity" (girl, 5th grade)	Incorrect/incomplete [0]	Naïve [0 × 0]
	b		"Scheme 'b' has more species" (boy, 6th grade)		
	c	Correct [1]	"Both schemes have the same quantity of diversity" (boy, 5th grade)		Novice [1 × 0]
			"Either represents the same because they contain the same number of individuals and the same amount of different species" (boy, 5th grade)	Correct [1]	Master [1 × 1]
	d	Incorrect [0]	"There is no diversity, the species are the same in 'a' and 'b'" (girl, 4th grade)	Incorrect/incomplete [0]	Naïve [0 × 0]
7	a	Correct [1]	"Biodiversity is best represented in option 'a' as there are equal numbers of plants" (boy, 5th grade)	Incorrect/incomplete [0]	Novice [1 × 0]
			"Scheme 'a' has the same species than in 'b' but in equal proportions" (boy, 6th grade)	Correct [1]	Master [1 × 1]
	b	Incorrect [0]	"Scenario 'b' is more diverse because it has a higher number of shrubs" (boy, 6th grade)	Incorrect/incomplete [0]	Naïve [0 × 0]
	c		"Species composition and the number of plants are identical in the two environments (girl, 5th grade)		
	d		"What matters to biodiversity is species number" (girl, 6th grade)		

[a] See "correct" model answers in the text; 4th, 5th, and 6th grades of Argentine secondary education are equivalent to grades 10, 11, and 12 of the US education system (15–18 years old)

individuals per species). "Correct" model answer to scenario 2 admits that the number of species is the same for the two schemes, but that the number of types of plants was higher in scheme "a" (feasibly giving the number of trees, cacti, etc.). Conversely, "correct" model answer to scenario 4 recognizes that species richness and number of functional groups are higher in scheme "b." "Correct" model answer to scenario 5 acknowledges that although species number is the same in both schemes (possibly providing species richness), it is higher at each sector (local scale) in scheme "b." "Correct" model answers to scenarios 6 and 8 admit that species richness are the same (possibly providing species number), but that the tree canopy structures are more contrasting in schemes "b" than in schemes "a." "Correct" model answer to scenario 9 acknowledges that the number of alimentary interactions (and interconnectedness) among species is higher in scheme "a," although the number of species is the same in both schemes. "Correct" model answer to scenario 3 admits that the number of individuals of each species is higher in scheme "b," yet the number of species is constant (possibly providing species richness). "Correct" model answer to scenario 10 acknowledges that "corn" is shown in both schemes, but that there are many more types in scheme "b." Examples of "correct" students' answers for scenarios 1 and 7 are presented in Table 2 and in the "Results" section. After the coding of students' answers, they

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were sorted into two broad categories of understanding of biodiversity: "incorrect/incomplete" (= "0") and "correct" (= "1").

Although we acknowledge the difference between "incorrect" and "incomplete" understanding of biodiversity, we decided to group them into one category in order to facilitate the statistical analysis. In addition, the distinction of intermediate levels of understanding (Wiske 1998) would have allowed the coding of not mutually exclusive codes (To et al. 2017). In the current study, "incorrect" students' responses showed mainly their misunderstanding of the biodiversity components or the possibility of picking an option by chance. For instance, a boy's answer to scenario 1 saying that "Scheme 'b' has more species*"* (6th grade, Table 2) was considered to be "incorrect" because species richness was the same in both schemes. An "incomplete" understanding of the biodiversity components points out that students' conceptual frameworks are only partially correct within the context of the questionnaire. For instance, a girl's response to scenario 1 saying that "There is no diversity, the species are the same in 'a' and 'b'" (4th grade, Table 2) was interpreted to mean that she acknowledged "species composition," but that she disregarded "species richness" and "evenness" for biodiversity conservation, and thus the girl's answer was coded as "incomplete." Other examples of "incorrect/incomplete' students" answers are presented in Table 2 (for scenarios 1 and 7) and in the result part.

Students' choices for each scenario and respective explanations were jointly analyzed by multiplying each choice (0 = "incorrect," 1 = "correct") with the corresponding explanation (0 = "incorrect/incomplete," 1 = "correct") (Table 2) and thus generating a new variable of students' conceptual understanding. Coding for jointly biodiversity understanding included "master," "novice," and "naïve" levels (Wiske 1998). A "master" level of understanding of biodiversity represented students who had picked the "correct" choice for a given scenario and also provided the "correct" explanation for their choice (1 × 1 = 1). A "novice" understanding of biodiversity was coded for "correct" choices and "incorrect/incomplete" reasons (1 × 0), and "naïve" students' understanding of biodiversity indicated the students' "incorrect" choices and "incorrect/incomplete" reasons (0 × 0). After that, an additive scenario approach was undertaken in order to integrate the components of biodiversity of each scenario into our operational conceptualization of biodiversity. Therefore, a new variable was created by the summation of the answers coded as "master" understanding throughout the questionnaire, resulting in a maximum score of 10 (= number of scenarios). This "additive master" variable was seen as an indicator of the understanding of the operational conceptualization of biodiversity. Mean values, standard deviation (SD), and range were calculated and informed for the "additive master" variable.

