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Brazilian teachers' views and experiences regarding teaching biodiversity in an evolutionary and phylogenetic approach

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Abstract

Background The centrality of evolution to the biological sciences is recognized by many authors. Given the importance of evolution to biology, we intend to understand if, and how, science and biology teachers teach about biodiversity from an evolutionary perspective. In the first part of the research (Study 1), teachers from all geographic regions of Brazil (n = 147) answered a questionnaire containing both open-ended and Likert scale items in order to compare biodiversity-related contents to evolution. Considering the results obtained, a second study sought to analyze what challenges and possibilities Brazilian teachers who were enrolled in a continuing professional development course find in their classroom practices and the teaching materials they use when approaching cladograms while teaching about the diversity of organisms, as well as the experiences they had with cladograms during their education. These teachers responded to open-ended questionnaires concerning their experiences when learning and teaching about cladograms.

Results Findings in Study 1 revealed that the concepts with the least emphasis among teachers were those related to macroevolution and phylogenetics. We found in Study 2 that teachers recognize cladograms as an important biological representation. In general, they approach it in biology and science classes, but often not relating it to topics concerning biodiversity. Teachers reported using multiple resources for teaching about cladograms, but textbooks were the most used teaching material. However, teachers reported that textbooks do not approach the theme sufficiently enough and mentioned it as a challenge. They also reported learning about phylogenetic content during teacher education but did not discuss aspects regarding teaching about cladograms.

Conclusions These findings suggest that it is important that teacher education courses and new teaching materials consider the importance of cladograms and the specificities of phylogenetics within the teaching context.

Keywords Tree thinking, Biology education, Cladograms, Phylogenetic trees, Biodiversity, Evolution education

Introduction

The centrality of evolution to all biological sciences is recognized by many authors. This notion is summarized within the well-known essay of Theodosius Dobzhansky (1973): "Nothing in biology makes sense except in the light of evolution". Therefore, the theory of evolution is considered central in science education curricula and standards in many countries, such as the United States, Germany, and Brazil[1], among others (e.g., German

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National Academy of Sciences 2017; Ministério da Educação 2006).

Although the centrality of evolution is consolidated within the scientific community, and even in the science education curricula and standards in many countries, several studies have indicated that evolution is commonly presented as one discrete topic among many others in the biology curricula (Araújo 2022; Bizzo and El-Hani 2009; Hanisch and Eirdosh 2020; Price and Perez 2016). Evolution is often covered in only a few class sessions of secondary education and does not play a central role in many higher education programs (Alters and Nelson 2002). There are also studies showing that not all subjects in evolution are covered (see, for example, Kuschmierz et al. 2020; Sanders and Makotsa 2016; Vázquez-Ben and Bugallo-Rodríguez 2018).

Given this situation, there are a number of proposals to encourage the evolution education community into a deeper discussion towards a more pluralistic (Araújo 2020), interdisciplinary (Hanisch and Eirdosh 2020), and wider treatment of evolution across grade levels in general education (Wilson 2005). This would include efforts to expand beyond the biological domain into the human sciences (Geher et al. 2019). However, as far as we know, there are still only a few concrete proposals that have been constructed in order to implement the centrality of evolution across biology as a whole. Some proposals in this regard are offered by Araújo (2022), Hanisch and Eirdosh (2020), and Geher et al. (2019). Such attempts to expand the evolutionary theory to different domains of knowledge must be accompanied by studies on the reality of teachers (in terms of initial and in-service teacher education in evolution), curricular goals, teaching materials available, teaching–learning process, and assessment, among other demands and specificities of teaching work.

The teacher is the most important factor in student learning (Bravo and Cofré 2016; Abell 2007). Therefore, to promote the centrality of evolution in biology teaching, we must know the concepts and practices of these professionals. Considering the importance of teaching education programs, authors suggest that they must include scientific knowledge about evolution and the Nature of Science (NOS) (Tekkaya et al. 2012; Nehm and Kampourakis 2022). Despite its importance, teachers have difficulties in teaching evolution, especially when they are still developing their knowledge and pedagogical content knowledge related to evolution in preservice education (Borgerding et al. 2015). Regarding these aspects, researchers conclude that teachers' understanding of evolution and NOS influences their acceptance of scientific knowledge about evolution and their beliefs regarding the topic (Tekkaya et al. 2012). In addition, studies identified that teachers' rejection of evolution, their resistance to addressing the topic, and their concerns regarding religion are challenges in teaching the subject (Borgerding et al. 2015). Two difficulties for religious teachers are to conciliate the theory of evolution and the story of creation to explain: the randomness of the process, while they believe that the diversity of life is a God's creation; and the idea that Man is just one of the products of the evolution and not the most important creature (Dodick et al. 2010).

Pedagogical Content Knowledge (PCK) is a tool for studying certain aspects of teacher knowledge. Shulman (1987, p. 8) introduced this concept as "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction". However, Van Dijk (2009) observed that there is a lack of studies on science teachers' PCK concerning evolutionary theory. Moreover, to better teach evolution, some aspects are relevant such as understanding students' biases and misconceptions, knowing pedagogical practices, being able to use good examples in classes, comprehending how to connect the curricula with students' interests, and knowing how to assess the learning of students regarding the topic. It is also essential to understand that the theme has specific terms, which may be difficult for students who use words that differ from everyday meanings (Nehm and Kampourakis 2022).

Previous studies in which teachers were asked to report the topics they teach during evolution instruction reveal an emphasis on natural selection, evidence for evolution, and genetic mutations (Sickel and Friedrichsen 2013; Schulteis 2010; van Dijk 2009). The same studies show a deficit in the teaching of topics such as human evolution, speciation, and macroevolution. Researchers also identified that teachers show difficulties in integrating specific knowledge regarding the classification of living things with pedagogical knowledge (Putri et al. 2020). Teachers can improve their understanding of teaching evolution by, for example, recognizing the importance of a phylogenetic approach in which it is possible to address students' alternative conceptions regarding linearity (Bravo and Cofré 2016).

Given the importance of evolution to biology, we intend to understand if, and how, science and biology teachers teach about biodiversity from an evolutionary perspective. This article presents two studies examining biodiversity-related contents to evolution within teachers, with the main objective of understanding the challenges and possibilities that teachers face in teaching biodiversity from an evolutionary perspective. This topic was chosen both for its relevance and for being one of the most obvious when it comes to the importance of evolutionary thinking in biology. The definition of biodiversity that we considered includes different levels, such as the genetic level (the diversity of information present in the organisms' genetic material), the taxonomic level (diversity of species, genres, families, and other taxonomic groups) and the ecosystemic level (the diversity of ecosystems) (Wilson 2012; Lévêque 1999).