Possible relationships between the explanatory variables and the "additive master" variable were tested with nested analysis of variance (objective 3). The effect of school location (urban, rural) was tested against the residual variation among the classes, while the effects of school class and sex were tested against the error term. All analyses were carried out with IBM SPSS 22 for Windows.

Results

We first present the results of our ideographic study, identifying the emergent categories and mind maps that reflected the students' frameworks of biodiversity. Next, we report the results of our nomothetic study, which includes descriptive and statistical analysis of students' understanding of biodiversity compared to our operational definition and according to school location and student's sex.

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Ideographic Study (Objective 1)

From the inductive analysis, we performed a mind map of the students that participated in the survey and identified three general codes and 11 categories that describe students' frameworks of biological diversity (Table 3, Online Resource 2). We see these codes and categories as providing a useful structure underlying our informants' frameworks that allow us to think and discuss about biodiversity conceptual frameworks. However, we acknowledge variations within these categories and a different relative importance in students' argumentations to protect biodiversity. For instance, "*variety*" as the "*number of*" "*species*" was the most frequent framework in students' argumentations, although "*variety*" as the "*divergence in*" "*tree forms*" was one of the least frequent.

"*Variety*" as the "*Quantity*"/"*Number of*" and "*Divergence in*"/*Range of*

"*Variety*" was found in students' argumentations as a reference to "*quantity*" or "*number of*" biological entities (Table 3, Online Resource 2). "*Variety*" was mainly ascribed to "*species*" and, to a lesser extent, to the number of "*individuals*," "*types of species*," and "*relationships*" among species. "*Variety*" was also expressed in students' argumentations as "*divergence in*" or *range of* "*types of vegetation*" and, more rarely, "*tree forms*," thus making evident that students acknowledged the differences among trees, shrubs, and herbs.

"*Type of*" Organism as a "*Plant*," "*Animal*," "*Man-Made Plant*," and "*Vegetable*," According to Its *Origin* and "*Size*"

The "*type of*" code was mainly ascribed by students to "*plants*" and "*animals*," especially to "*trees*" (Table 3, Online Resource 2), using utilitarian and relational reasons (e.g., oxygen production and shelter provision). The "*tree*" preference could also be explained by the "*size*" category, since students argued for "*shrubs*" and "*herbs*" as subordinate "*plants*."

Although many students expressed their preference to protect different "*types of*" "*maize*," and because of its *origin* (i.e., "*native*" to America), others argued that "*vegetables*" (or parts of plants), "*man-made plants*" or "*genetically modified organisms*" ("*GMO*") reduce biodiversity or are not related to biodiversity.

"*Balance*" in Species "*Distribution*," *Species Evenness*, and "*Trophic Chain*"

The notion of balance was identified in the argumentations when students explained species spread over an area ("*distribution*") (Table 3, Online Resource 2), and then, how "*proportioned*," "*equitable*," and "*mixed*" species were. However, students argued that a "*plantation*," or when plants were "*aligned*," "*not mixed*" or when they were distributed in a "*monoculture-like*" place, biodiversity was excluded from the decision-making task. *Species evenness* was identified when students decided to protect biodiversity on the basis of the species relative abundances, i.e., when the number of individuals was "*proportioned*," "*equal*," or "*distributed*" among species. Likewise, some students described "*trophic chains*" as being "*balanced*," "*complete*," or "*long*" when species relationships were richer and more interconnected. The idea of "*balance*" was also used by students to explain how the chances to become extinct of "*species*," "*animals*," and the "*trophic chain*" itself decreased. Other students kept "*trophic chains*" out of the conservational biodiversity task.

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Table 3 Codes and categories of biological diversity contextualized to high school students' arguments about a conservational decision-making task (ideographic study)

Code [a]	Category	Examples
"Variety"	*"Quantity"/"Number of"*	"Scheme 'a' has a higher number of species" (girl, 6th grade). "In both schemes there is the same quantity of types of species" (boy, 6th grade). "The number of specimens matters to biodiversity" (girl, 4th grade). "The variety in the ways animals relate to each other seems to be greater in 'a'" (boy, 4th grade)
	"Divergence in"/Range of	"Variety of plants is higher since there are trees, shrubs and herbs" (boy, 6th grade). "Scheme 'b' has trees of different shapes, sizes, colors, etc." (boy, 6th grade)
"Type of"	*"Plant"*	"I prefer trees to other types of plants" (boy, 5th grade). "Trees provide more oxygen" (girl, 4th grade).
	"Animal"	"It has more shrubs and then, these could offer shelter to animals" (boy, 5th grade). "The variety of trees is greater in 'a', and it is more likely to have higher animal species diversity" (boy, 5th grade)
	"Man-made plant"/"GMO"	"Corn has been genetically modified for commercial purposes" (boy, 5th grade). "These corns are perfect and identical to each other, so they are man-made plants" (girl, 6th grade)
	"Vegetable"	"It is a vegetable, it has nothing to do with biodiversity, plus it is a part of a plant, not a plant itself" (girl, 4th grade)
	Origin	"Corn is native to America" (boy, 5th grade)
	"Size"	"As they are of big size and of different type, it is better for conservation" (girl, 6th grade)
"Balance"	*"Distribution"*	"The quantity of species is the same, but they are placed in a mixed-way" (girl, 4th grade). "Species distribution is more proportioned; they are dispersed in all three areas" (girl, 6th grade). "This is not related to biodiversity, this is a human plantation" (boy, 6th grade). "Species are really parceled, they do not relate or mix" (boy, 4th grade)
	Species evenness	"Species are more proportioned in scheme 'a', there are three individuals of each species" (girl, 6th grade). "Species variation is more equal, no one predominates over the other" (boy, 4th grade).
	"Trophic chain"	"There is a higher probability of this trophic chain to remain balanced, although some animals may die" (girl, 4th grade). "All animals eat each other; there is no chance of overpopulation. This balance helps species not to become extinct" (boy, 6th grade). "This chain is more complete" (girl, 4th grade). "There is a longer chain in here" (girl, 4th grade)

GMO genetically modified organism

[a] Researchers' codes and categories are italicized, while actors' codes and categories are italicized and quoted

Nomothetic Study: Individual Scenario Approach: Components of Biodiversity That Are Worth Protecting (Objective 2)

Scenario 1: Same Species Richness, Same Evenness

About 56% of students achieved a "master" understanding of biodiversity (option "c," "correct" reason for conservation) (Fig. 1a). Typical explanations were as follows: "Both vegetation schemes represent the same biodiversity. There are four different species in picture 'a' and in picture 'b'; they have the same number of individuals, but in different groups" (boy, 4th grade). "'A' and 'b' represent the same diversity as 'a' shows one tree, five herbs and one

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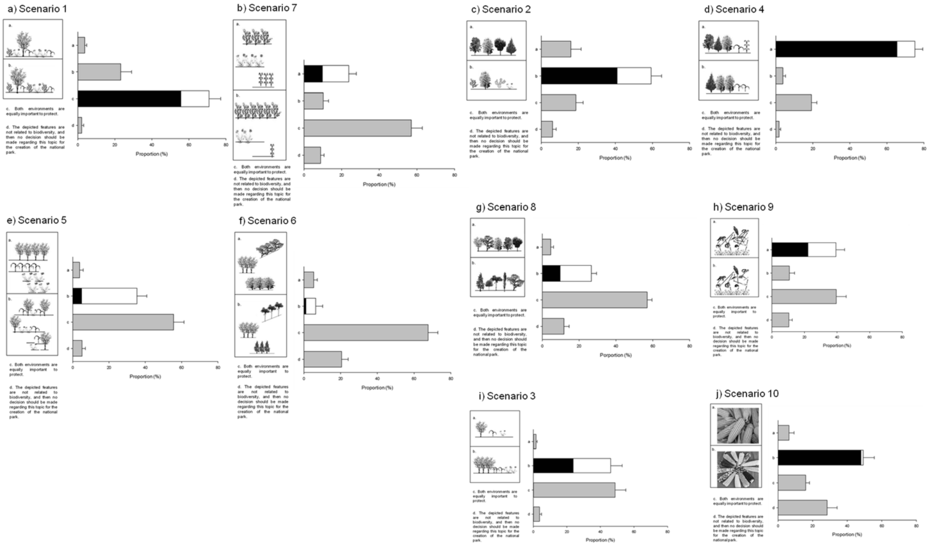

Fig. 1 Students' understanding of the components of biodiversity for ten different biodiversity scenarios (**a**–**j**). The different bar colors represent different levels of biodiversity understanding. Gray: proportion of incorrect choices with incorrect explanations ("naïve" level); black: proportion of correct choices with correct explanations ("master" level); white: proportion of correct choices with incorrect explanations ("novice" level). Between 292 and 304 students answered the questions. Horizontal lines denote + 1 SE

shrub, which is the same as having one tree, three shrubs and three herbs, as depicted in 'b'" (girl, 6th grade). "Novice" students (about 23%) justified their choice only with "species richness." About 25% of students reached a "naïve" understanding of biodiversity and reasoned with the presence and value of certain functional groups, and did not identified "species richness": "Scenario 'b' is more developed as there are more bushes" (girl, 5th grade). "There are more bushes in 'b' than in 'a', and bushes are more important for biodiversity than herbs" (boy, 5th grade).