Attitudes concerning nature can be transformed through people's education and empowerment (Ehrlich and Pringle 2008; Schneiderhan-Opel and Bogner 2020). In this sense, it is considered important to expand students' knowledge about the diversity of organisms on our planet, through what is called biodiversity education (Ballouard et al. 2012; Barrico and Castro 2016; Schneiderhan-Opel and Bogner 2020; Ehrlich and Pringle 2008; Gayford 2000; Schneiderhan-Opel and). Proposals for biodiversity education are based on the idea that it is important to improve biodiversity knowledge, and the school has a significant role in this process of learning (Ballouard et al. 2012; Gayford 2000; Oliveira et al. 2020). Enhancing people's knowledge of biodiversity may influence their concerns regarding its preservation, promoting individual actions to reduce the impacts, such as conscious and sustainable consumer behavior (Barrico and Castro 2016; Buijs et al. 2008; Hunter and Brehm 2003; Schneiderhan-Opel and Bogner 2020).

Researchers studying evolution have always had something to say about the origins of biodiversity, which is also a major theme within Darwin's writings. He extensively discussed specific issues and foundational questions about biodiversity, its origin, patterns, and changes (Benton 2016; Darwin 1859). Darwin (1859) is best known for having presented two processes driving evolution in nature—natural and sexual selection-, as well as in the core of understanding of evolutionary patterns and processes. It is sometimes forgotten that Darwin had important insights about evolution in deep time through studying a significant number of fossil collections and geological formations (Herbert 2005). *On the Origin of Species* only had a single illustration, which was a tree demonstrating how the degree of similarities between a number of varieties and species was explained by descent from common ancestors (Darwin 1859; Gregory 2008). This idea of phylogeny, in a broad sense, has served as a basis on which biologists have attempted to reconstruct the pattern of events that have led to the distribution and diversity of life.

More recently, evolutionary theory has also helped scientists to conserve species. This has been achieved by using the theory of life histories and other characteristics in order to predict which species are most vulnerable to extinction, are vulnerable to the impacts of human activity (such as the consequences of overpopulation), as well as in regard to ground techniques that prevent inbreeding depression and design corridors that allow gene flow, among other strategies that are based on evolutionary knowledge (Futuyma and Meagher 2001).

Evolution is also relevant to understand and solving current issues. For example, the knowledge of evolutionary biology is relevant to solve issues related to human lifestyle and its consequences on human health. Humans dominate evolutionary dynamics on planet Earth, even leading some scientists to name "Anthropocene" this new phase in the history of the Earth characterized by human impact (Jørgensen et al. 2019). Evolution knowledge can also be used to improve agriculture and solve issues such as the impact of climate change and water pollution, and improve clean energy. Additionally, it can also be used to protect biodiversity and build more sustainable societies (Carroll et al. 2014).

All these questions regarding biodiversity, their evolutionary explanations, and related concepts, comprise broad biodiversity topics that students must understand from an evolutionary perspective (Table 1).

Therefore, the goal of this article is to investigate teachers' approach to teaching biodiversity through an evolutionary perspective. The first part of the research (i.e., Study 1) examines how teachers conceptualize evolution and its importance in teaching biodiversity. Findings reveal that the concepts with the least emphasis among teachers are those related to macroevolution and phylogenetics. In Brazil, we often have an issue regarding the fragmentation of contents in biology education (Krasilchik 2016). This issue impacts directly the approach to the diversity of organisms, in which groups of organisms are taught separately, without showing clearly the evolutive relationships among them (Lopes and Vasconcelos 2012, 2014). In this sense, the approach of cladograms is important to show these relationships (O'Hara 1997; Horn 2016; Novick et al. 2011) and may help solve the issue of fragmentation in this topic (Ferreira et al. 2008; Lopes and Vasconcelos 2012, 2014). Therefore, considering the results obtained in Study 1 and to explore in more details teacher's approaches about phylogenetics, Study 2 aimed to understand what challenges and possibilities Brazilian teachers find in their classroom practices and the teaching materials they use when approaching cladograms while teaching about the diversity of organisms, as well as the experiences they had with cladograms during their education.

Method

Subjects, design, and procedure (study 1)

We developed a teacher contact database in the middle of the 2020 coronavirus pandemic. Teachers that had engaged in outreach and research activities that the

Table 1 Major concepts relating to biodiversity topics that students must understand from an evolutionary perspective. This list is not exhaustive, nor does it contain all the nuances of these topics

Evolutionary and Biodiversity topics	Questions	Some related concepts
Origin of biodiversity	How do new species come into being?	Speciation, Fossil records, Macroevolution
	Where do new traits come from?	
Evolutionary patterns	What drives the patterns of diversity that we see across the earth?	Macroevolution, Fossil records, Developmental biology, Biogeography
	Why is life so diverse?	
	Why are there so many species on Earth?	
Evolutionary process	How do different species affect each other's evolution?	Natural selection, Adaptation, Sexual selection, Genetic drift, Speciation
	How do species change over time?	
	How are species often so well adapted to their current environment?	
Systematics, Evolution, and Biodiversity	How closely organisms are related to one another?	Phylogenetics, Common ancestry, Fossil records
	What are the advantages of using evolutionary relationships between organisms to inform biodiversity classification systems?	
Conservation of biodiversity	Why did some species go extinct?	Population genetics, Habitat loss, and fragmentation, Habitat changes, Extinction of species
	How can evolutionary knowledge inform conservation decisions?	

authors of this work participated in the last years were invited to answer a survey anonymously. We sent an email to a national list of 983 elementary and high school science and biology teachers, presenting the research and inviting them to answer a survey anonymously (for more details, see Araújo and Alitto 2021). Approximately 18% of the teachers responded to the invitation message agreeing to participate in the survey, with 15% of the teachers filling out the questionnaire (n = 147 valid cases). Teachers from all geographic regions of Brazil answered the questionnaire, with a greater number of respondents from the south and southeast regions (72%), living in urban areas (69%), females (70%), and teaching in public institutions (57%). Thus, our sample data is not representative of the elementary and high-school biology teacher population in Brazil.

We used a questionnaire containing both open-ended and Likert scale items to compare how teachers approach teaching biodiversity through an evolutionary perspective. We began this process by creating a list of evolutionary topics that are relevant to understanding biodiversity questions, from what is discussed in the literature (e.g., Darwin 1859; Benton 2016; Futuyma and Meagher 2001; Gregory 2008). We discussed disagreements until we reached a consensus to combine the concepts presented in Table 1. However, the listed topics have not been validated by experts in ecology and evolution. Therefore, it cannot be considered an exhaustive list. To assess how teachers conceptualize evolution and its importance in teaching biodiversity, we asked the following question: "Do you think an evolutionary perspective is important in teaching biodiversity? Why?".

The results from the Likert-scale questions were tabulated and analyzed to obtain descriptive statistics. Individual responses to open-ended questions were qualitatively grouped and categorized by the first author and an external research colleague, based on previous categories established (Table 1). Emergent categories unforeseen in the broader scheme of classification were established inductively as the analysis progressed. Therefore, we used procedures for the analysis of qualitative data, with *organization*, *immersion in the data*, *categorization*, and *codification* (Marshall and Rossman 2014). Categories were established by two researchers, who analyzed simultaneously the data. Through the procedure of multiple coding, different researchers engage in an independent analysis of the data, followed by a subsequent comparison of their findings (Patton 1999). During the comparison, the researchers engage in discussions regarding the differences, similarities, and patterns observed in their analysis (Sweeney et al. 2013). The utilization of multiple researchers in data analysis enables the provision of alternative interpretations (Barbour 2001), while simultaneously addressing concerns regarding the potential influence of researchers on the analytical process (Berends and Johnston 2005).

The responses to the open-ended question provide a further understanding of how teachers conceptualize evolution and its importance in teaching biodiversity. Furthermore, open-ended questions allow answers in as much detail, complex description, and explanation that may be required in any given situated context. During the encoding and data analysis, we considered previous and emergent categories. The emergent categories were obtained by the recurrence of similar answers offered by respondents from an inductive approach. They were also recurrent in the units selected for analysis, as well as in other information existing in the scientific literature.

Subjects, design, and procedure (study 2)

It is important to develop a tree thinking, by understanding that the organisms are interconnected as a part of a tree that represents evolutionary relationships among them (O'Hara 1997). Therefore, the second investigation aimed to understand what challenges and possibilities Brazilian teachers find in their classroom practices and the teaching materials they use when approaching cladograms while teaching about the diversity of organisms, as well as the experiences they had with cladograms during their education. Although biodiversity education comprises many aspects, such as environmental issues, ecology, and genetics, here we consider the use of cladograms in classes concerning the diversity of organisms (i. e. zoology, botany, microbiology, mycology, etc.), which here we call biodiversity classes, classes in which the characteristics of the groups of organisms are described. This study was conducted with teachers that participated in a teacher's continuing professional development course about biodiversity and evolution education, which, in turn, was focused on tree-thinking. Teachers who participated in Study 2 were different from the teachers in Study 1.

Thus, in order to make it possible to understand teachers' experiences, a qualitative approach was chosen; as such, it was not necessary to obtain a large sample size (Creswell 2012; Lankshear and Knobel 2004). The sampling criteria chosen were the purposeful sampling criteria (Patton 1990), in which cases that are rich in information are chosen such that they can contribute to the research goals.

The continuous professional development course occurred in 2021, during the COVID-19 pandemic. In total, 120 teachers, from all Brazilian regions, participated in the course and were divided into two groups. One group of 50 teachers and another of 70 teachers. The course was delivered fully remotely, through online activities. Each group participated in a 7-week course that included asynchronous activities, such as the construction of didactical plans about biodiversity and evolution, as well as responses to questionnaires. They also participated in synchronous activities, which consisted of 4 h online meetings in which teachers participated in discussions, answered questionnaires, and engaged in other activities regarding biodiversity and evolution education. Among the themes addressed during the course, one of them was the approach to biodiversity considering an evolutionary and phylogenetic perspective.

Although 120 teachers participated in the course, not all of them stayed until the end of it. The activities analyzed in this investigation were applied approximately after the 3rd week of the course, at different moments. Additionally, not every teacher participant in the course participated in all the proposed activities. Therefore, the number of responses varies depending on the activity.

One of the reported themes that teachers present more difficulties when teaching about evolution is the cladograms, which are often one of the least taught themes (Friedrichsen et al. 2016). Therefore, considering the similar results presented by Study 1, we chose to focus on asking general aspects regarding the use of cladograms in the classroom. Thus, during the course, teachers answered online questionnaires, answering questions such as if they used cladograms in the classroom, what challenges and possibilities they found while working with this representation if they had contact with this theme during their teacher education, and what were the topics during the course in which they had difficulties or that were new to them.

Initially, we investigated if teachers used cladograms in the classroom. Then, considering the importance of cladograms to biodiversity education, the further questions approached in our research were focused on the use of cladograms to teach about organisms (Table 2).

Since one of the main challenges reported by the literature is the conceptual understanding of cladograms (e.g., Halverson 2011; Kummer et al. 2016; Peñaloza and Robles-Piñeros 2016) and it was also reported by the teachers in this research, we also investigated the main difficulties reported by them during the course. Brazilian literature indicates that cladograms are often a theme that is little approached in teacher education (Santana 2019; Lopes and Vasconcelos 2014), thus, we also investigated their main conceptual difficulties and if they already learned this topic in their pre-service or in-service teacher education. Therefore, we also aimed to understand the aspects described in Table 3.

The questions posed to the teachers in Study 2 were also asked during an interview with one pilot teacher who participated in an interview, about the use of cladograms to teach about biodiversity. Only the question regarding the doubts and new concepts was not approached in these interviews, since it was specific to the course context. Pilot studies are important to test and refine aspects of the investigation. Through a pilot study, it is possible to understand aspects regarding the time necessary to collect or analyze the data and to refine the

Table 2 Topics and questions about the classroom practices of Science and Biology teachers regarding the use of cladograms in the classroom

Topic	Description	Question asked
Cladogram approach in Science and Biology Classes	If the teacher reported using cladograms in any Science or Biology class	Do you usually use this kind of representation in the classroom? In which grades?
Cladogram approach in Biodiversity Classes	If the teacher reported using cladograms specifically in classes in which the characteristics of the groups of organisms are described	Specifically in biodiversity classes, do you usually use this kind of representation?
The possibilities for cladogram use in the classroom	Possibilities reported by the teachers regarding the use of cladograms in the classroom to teach about organisms	What are the main possibilities that you find in your classroom practices when using cladograms in biodiversity education?
Teaching materials used in the classroom that contains cladograms	What teaching materials they reported using in the classroom when teaching with the use of cladograms to teach about organisms	What teaching materials used by you in the classroom contain this kind of representation for biodiversity education?
Challenges in cladogram use in the classroom	Challenges reported by the teachers regarding the use of cladograms in the classroom to teach about organisms	What are the main challenges that you find in your classroom practices when using cladograms in biodiversity education

Table 3 Topics and questions regarding Science and Biology teachers' difficulties regarding cladograms and their experiences on teacher education about the theme

Topic	Description	Question asked
Doubts and/or new concepts for teachers during the course	Doubts or concepts that the teachers considered as new to them reported by the teachers during the course	There were was any concept that was approached during the meeting that you did not know or that you have some difficulty with? If yes, what concept?
Topics regarding cladograms in teacher education	The presence or absence of topics regarding cladograms during teacher education reported by the teachers	During your teacher education (preservice or in-service), did you learn about cladograms?
Topics regarding teaching about cladograms in teacher education	The presence or absence of topics regarding teaching about cladograms during teacher education reported by the teachers	During your teacher education (preservice or in-service), did you discuss topics regarding Science/Biology education using cladograms?"

questions of an interview (Yin 2011). In the pilot interview, the teacher could understand the questions in the same way that the researchers did. Questionnaires were validated within the research group before their application, being revised by doctorate students, researchers, and other members of the group, through a peer review process (also known as peer debriefing) (Lincoln and Guba 1985). Study 2 included two groups of teachers, who participated in both synchronous and asynchronous activities. The synchronous activities answered by teachers included discussions about the activities, such as the questions included in this paper. Therefore, we could understand their perception of the questions, which were the same as ours.

The teachers' answers were organized in electronic sheets and analyzed using procedures proposed for the treatment and analysis of qualitative data (Marshall and Rossman 2014), including *organization of data*, *immersion of data* (by reading the content multiple times), the *definition of the categories*, and the *codification of the categories*. In order to achieve this, we utilized certain elements of content analysis, as proposed by Bardin (2016), which consists of techniques that allow the analysis of the textual content.