Scenario 7: Same Species Richness, Different Evenness

Only about 10% of students achieved a "master" level of biodiversity understanding (Fig. 1b). Typical explanations included "Scheme 'a' has the same variety of species as scheme 'b', but in equal proportions" (girl, 5th grade). "Novice" students (about 14%) showed no clear pattern of understanding. Students argued, for example, that "species can better interact in 'a' than in 'b' because one species in 'b' has no partner to interact with" (girl, 6th grade) or that "scheme 'a' has more herbs than scheme 'b'" (girl, 4th grade).

Most students (about 76%) reached a "novice" level of understanding. Almost 60% of students picked option "c" and explained their choice exclusively with species richness: "In both pictures are three different species" (girl, 5th grade). A focus on species richness was also typical for students who chose option "d": "The species do not differ" (boy, 6th grade). Students who chose option "b," on the other hand, reasoned with the presence of certain functional groups or regarded an uneven distribution of individuals of species as beneficial for biodiversity. Typical explanations included "In 'a' and 'b' are the same species, but there is more diversity in the number of individuals in 'b'" (boy, 6th grade).

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Scenario 2: Same Species Richness, Different Number of Functional Groups

About 40% of students reached a “master” understanding of biodiversity (Fig. 1c). They explained, for example, that “in ‘a’ and ‘b’ are the same number of species (four different species each) and an equal number of individuals (four in each scheme), but there is more diversity in ‘b’, because there is a cactus, a shrub, a tree, and a herb, while in option ‘a’ there are only trees” (boy, 5th grade). “Novice” students (about 20%) disregarded functional groups and explained: “There are more species in ‘b’ than in ‘a’” (boy, 6th grade). “Scheme ‘b’ shows us four different species” (girl, 5th grade).

About 40% of students reached a “naïve” understanding of biodiversity and focused mainly on species number or the value of trees and bushes species and explained: “Both environments contain a variety of species and should both be protected” (boy, 5th grade). “Trees are more important than other plants as they provide a lot of benefits and are very important to people” (boy, 4th grade). “I think it is better to have trees and bushes than to have a cactus” (boy, 5th grade). “Trees release more oxygen” (girl, 5th grade). “In ‘a’ biodiversity is greater because species have more in common” (girl, 5th grade).

Scenario 4: Different Species Richness, Different Number of Functional Groups

About 65% of students reached a “master” understanding of biodiversity (Fig. 1d). Typical explanations were as follows: “Scheme ‘a’ has more species than scheme ‘b’ and also more different types of trees and forbs” (girl, 6th grade). “In ‘a’ are more species and more different types of trees, a bush, and a grass” (boy, 6th grade). “Novice” students (about 10%) justified their choice only with species richness: “Scheme ‘a’ has more species than scheme ‘b’” (girl, 5th grade). “Species diversity is higher in ‘a’ than in ‘b’” (girl, 5th grade).

About 23% of students showed a “naïve” understanding of biodiversity and focused mainly on the presence of trees: “Scheme ‘a’ and ‘b’ have the same amount of trees, and what remains is not very important” (girl, 6th grade, choice of “c”). “Scheme ‘b’ has more biodiversity because it has more trees” (girl, 4th grade, choice of ‘b’).

Scenario 5: Different Species Richness at Local Scale, Same Species Richness Among Habitats

Most students (56%) showed to be at a “naïve” level of understanding of biodiversity (Fig. 1e) and reasoned only with species richness: “In both schemes are three different species” (girl, 5th grade). “Similar numbers of species are represented; what varies is the order” (girl, 5th grade). Only 5% of students reached a “master” understanding and explained: “Each line in ‘b’ is a mixture of species, whereas in ‘a’, each line contains only of one species” (girl, 5th grade). “Scheme ‘b’ has more biodiversity. Although both schemes have the same number of species, the species are distributed more uneven in each line” (girl, 6th grade). About 35% of students achieved a “novice” level of understanding and their reasons showed no clear pattern.