Initially, we did a pre-analysis of the data, with floating readings that allowed us to understand the data, and have the first impressions about it. Then, after reading the data a few times, we began the process of separating the data into units of analysis, which are the register units and the context units (Bardin 2016). After that, we separated the segments of teachers' answers that would be categorized, the register units, as described by Bardin (2016). Register units were defined in consideration with the semantic criteria, i.e., considering the meaning of the answers given by teachers. Those segments corresponded with parts of the answers, as words or sentences that were related to the questions that were asked. Therefore, we searched for parts that were related to the themes: use of cladograms in the classroom, possibilities, challenges and teaching material they use, doubts/new concepts, and if they had already learned about the theme. We also separated the fragments that would help to understand the meaning of the register units, which Bardin (2016) calls context units. In this case, the context units were defined considering the question and the totality of the answers, thereby allowing the understanding of the register units. After the process of defining the register and context units, the register units were then grouped. This grouping occurred considering initially the main themes of this research, described above. Then, inside the themes, we did another grouping, according to their similarities. This second grouping emerged from the data, considering the main answers given by teachers and, through an inductive process, provided an origin to the categories that were used. Categories were counted by frequency, when the question admitted more than one answer by the participant, or by occurrence when the question admitted only one answer by the participant. The categories were also validated within the research group, which revised the description and examples of each category through a peer review (also known as peer debriefing).

In this process, the researcher exposes themselves to a disinterested pair, to discuss aspects of their investigation (Lincoln and Guba 1985). A disinterested peer refers to an individual who lacks a direct stake in the project's outcome but has expertise in the subject matter (Hail et al. 2011) and familiarity with the research or phenomenon under investigation (Cresswell and Miller 2000). Through engaging with the peer and addressing their inquiries, researchers can engage in a reflective process that examines potential biases impacting the formulation of research questions, methodological design, and interpretation of findings (Amin et al. 2020). This process is important to ensure credibility in qualitative research (Lincoln and Guba 1985), and there is no unique way to develop a peer review process (Janesick 2015).

In our research, peer review was employed during the research design and the validation process of the categories. Since this study involved collaboration between researchers from two different research groups, the peer review process was conducted separately, followed by a subsequent discussion between the first and second authors. The peer group for Study 2 consisted of the second and third authors of this paper, along with other members of the research group GPEnCiBio (Research Group in Science and Biology Education—Grupo de Pesquisa em Ensino de Ciências e Biologia, in Portuguese). At the time of the category validation process, the research group comprised, besides the author of this paper, three doctoral students, five master's students, and two undergraduate research students, all actively involved in various Science and Biology education projects, and possessing familiarity with qualitative research. Besides the second and third authors, none of the members of the group were involved in this research project. Monthly meetings were held in which the members presented their data instruments or previous results for validation. The research design, along with all the categories presented in the second study, was validated through the peer review process involving the research group. Consequently, the second author presented and explained the categories to the research group, providing examples for each category. The group then posed questions regarding the categories. In this process, they suggested improvements, evaluated the clarity of the category definitions and the relevance of the presented examples, as well as identified redundancy among categories, and proposed any other changes to the categories. The research was approved by the Research Ethics Committee of the University and all participants provided their informed consent.

Results

Teacher's approach to evolution and its importance in teaching biodiversity (study 1)

According to the data about the emphasis on evolution and biodiversity topics, most of the respondents tend to place less emphasis on macro-scale concepts, such as biogeography, phylogeny, and macroevolution (Fig. 1). The majority of teachers 'often' or 'always' emphasized concepts regarding adaptive evolution (natural selection and adaptation), as well as those related to conservation (extinction and habitat loss). On the other hand, it is surprising that the concepts related to the conservation of biodiversity and evolution are among the most emphasized by teachers. However, we should be careful with conclusions in this regard, due to the fact that an important conceptual piece for the relevance of evolutionary theory in conservation is population genetics, which is one of the topics that is least emphasized by teachers (Fig. 1). The responses to the open-ended questions provide a further understanding of how teachers conceptualize evolution and its importance in teaching biodiversity (Table 4).

All teachers considered that the evolutionary perspective is important in teaching biodiversity (100%), but the justifications for the importance vary between them. Some of the categories overlapped. Therefore, we ranked each answer according to the greater amount of importance it attaches to evolutionary thinking, in relation

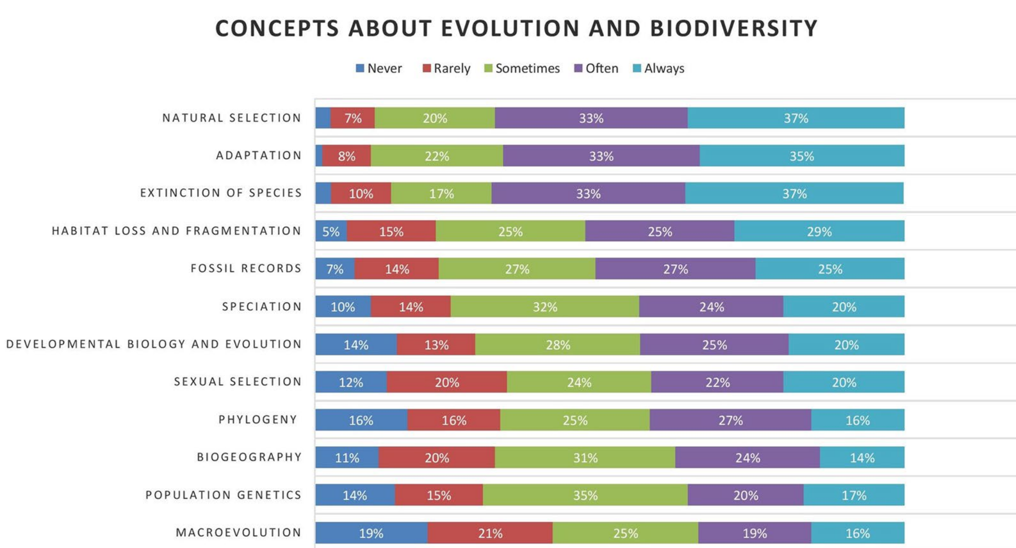

Fig. 1 Brazilian teachers indicated how often they taught about biodiversity-related content in relation to evolution. The x-axis represents the frequencies of the participants' (n = 147) answers to a five-point Likert scale for each topic

Table 4 Categories of teachers' conceptions of the reasons that justify the importance of evolution to the study of biodiversity, including a brief description of each category and two key examples from the responses

Answers expressed when teachers were asked: "Do you think an evolutionary perspective is important in teaching biodiversity? Why?"