Scenario 6: Same Species Richness, Different Range in Canopy Structure

Most students reached a “naïve” understanding of biodiversity (range in tree canopy structure, a functional trait) and focused only on species richness, evenness, and species

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composition: "both schemes contain three different species" (girl, 5th grade, option "c"), "they are the same as there are three species and the same number of individuals" (girl, 5th grade, option "c"), "there is no diversity as there are just trees" (girl, 6th grade, option "d"), and "there are different tree species, but they are in the same locations" (boy, 6th grade, option "d").

Only 1% of the students achieved a "master" understanding of biodiversity (Fig. 1f) and explained with an almost sufficient explanation: "Although both pictures have the same number of species, scenario 'a' depicts the wider difference among the trees" (boy, 6th grade). "Novice" students were about 5%.

Scenario 8: Same Species Richness, Different Range in Canopy Structure

Most students (about 72%) showed a "naïve" understanding of the range in canopy structure for biodiversity conservation (functional group) (Fig. 1g). They reasoned with species richness, evenness, and composition or felt that scenario 8 had nothing to do with biodiversity. Typical explanations were as follows: "There are five species in each scheme" (girl, 5th grade, option "c"). "There is one individual per species in both schemes" (boy, 5th grade, option "c"). "In both schemes, species are of the same type (trees)" (boy, 6th grade, option "c"). "Both images present a single type of species (trees)" (boy, 6th grade, option "d").

Only about 10% students achieved a "master" understanding of biodiversity, and their explanations included "It has more diversity as there are many kinds of trees that vary in height" (girl, 6th grade, choice of option "b"). "Species vary from one scheme to the other, and I see trees that also vary in size and height" (boy, 5th grade, choice of option "b"). "Novice" students were about 18%.

Scenario 9: Same Species Richness, Different Number of Interactions (Food Web)

About 22% of the students achieved a "master" understanding of the value of species interactions for biodiversity conservation (Fig. 1h) and explained "In 'a' are more relationships between individuals; it is a bigger food web" (girl, 6th grade), and "In 'a' an animal is not only supplied by one, but by two or three species" (girl, 6th grade). An equal proportion of students reached a "novice" understanding of biodiversity and focused on species competition for preys: "It is a chain that is not very branched. In scheme 'a' we see that every species eats several others. That tells us that there is not much competition by other predators" (boy, 5th grade).

The other students (about 56%) showed a "naïve" understanding and neglected species interactions or reasoned mainly with species richness: "'a' and 'b' are equal; regardless of who eats whom, there are the same number of species" (girl, 5th grade, choice of "c"), "there is the same number of species; no matter of their relationships" (boy, 5th grade, choice of "c"), "the species are the same" (girl, 6th grade, choice of "c"), and "food webs have nothing to do with biodiversity" (girl, 6th grade, choice of "d").

Scenario 3: Same Species Richness, Different Population Sizes

About 24% of the students achieved a "master" understanding of biodiversity (Fig. 1i) and argued that "both scenarios have the same amount of species (three), but in picture 'b' there are

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more individuals" (boy, 5th grade) and "there is the same number of species, but individuals are repeated in scheme 'b'" (boy, 5th grade). A similar proportion of students reached a "novice" understanding of biodiversity, who focused on human consumption and confounded individuals' abundance with species richness: "There is more quantity of species" (girl, 6th grade), and "It is better for human consumption" (girl, 5th grade).

About half of the students (about 52%) showed a "naïve" understanding that was centered on species richness and composition, and included that "both environments show the same thing, because they have the same number of species and only vary in the number of individuals" (boy, 4th grade, choice of "c"), "the variability is the same, although there are different numbers of individuals" (girl, 5th grade, choice of "c"), "both scenarios present the same type of trees, shrubs and herbs" (boy, 6th grade, choice of "c"), and "less quantity does not mean less biodiversity" (boy, 6th grade, choice of "c").

Scenario 10: Different Genetic Composition

About half of the students (about 49%) achieved a "master" understanding of genetic diversity (Fig. 1j) and explained that "there are more varieties of maize in scheme 'b' than in the first one" (boy, 6th grade), and "there are many types of corn" (boy, 5th grade). The students who showed a "naïve" level of understanding centered on species richness or explained that the concept of biodiversity does not apply for crops. "Although both schemes consist of corn and 'b' has more variability, there is just one species" (girl, 5th grade, option "c"). "Although there are differences in appearance, it is only one species" (boy, 6th grade, option "d"). "All these are examples of one species (maize)" (girl, 6th grade, option "d"). They argued that "since these are crops, it has nothing to do with biodiversity" (girl, 5th grade, option "d"). "These cultures are food for people, which has nothing to do with biodiversity" (boy, 5th grade).

Nomothetic Study: Additive Scenario Approach and the Influence of Explanatory Variables (Objective 3)

On average, students achieved a mean of 4.2 "correct" choices throughout the questionnaire (SD = 1.80, range between 0 and 9 scores). However, only few of them reached an "additive master" level of biodiversity understanding (overall mean score = 0.5, SD = 0.80, range between 0 and 4). In the model, students' "additive master" understanding of biodiversity was not related to sex or school location (urban, rural). Only the school class had a significant effect (Table 4).

Table 4 Nested analysis of variance of the effects of school location (urban, rural), class, and sex on students' overall "master" understanding of biodiversity (additive scenario approach)

Source	SS	*df*	MS	*F*	Sig.
School location	0.383	1	0.383	0.135	0.720
Class	31.226	11	2.839	5.670	< 0.001
Sex	0.007	1	0.007	0.013	0.901
Error	83.611	167	0.501		
Total	168.000	181			

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Discussion and Educational Perspectives

In this study, we aimed to identify and describe high school students' frameworks of biodiversity, to assess students' conceptual understanding against scientific definitions of biodiversity, and to explain whether these conceptualizations are influenced by school location and sex. Considering our findings, we can say that students have a range of frameworks of biodiversity and that some of them are in agreement with scientific conceptualizations (from the one stated by CDB in 1992 and beyond). As an example, the students' idea of "*variance*" as "*number of*" and "*divergence in*" was used to express the importance of protecting a wide range of biological entities (e.g., "*species*," "*types of species*," "*species relationships*," "*individuals*," and "*tree forms*") that strongly relate to scientifically accepted biodiversity components (species richness, functional type richness, biological interactions, genetic diversity, population size, and range in a functional character) (Díaz et al. 2006, 2007, 2015a; Hooper et al. 2005; Mason et al. 2005). However, while some students acknowledged and valued the protection of certain components of biodiversity, other students ignored them or did not consider them important in the context of a conservational issue. Nevertheless, we believe that the identified and assessed students' frameworks have a potential to be starting points for a more updated and integrated science curricula that is contextualized in students' own understanding (Kilinc et al. 2013). Therefore, we discuss students' frameworks in detail and then suggest curricular and practical implications.

Although most students argued in favor of the highest species and functional richness (scenarios 1, 2, and 4), the "*number of*" individuals (population size, scenario 3) and "*divergence in*" "*tree forms*" (functional divergence, scenarios 6 and 8) were mainly disregarded. Species richness represents a single but important metric that is valuable as the common currency of the diversity of life, but it must be integrated with other metrics to fully capture biodiversity (MEA 2005). Other studies found that the most common notion of the concept of biodiversity among laypersons is built on the word itself "biodiversity," i.e., the diversity of living things (e.g., Fischer and Young 2007; Fiebelkorn and Menzel 2013; Hunter and Brehm 2003; Kilinc et al. 2013; Lindemann-Matthies and Bose 2008). However, there is growing consensus that functional diversity rather than species richness determines ecosystem functioning (Díaz and Cabido 2001; Díaz et al. 2006; MEA 2005). We identified several, not mutually exclusive, reasons for students' centrism in species richness. (1) High school curricula and textbooks in Argentina often explain the concept of biodiversity by using the original CBD definition from 1992 (Bermudez and De Longhi 2015; Vilches et al. 2015). (2) Even if teachers include in their lessons genetic and ecosystem components, or more up-to-date definitions of biodiversity than that of the CBD in 1992, students might conceptualize them in terms of their own frameworks, by which the "*number of*" biological entities, such as "*individuals*" (population size), "*species relationships*" (food web), "*types of plant*" (functional group) and, mainly, "*species*" may frame their school science understanding. (3) It could also be that the understanding of species richness in a scenario immediately captured students' attention as school science learners, drawing it away from the other components depicted. A single survey data source may lent itself more to student responses reflecting a predominant traditionally species-centered "scientific" view, whereas a more multimodal approach might have opened up possibilities or esthetic/perceptual or more ethical/political responses (Pointon 2014).

Functional diversity can be measured as the number of functional groups or as the presence of a variety of functional trait values (Mason et al. 2005). As stated above, students acknowledged the importance of protecting a high number of types of vegetation, but only few students

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valued the variety of trait values ("*divergence in*" "*types of vegetation*" or "*tree forms*", scenarios 6 and 8). Functional traits such as canopy size and architecture or growth form compositions can affect carbon sequestration and, thus, contribute to climate regulation, a key environmental service performed by nature (de Bello et al. 2010). Research on students' understanding of global change has also shown that plant functional diversity was hardly recognized as a driver for ecosystem functioning (Lambert et al. 2012; Ratinen et al. 2013).