Categories	Description	Key examples	Teachers (%)
Self-explanatory/Unjustified	The importance of evolution to biodiversity is evident and without the need for further instruction or information	"It's not possible to speak of life and its diversity without understanding evolution" "The understanding of diversity is closely linked to evolution. It's almost impossible to talk about biodiversity without mentioning evolution"	43 (29.2%)
Evolutionary processes/patterns	Evolutionary processes manifested in patterns that can be observed in biodiversity	"Certainly, evolution is constant and so are changes and adaptations in environments" "Yes, because through it [evolution] we have a greater understanding of the factors that shape and maintain diversity"	28 (19%)
Epistemic	The knowledge regarding biodiversity is based on evolution	"[…] evolution guides all biological areas, especially when talking about biodiversity, is of paramount importance to understand biological processes" "Yes, because the knowledge of Biology is all based on evolution"	20 (13.6%)
Meaning/ Value Biodiversity	Evolutionary perspective allows students to find meaning and value in biodiversity	"Through evolutionary perspective on the teaching of biodiversity there is an awakening to the beauty and at the same time to the fragility of ecosystems, as well as to their importance for the maintenance of the planet" "[…] In addition to importance as knowledge, evolution teaches students to value the existence of living beings"	19 (12.9%)
Conservation of biodiversity	Evolution is crucial to understand species better and it would help for conservation action plans	"Yes, only by knowing the evolution of species can we devise strategies for more effective preservation" "Evolution allows the student to understand the effects of human action on species diversity and how this action, in particular climate change, can limit human survival and ecosystem health"	12 (8.1%)
Learning	Evolution facilitates understanding of biodiversity	"Teaching based on an evolutionary perspective is important, once it facilitates learning, allowing that information becomes connected in a logical and grounded way" "Yes, very important [evolution] because it helps the student to form a clearer understanding of biodiversity, expanding their understanding"	12 (8.1%)
Emergence of new species	Evolutionary process is the mechanism by which a new species comes into being	"Yes, because to know better the current species we need to know about the ancestral species" "Yes, because it makes the student understand more easily the history of animals and how the emergence of different groups happened"	8 (5.4%)
Phylogenetics	Evolution provides a system of classification that names groups of organisms according to their evolutionary history	"The evolutionary approach can rely on the identification and classification of new plant species, then, it is indeed important to study from this perspective, in the search for more dynamic and practical studies within a regional context" "[…] because it focuses on knowledge about biodiversity—and sociodiversity—without giving up phylogenetic hypotheses in proposing models for classifying living beings"	5 (3.4%)
Total			147 (100%)

n = total of respondent teachers to the question; teachers = number of occurrences in the category; % = percentage of responses in the category to teaching biodiversity. Interestingly, four categories emerged, three of which were among the most frequent among teachers (Self-explanatory/Unjustified, Epistemic, Meaning/Value Biodiversity, Learning; see Table 4).

Categories such as the importance of evolution for learning and the conception that evolution is the basis for knowledge about biodiversity (we thus named it "epistemic") are specific to the teaching context (Table 4). It is also interesting to note how the category "meaning", despite being close to the conservation category, is not to be confused with the latter. This is because it is not about the importance of evolutionary knowledge to support conservation strategies (as conservationists would do) but is instead regarding the importance of evolutionary thinking to the value and the provision of meaning to biodiversity. In this category, we found answers from teachers who considered evolutionary knowledge important as a strategy to bring students closer to environmental issues.

Many answers attribute importance to evolution for the teaching of biodiversity but do not give reasons for this, indicating a circular or unjustified answer. The category with the least emphasis among teachers was the importance of evolution to phylogenetics. Macroevolution and phylogenetics were poorly considered by teachers both in the data expressed in Fig. 1 and in Table 4.

Challenges and possibilities regarding teachers' approaches about cladograms in biodiversity education (Study 2)

Most of the participant teachers (86.3%) answered that they use cladograms in the classroom. However, although they reported its use in their teaching practices, this use may be limited; this is due to the fact that some teachers answered that cladograms are presented only in certain school years, or even only in a few topics. Nevertheless, when they were asked about if they used this representation within biodiversity classes, the number of teachers that reported not using cladograms was more than double (33.8%) of the teachers that reported not using cladograms in Biology or Science classes, in general (13.7%). The reasons given by them for not using this representation in biodiversity education may be explained by many aspects: for example, the teacher did not recognize it as a possibility (Table 5).

Teachers also answered questions to detail their approaches regarding cladograms in the classroom. Thus, they reported what possibilities and challenges they find in their practices when teaching about cladograms and what teaching materials they use that contain cladograms (Table 6).

In regard to the possibilities of the use of cladograms in Science and Biology classrooms, most teachers

Table 5 Use of cladograms in Biology and Science classes

Use of cladogram in Science/Biology classes (n = 73)
(Answers expressed when teachers were asked: "Do you usually use this kind of representation in the classroom? In which grades?")

Categories	Description	Key examples	Teachers (%)
Use in general classes	Teacher reported using cladograms in Science/Biology classes	"Yes, but only in 12th grade"	63 (86.3%)
Does not use in general classes	Teacher reported not using cladograms in Science/Biology classes	"No. I should use it with 9th graders"	10 (13.7%)
Total			73 (100%)

Use of cladograms regarding biodiversity education (n = 71)
(Answers expressed when teachers were asked: "Specifically on biodiversity classes, do you usually use this kind of representation?")

Categories	Description	Key example	Teachers (%)
Use in classes about biodiversity	Teacher reported using cladograms in classes about biodiversity	"Yes. I am used to initially bringing many images of organisms and asking students to group them, not necessarily by ancestry, but by morphological similarities in the beginning. After that, I work with the content about organisms' classification, the importance of classification to study them and, then, I try to approach cladograms. This also happens in 7th grade"	47 (66.2%)
Does not use in classes about biodiversity	Teacher reported not using cladograms in classes about biodiversity	"I do not use the representation. Even a simple tree of life… I really do not use it; I did not realize how important it is"	24 (33.8%)
Total			71 (100%)

n = total of respondent teachers to the question; teachers = number of occurrences in the category; % = percentage of responses in the category

Table 6 Possibilities for the use of cladograms

Possibilities for the use of cladograms (n = 48)
(Answers expressed when teachers were asked: "What are the main possibilities that you find in your classroom practices when using cladograms in biodiversity education?")

Categories	Description	Key example	Teachers (%)
To visualize the kinship among organisms	Teacher reports that cladograms make it possible to see the ancestry relationships among organisms	"To approach the biodiversity in an evolutionary perspective using cladograms makes it possible to show how evolution "organized" life on the planet and what are the impacts of environmental changes on biodiversity"	30 (49.2%)
To connect different themes related to biodiversity education	Teacher reports that cladograms make it possible to connect themes about biodiversity education, such as evolution, ecology, among others	"Working with cladograms on biodiversity education makes it possible for me to make connections with ecology, evolution, genetics, philosophy, history, anthropology, and sociology. Cladograms graphically represent the evolutionary history and how that history directly affects the relationships of organisms with the environment. It allows me to build bridges with transversal themes"	11 (18.0%)
To use playful/practical activities	Teacher reports that using playful or practical activities is a possibility to teach about cladograms	"This week I brought into the classroom plants, moss, plants with flowers, strobilus, and leaves of ferns. I also brought scissors, tape, paper, and pens. I had already explained the content in a previous class, and I proposed a cladogram construction activity. Students made it on the classroom floor and had contact with plant species, which facilitated their understanding. It was really cool!!!"	10 (16.4%)
To use activities of cladogram construction	Teacher reports that using activities of cladogram construction is a possibility to teach about cladograms (but not specifying any playful or practical activity)	"I see as a possibility an activity in which students can build a cladogram, demonstrating the degree of kinship among some species and, thus, working at the same time evolution and biodiversity"	4 (6.6%)
To use small cladograms	Teacher reports that, when teaching about cladograms, prefers to use small cladograms, with only some groups of organisms	"I used something really simple, just to demonstrate the evolution from bryophytes to angiosperms"	3 (4.9%)
To use supplementary material	Teacher reports bringing supplementary materials to teach about cladograms	" To explain it through images, videos[…]"	3 (4.9%)
Total			61 (100%)

Teaching materials used in the classroom that contains cladograms
(Answers expressed when teachers were asked: "What teaching materials used by you in classroom contains this kind of representation for biodiversity education?")