In biological terms, a population can be defined as a collection of individuals of the same species in a defined geographic area that interbreed (Hellmann 2013). When a population decreases in size, genetic diversity is lost and its robustness against environmental changes and ability to survive substantially reduced (Barbault 2013; Zedler and Lindig-Cisneros 2013). These processes are magnified in genetic bottlenecks, i.e., when populations contain low numbers of individuals with very few genotypes (Zedler and Lindig-Cisneros 2013). In the present study, the students' framework of "*number of*" "*individuals*" or specimens was found to be related to the idea of "*quantity*" than to students' argumentations for population size effects (scenario 3). Likewise, the importance of genetic diversity (scenario 10) was mainly expressed as the "*quantity*" of "*types of*" species and "*divergence of*" "*types of vegetation*" ("*corn*," "*maize*"), rather than arguing in favor of a variety in maize genotypes or phenotypes. In other studies, both students and preservice teachers failed to consider genetic diversity as being an integral component of biodiversity (Dikmenli 2010; Fiebelkorn and Menzel 2013; Kilinc et al. 2013; Vilches et al. 2015).

The fact that students' reference to "*man-made*" plants or "*GMOs*" as the absence of or diminished biodiversity could be related to a more general mental model of considering "natural" as separate from "human" and "artifactual" (Cobern et al. 1999; Fischer and van der Wal 2007; Siipi 2004). Also, ecojustice values have gained visibility in recent years in the Córdoba province due to socioenvironmental conflicts originated by the expansion of agribusiness and the use of transgenic seeds and agrochemicals (Cáceres 2015). These values, that aim to protect local biodiversity, native gene pools, and traditional agriculture (Fitting 2006; Mueller 2009), may have influenced students' background knowledge and teachers' decisions to teach biodiversity. However, the students' notion that cultures are contrary to biodiversity could translate in the undervaluation of agrobiodiversity, i.e., the variety and variability of organisms at the genetic and other levels, which are necessary to sustain key functions of agroecosystems (https://www.cbd.int/agro/whatis.shtml).

In several scenarios, a number of students focused on the presence of "*trees*" or shrubs, as providers of shelter to animals, also arguing in favor of "*big*" plants. One reason for students' conceptual understanding could be that trees are usually introduced in textbooks and science lessons as *the* principal organisms, sustaining ecological processes and providing ecosystem goods and services (Hadzigeorgiou et al. 2011). Another, not mutually exclusive, reason could be that students had utilitarian, esthetic, or economic rather than ecological frameworks when thinking about the conservation of biodiversity (Grace and Ratcliffe 2002). This was reflected in students' references to the roles and benefits of "*trees*" (e.g., release of oxygen for humans, better than a cactus, for logging) (Palmer 1997).

The idea of "balance" in nature is a long-lasting assumption which is well established in popular knowledge, but has strongly been criticized within the scientific community (Ergazaki and Ampatzidis 2012 and references therein). This notion implies a predetermined order and stability, attributed to either nature itself or a divine force. In the current study, the "*balance*" framework was found to refer to the equity of the "*species distribution*" among habitats,

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species evenness and, mainly, "*trophic chains.*" Although most of the students decided not to protect the environment with the most even distribution among habitats (scenario 5), alpha diversity gains importance in an evolutionary context and a multiscale spatial ecology (Enquist et al. 2001). Then, students' disregard of the potentially interacting species within a local habitat might impede them to recognize and value species evenness and changes in species number and composition in face of global environmental drives (e.g., climate change, agricultural frontier).

In agreement with Fischer and Young (2007), *species evenness* was also associated with the framework of "*balance*" (e.g., "*balanced*" and "*proportioned*" ecosystems, scenario 7). However, most students did not evaluate the dominance of a single species as negative, since they favored species richness. The dominance of species, both through their number of individuals or biomass, influences ecosystem structure and processes most (Chapin III et al. 2002; Grime 1998), and then, more importantly, some key ecosystem benefits, such as those relating to the regulation of carbon and water cycling, trophic transfer, and climate regulation (see detailed discussions in Díaz et al. 2007). In addition, species evenness influences the temporal and spatial stability of a community in terms of its condition of being invasible (Hillebrand et al. 2008), which is of utmost importance in the context of biodiversity loss in Córdoba province (Mason et al. 2005).