Categories	Description	Key example	Teachers (%)
Textbooks	Textbooks are the teaching material that contains cladograms and teacher uses in the classroom	"In the 9th-grade textbook"	40 (32.6%)
Slide Presentations	Slides presentations are the teaching material that contains cladograms and the teacher uses them in the classroom	"Usually lectures, with slides presentations made by the teacher"	23 (18.7%)
Other printed materials	Printed materials such as workbooks are the teaching material that contains cladograms and teacher uses in the classroom	"[…] I also bring printed activities for students to build their own cladograms"	22 (17.9)
Internet teaching materials	Teaching materials from the internet are the teaching material that contains cladograms and teacher uses in the classroom	"Through […] internet research"	10 (8.1%)

Table 6 (continued)

Teaching materials used in the classroom that contains cladograms
(Answers expressed when teachers were asked: "What teaching materials used by you in classroom contains this kind of representation for biodiversity education?")

Categories	Description	Key example	Teachers (%)
Videos/other media	Videos are the teaching material that contains cladograms and teacher uses in the classroom	"Not always the textbooks present the image. It is more common to see the linear representation, thus, I bring it in supplementary materials and videos"	10 (8.1%)
Teaching materials made by the teacher	Teacher builds teaching materials with cladograms to use in the classroom	"In my construction of teaching materials"	10 (8.1%)
Blackboard	Teacher uses the blackboard to teach about cladograms	"[…] I draw the image on the blackboard"	8 (6.5%)
Total			123 (100%)

Challenges in cladogram use in the classroom. (n = 55)
(Answers expressed when teachers were asked: "What are the main challenges that you find in your classroom practices when using cladograms in biodiversity education?")

Categories	Description	Key example	Teachers (%)
Teacher's conceptual challenges about the theme	Teacher reports having challenges in understanding the concepts about systematics	"I still did not approach cladograms in my science classes, but I am thinking about using it. I believe I will have many challenges because I need to be well-prepared to do it. Studying more about this topic and looking for an efficient approach"	18 (28.1%)
Students' difficulty in understanding about the theme	Teacher reports that students usually have challenges in understanding the concepts about systematics	"The few times that I used this resource (cladograms), students presented interpretation challenges"	16 (25%)
*Students' alternative conceptions	Teacher reports that students usually have challenges in understanding the concepts about systematics due to alternative conceptions	"Knowing students' conceptions about evolution and about its main terms and analyzing the influence of external factors, such as religion, culture, among others, in their conceptions"	12 (18.8%)
Insufficient/incorrect approach by the textbooks	Teacher reports that textbooks usually do not approach enough the theme or that it contains incorrect information	"I always bring supplementary materials, because in textbooks the most present model is the linear model of evolution"	11 (17.2)
Insufficient approach by the curriculum	Teacher reports that curriculum usually does not approach enough the theme	"Time of class and the "short" curriculum"	5 (7.8%)
Insufficient approach in previous grades	Teacher reports that since the theme is not present in previous grades, it is harder to work with the theme with students	"Unfortunately, the majority of teachers do not usually approach the theme in initial grades. Therefore, when these students come in final grades of Basic Education (my field of work), those students cannot understand the basic knowledge about biological evolution, even less knowing a cladogram"	2 (3.1%)
Total			64 (100%)

n = total of respondent teachers to the question; teachers = number of occurrences in the category; % = percentage of responses in the category. *Religious aspects of students were grouped with other alternative conceptions that students may present that are reported by the participant teachers.

reported that the importance of the use of those representations is found in the presentation of the kinship, in a dynamic manner, between different groups of organisms. Furthermore, teachers also related the use of cladograms in the classroom with the possibility to work with different themes regarding biodiversity education beyond evolution. For example, by connecting environmental issues with kinship among organisms. Teachers also brought up, as a possibility, the topic of the use of playful activities, such as supplementary materials and activities of cladogram construction. Thus, this would come with the advantage of rendering science and biology classes more dynamic and interesting for the students.

Regarding the teaching materials used in the classroom that contain cladograms, the material that was the most mentioned was the textbook. Furthermore, teachers also mentioned the use of other teaching materials, such as slide presentations; other printed materials; workbooks; materials from the internet; videos and other digital media; the blackboard; and materials created by teachers. However, although they mentioned that the textbook contained this kind of representation, some of them also said that it is not enough and that sometimes it presented incorrect information and, thus, it is necessary to search for other teaching materials. Therefore, certain teachers mentioned that they elaborate their teaching materials in order to enable the work with cladograms in the classroom. For example, they elaborated workbooks and exercises of cladogram construction and interpretation.

Topics regarding textbooks were also brought up as an issue regarding biodiversity education and cladograms. In addition, teachers also mentioned issues regarding their own knowledge about this topic, as well as the issues with cladogram interpretation and alternative conceptions that the students may have. Furthermore, some of them also emphasized that the curricular approach is not adequate and that the topic itself is not present enough in the curricula. It is also important to consider that teachers often have to search for other resources to approach this theme in the classroom since textbooks often do not possess sufficient cladograms to work with. Therefore, it is important to provide teaching materials that contain cladograms for teachers to utilize in the classroom.

The challenge that was mentioned most often by teachers was the conceptual challenges that they have about the theme, especially concerning cladogram interpretation (40.35%). Considering that one of the main challenges reported by teachers is regarding their knowledge about the theme, it is thus relevant to understand what knowledge they have on this topic. Therefore, we also analyzed the doubts and concepts that teachers considered to be unknown during the course, as well as the educational experiences that they reported having on the topic (Table 7).

Most of the teachers reported having difficulties related to cladogram interpretation and concepts about this theme. When they detailed their answers about the themes that they considered as new or difficult, it was possible to notice that many of their difficulties were regarding specific content of phylogenetics, such as monophyletic groups and apomorphy, among others.

Furthermore, we also considered it relevant to understand the experiences before the course that those teachers had during their teacher education regarding the theme. Most of the teachers reported that they learned about the theme during their teacher education, whether in pre-service or in-service education. However, although most of the teachers reported that they learned about cladograms, some of them also reported that this approach was not in-depth. In addition, the use of cladograms in the classroom was not a topic that was approached very frequently during their teacher education, which is notable when considering that many of the respondents reported not discussing this theme in the science and biology education context.

Discussion

Students need to have contact with a greater diversity of explanations about biodiversity, supported by a myriad of evolutionary studies. There are many studies that explore pre-service and in-service biology teachers' tree-thinking abilities (e.g., Halverson 2011; Halverson and Friedrichsen 2013; Lopes and Vasconcelos 2012; Phillips et al. 2012). However, there are only a few studies that assess the challenges and possibilities that teachers find when teaching the multiple issues that involve biodiversity in the context of an evolutionary perspective as discussed throughout this work.

The type of teacher knowledge associated with student learning is influenced by pedagogical content knowledge (PCK), which is topic-specific knowledge regarding teaching and learning (Shulman 1987; Ziadie and Andrews 2018). In Study 1, we found certain specific teaching context issues, such as the emergent epistemic and learning categories in the teacher's response, thereby showing how they promote students' knowledge about biodiversity in accordance with pedagogical content knowledge. It is noteworthy that many teachers considered evolutionary knowledge important as a strategy to bring students closer to environmental issues. This is in line with a broader understanding that evolution has impacts in several fields, including humanity's place in nature to the importance of evolution in predicting biodiversity changes during climate change, contributing to its preservation (Sá-Pinto et al. 2022).

Table 7 Topics involving participant teachers' education about topics involving cladograms

Doubts and/or new concepts for teachers during the course (n = 47)
Answers expressed when teachers were asked: "Were there any concepts approached during the meeting that you did not know or that you have some difficulty with? If yes, what was the concept?" and "Do you have any doubts?")

Categories	Description	Key examples	Teachers (%)
Cladogram interpretation	Difficulties or unknown concepts involving cladogram interpretation in general	"I have difficulty with phylogenetics content in general, mostly cladogram interpretation. The proposed activities helped me remember it"	23 (40.4%)
Concepts about Phylogenetic Systematics	Difficulties or unfamiliarity involving specific concepts about phylogenetics, such as monophyletic and paraphyletic groups, apomorphy, homoplasy, among others	"The concepts of monophyletic and paraphyletic groups […]. I had seen these concepts a long time ago, in my undergraduate education. After that, because they are not used in the classroom and are not present in textbooks, I forgot about them"	21 (36.8%)
Cladogram construction	Difficulties or unknown concepts involving cladogram construction	"I learned to interpret and, mostly, to visualize the construction of the phylogenetic matrix in such a didactical way that will allow me to improve my classroom practice"	13 (22.8%)
Total			57 (100%)

Topics regarding cladograms in teacher education (n = 68)
Answers expressed when teachers were asked: "During your teacher education (preservice or in-service), did you learn about cladograms?"

Categories	Description	Key examples	Teachers (%)
Learned about cladograms	Teacher reported having learned about topics involving cladograms during teacher education	"In my teacher training I was presented in a subtle way, the terms are not unknown, but not all of them are understood"	59 (86.8%)
Did not learn about cladograms	Teacher reported don't learned about topics involving cladograms during teacher education	"No, this was the first time that I participated in a course that approached this theme"	9 (13.2%)
Total			68 (100%)

Topics regarding cladograms in teacher education (n = 68)
Answers expressed when teachers were asked: "During your teacher education (preservice or in-service), did you discuss topics regarding Science/Biology education using cladograms?"

Categories	Description	Key examples	Teachers (%)
Did not discussed topics involving teaching about cladograms	Teacher reported not discussing topics involving teaching about cladograms during teacher education	"In my teacher training, it was approached more about the importance of teaching Biology from an evolutionary perspective than it was given a tool for actually doing it in a classroom. In my in-service teacher education, this has been the first course that has this focus"	39 (60.1%)
Discussed topics involving teaching about cladograms	Teacher reported discussing topics involving teaching about cladograms during teacher education	"The University offered, in "Biology Weeks", lectures and workshops, and there were always activities of this kind for Zoology and Paleontology areas, in which topics about cladograms were approached, as well as its use in Science and Biology education"	27 (40.9%)
Total			66 (100%)

n = total of respondent teachers to the question; teachers = number of occurrences in the category; % = percentage of responses in the category.

We also saw that the teachers made certain choices of what to prioritize in this topic, such as the concepts of natural selection and adaptation (Fig. 1). However, we understand that the curricula may have an important influence on the teacher's approach, since the Brazilian Common Core mentions the contents of adaptation and Natural Selection on the topic related to evolution (Ministério da Educação 2018).

Macroevolution and phylogenetics were poorly considered by teachers in this first study. Other researchers documented teacher emphasis on natural selection to the detriment of other topics, such as macroevolution (Sickel and Friedrichsen 2013; Schulteis 2010). However, it is an important aspect to consider in further research. Macroevolutionary issues are one of the main targets of creationist movements and, moreover, the story of evolution above the populational level has the potential to make evolutionary theory more interesting and meaningful (Padian 2010).

There are a number of studies that explore misconceptions in the understanding of cladograms (e.g., Bokor et al. 2014; Catley et al. 2013; Phillips et al. 2012). However, our goal here was to understand what challenges and possibilities Brazilian teachers find in their classroom practices and the teaching materials they use when approaching cladograms while teaching about the diversity of organisms, as well as the experiences they had with cladograms during their education.

Most teachers reported using cladograms in the classroom. However, approximately a third of the teachers reported not using cladograms when teaching about the diversity of organisms. In addition, many teachers reported the possibilities related to its use in the classroom, especially for making it possible to understand the kinship among organisms, as highlighted by the science education literature (Catley et al. 2013; Horn et al. 2016; Novick et al. 2011; Rosa and Tricarico 2016). Teachers also reported that by using cladograms it is possible to work with different activities in the classroom other than simply lectures. They mentioned, for example, the use of supplementary materials, activities of cladogram construction, and playful activities. Practical or playful activities are relevant to help students, for example, to understand how cladograms are built (Barboza and Braga 2020; Bokor et al. 2014; Cordeiro et al. 2018a; D'Ambrosio et al. 2016; Dinghi et al. 2020; Horn et al. 2016; Stenlund et al. 2021; Novick and Catley 2018; Russel and McGuian 2015).

Teachers reported the importance of playful activities and practical activities (such as games, field activities, cladogram construction, etc.), as relevant activities for the purposes of teaching on this theme. These activities are relevant for learning about cladograms and not only for use in the classroom. In addition, there are a number of studies that have been conducted in regard to the importance of those activities to basic education (Bokor et al. 2014; Cordeiro et al. 2018a; D'Ambrosio et al. 2016; Dinghi et al. 2020; Russel and McGuian 2015). These activities also have their importance in other educational contexts. For example, playful activities are used in science museums, in which the public is able to interact with interactive cladograms in a way in which they can explore more dynamically the "Tree of life" (Horn et al. 2016; Stenlund et al. 2021). Furthermore, those activities are also relevant with higher education contexts. This is achieved by rendering it possible to learn about cladogram construction and interpretation in a more dynamic and practical manner (Novick et al. 2018).