Previous studies have found that food webs are part of the public's conception of biodiversity (Dor-Haim et al. 2011; Fischer and Young 2007; Lin and Hu 2003). In the current study, most students interpreted species interactions as "*trophic chains*" (scenario 9), which is a related term also used by the scientific community (Wernecke et al. 2018). However, few students decided to protect the environment with a richer and more interconnected chain. They possibly understood the importance of multiple species interactions for ecosystem functioning. Loss of higher consumers, for instance, can cascade through a food web to reduce plant biomass and to alter vegetation structure, fire frequency, and even disease epidemics in a range of ecosystems (Cardinale et al. 2012; Vázquez and Simberloff 2003). Students' framework that a "*balanced*," "*complete*," or "*long*" "*trophic chain*" may help species to avoid "*extinction*" or to overpopulate is in accordance with previous studies in which students interpreted food webs in the context of ecosystem disturbances (Ergazaki and Ampatzidis 2012; Fischer and Young 2007; Palmer 1997). As a consequence, a "*plantation*" or monoculture-like scenario was seen by students as an example of human-driven disturbances that may interrupt such ecosystem "*balance.*"

Our additive scenario approach revealed students' restricted conceptual understanding of biodiversity since few components were integrated to the conceptualization of biodiversity ("master" level). In addition, students' conceptual frameworks of the components of biodiversity were not related to school location or sex, which is in line with Prokop et al. (2008), who also found no relationship between gender and conservation decisions. However, we found that the class itself was highly significant in the model (Bermudez et al. 2018; Cervini 2006, 2009). Differences between classes could be explained by different sociocultural backgrounds of students (independent of an urban or rural school location) or by different teachers and their approaches to biodiversity education (e.g., the meaning of biodiversity).

In a novel approach, the present study investigated students' conceptual understanding of the components of biodiversity. However, caution should be exercised in generalizing its results. The sample of students was small and restricted to only one province in one country, and it was also not possible to control for teachers' approaches to biodiversity education. Moreover, we used a single method to investigate students' conceptual understanding of

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biodiversity, consisting of formal questions asked in a traditional classroom context. This is likely to lead to a predominance of answers reflecting contextual and manifold frameworks of biodiversity. We acknowledge that a combined methodology, for example with in-depth interviews, would have resulted in a deeper interpretation of students' frameworks (idiographic study).

In light of the present findings, we recommend that teachers in the upper secondary level use students' frameworks as starting points to conceptualize more up-to-date biodiversity definitions than the traditional concept stated by CBD (1992) as an attempt to deal with students' centrism in species richness. A better understanding of alpha diversity, for instance, would help students to realize the impact of habitat fragmentation and homogenization on ecosystem functioning and, thus, ecosystem services (Cáceres 2015; Conti et al. 2016; Seidler and Bawa 2013). In the present case, deforestation of the Chaco forest due to soy bean cultivation would make an excellent starting point to illustrate and discuss the significance of alpha diversity. Related to this, the discussion could further tackle the socioenvironmental conflicts that are caused by the expansion of agribusiness in the Córdoba region (see Cáceres 2015) as part of an education for sustainability. Likewise, a better understanding of functional divergence would improve students' understanding of ecosystem functioning. High functional divergence, expressed by a wide range in functional traits, suggests an efficient and varied use of resources in a biotic community, which translates into increased ecosystem functioning (Díaz et al. 2006; Mason et al. 2005). Moreover, the functional composition of plants (here structural diversity and architecture dissimilarity) modifies albedo, heat absorption, and air mechanical turbulence, thus changing local air temperature and circulation patterns (Díaz et al. 2006). In addition, plant canopy size and architecture can also influence the provision of shelter and habitat to different species, thus also influencing species richness (de Bello et al. 2010).

The relationship between invasive species and food webs could be another starting point to help students understand more components of the concept of biodiversity. By building on a local issue (e.g., the spread of *G. triacanthos*, *L. lucidum*, and *P. elliottii*), the importance of evenness for biodiversity conservation could be explained. Also, as many invasive plant species in Cordoba are trees, students' exclusive conceptions of trees as beneficial for biodiversity could be challenged. In addition, species diversity indices are one of the most frequent measures of biodiversity, since they give more information on community functioning than the number of species itself. Species diversity indices relate species number to the relative abundance of each species (e.g., Shannon-Wiener index), and thus, students' understanding of species evenness may help them to make decisions regarding biodiversity conservation and environmental issues. Moreover, the notion of balance of nature could be tackled, as it is not representative of the natural systems in many ecological interpretations (Ergazaki and Ampatzidis 2012 and references therein).

By integrating students' frameworks with up-to-date biodiversity conceptualizations in upper secondary education, students become empowered to decide on socioscientific issues, including biodiversity management and sustainable development (United Nations 2015). However, as a requirement, teachers need suitable teaching material and a curriculum which update the original definition of biodiversity (CBD 1992). Preservice and in-service teacher education could also be a way of bringing the wider concept of biodiversity into formal education. However, teachers need an understanding of students' alternate and conceptual frameworks of biodiversity in order to develop biology lessons that stimulate students to revise and extend their knowledge toward target conceptualizations.

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