Textbooks are recognized as one of the most used materials in the classroom in several countries, such as in Portugal (Carvalho et al. 2007), Brazil (Bueno and Franzolin 2019), and Mexico (Palop and García 2017). Furthermore, in Brazil, textbooks are often the only available materials for the teacher to use in the classroom (Bizzo 2000). Such materials are provided to Brazilian public schools through the National Textbook Program (in Portuguese, Programa Nacional do Livro Didático—PNLD) (Ministério da Educação, 2020). This program analyzes and selects textbook collections based on evaluative criteria and distributes them throughout the country. Therefore, it is expected that this would be one of the materials most mentioned by teachers. However, teachers also mentioned this material as a challenge, especially due to the fact that it does not always contain the best representation of topics or because it contains an insufficient amount of detail.

Textbooks may have insufficient content on phylogenetic systematics (Rodrigues et al. 2011) and, in Brazil, they are often reported as possessing conceptual distortions about cladograms (Cardoso-Silva and Oliveira 2013; Cordeiro et al. 2018b; Coutinho and Bartholomei-Santos 2014; Lima et al. 2020; Lopes and Vasconcelos 2012; Moraes and dos Santos 2013). Such distortions can include, for example, the taxonomy approach as a synonym of phylogenetic systematics, as well as the impression that evolution is a linear process or a process related to improvement (Lopes and Vasconcelos 2012). Furthermore, even the materials that present cladograms may have a fragmented approach to the content regarding the diversity of life, in which groups are approached separately, without considering their kinship (Rodrigues et al. 2011; Lopes and Vasconcelos 2012, 2014). In this sense, it is important that teachers have access to materials that approach the theme properly.

Other than the issue related to the teaching materials, another relevant point raised by teachers concerning biodiversity education using cladograms was the difficulty that students often have with this topic and their alternative conceptions, such as seeing evolution as an improvement or religious aspects. It is important to understand what are the students' conceptions about evolution, to better teach this topic (Nehm and Kampourakis 2022). In the last years, there has been a rise of far-right (Knijnik 2021) and creationist movements in Brazil (Escobar 2020; Santos and Carvalho 2019), which aimed to affect educational policies (Escobar 2020; Knijnik 2021; Santos and Carvalho 2019). These movements were present even in an important scientific agency (Escobar 2020). However, there has been resistance from democratic groups of teachers, scientists, parents, and civil society (Knijnik 2021). It is known that conceptions regarding religious aspects are challenges reported by the literature on evolution education (Borgerding et al. 2015; Nehm and Kampourakis 2022). However, this might not always be the biggest issue. For example, it is reported that Brazilian teachers are influenced by religious values, but this influence is lower in Biology preservice and in-service teachers, who concomitantly show acceptance of biological evolution (Caldeira et al. 2012).

Other aspects besides students' religion may affect their understanding and acceptance of evolution (Oliveira et al. 2022; Oliveira and Bizzo 2015; Santana 2019; Santos and Calor 2008; Santana 2019). Throughout their lives, students will get in contact with different types of knowledge, such as cultural, scientific, and philosophical, and each one of them will explain the world in a way (Oliveira and Bizzo 2015). Furthermore, in Brazil, most of the information that students learn about evolution is often from mass media and other non-specialized sources (Santos and Calor 2008). For example, when comparing data about the knowledge and acceptance of Brazilian and Italian students, it is possible to see that Brazilian students lack knowledge about evolution, while Italians do not (Oliveira et al. 2022). This can be explained by the difference in contact that they have with the theme. While Brazilian students often see evolution only at the end of the educational process, Italian students start to learn about it when they are 9 years old (Oliveira and Bizzo 2015). Religion seems to be not as influential as sociocultural aspects, such as education (Oliveira et al. 2022). For example, when Brazilian students are asked to explain evolution, they often present a range of misconceptions, while their teachers report that evolution is a topic taught only at the end of schooling, in 12th grade (Santana 2019).

Furthermore, the issue regarding a lower acceptance of evolution by religious students is more prominent when talking about human evolution (Oliveira and Bizzo 2015). Since in our research, we asked teachers about the issues when using cladograms to teach about the diversity of organisms, this might not be a relevant issue to them.

The understanding of concepts about phylogenetics is not trivial, especially because it has been reported in biology educational literature that many undergraduate students have some difficulties to understand the theme (Phillips et al. 2012; Halverson 2011; Kummer et al. 2016; Rosa and Tricarico 2016; Whitenack and Drew 2019) as well secondary school students (Costa and Waizbort 2013; Lopes and Vasconcelos 2014, Coutinho and Bartholomei-Santos 2014). Therefore, it is important to give some attention to this issue, as well as adequate teaching materials and more time in the school curricula, in order to approach this subject properly. In addition to the issues mentioned above, teachers also reported a challenge in their understanding and education about the subject. Therefore, it is relevant to understand what formative experiences these teachers had regarding the theme and what conceptual challenges they report having.

The participating teachers reported the need to study the content in order to teach in the classroom; further, some of them even reported not working on the topic in the classroom precisely due to the lack of preparation they reported having regarding the topic. When analyzing the doubts and unknown concepts that were reported by them, it was possible to observe that the teachers presented difficulties, in particular with cladogram interpretation and with specific concepts regarding the theme.

These concepts are not trivial, they have been observed in the literature on science and biology education as aspects in both high school students (Catley et al. 2013; Mutiara et al. 2020) and undergraduate students (Phillips et al. 2012; Halverson 2011; Kummer et al. 2016; Rosa, Tricarico 2016; Whitenack and Drew 2019) as demographics who often have some difficulty in understanding the concepts. Although it is not the goal of teacher education that they know extremely specific concepts in the area, it is important that teachers know the key concepts that are detailed within them—e.g., monophyletic groups and apomorphy—in order to enable the teaching of this content in the classroom (Santos and Calor 2008).

Regarding teachers' education, most of them learned about cladograms during their education prior to the course offered in this research. However, this number drops considerably when asked if they discussed issues related to teaching about cladograms in the classroom during their education. Considering the fact that teachers often report having little contact with cladograms during their teacher education (Santana 2019), it is considered of great importance that this topic is more present throughout teacher preservice and in-service education (Coutinho and Bartholomei-Santos 2014). This is required, especially when considering the particularities of teaching about this theme.

It is important to discuss the particularities of teaching about cladograms, thereby making it possible to provide a more dynamic and interesting learning environment for students. Given the significance of cladograms and the challenges associated with their comprehension by students, it is relevant that these aspects are addressed in teacher education. Consequently, teachers can draw attention to these aspects and explore strategies for effectively teaching the content about cladograms in the classroom, thereby mitigating potential challenges with their students. Therefore, it is important to address not only the acquisition of content knowledge but also the development of pedagogical content knowledge, which facilitates the discussion on how to effectively teach this content in the classroom (Shulman 1987).

Finally, it is important to point out some limitations of this research. The groups of studies were drawn from different pools, with a relatively small number of teachers involved. We also can assume that teachers of Study 1 and Study 2 already had an interest concerning those topics, since they were engaged in in-service courses about biodiversity and evolution education. Although we recognize that the qualitative approach may provide a broader understanding of the topic and a deeper exploration of teachers' experiences, we understand that the results in this research cannot be generalized, as they are particular to this group of teachers. Furthermore, we cannot fail to mention the validity of the questionnaires could be improved with an analysis incorporating an index of reliability. In future research, it will be important to expand the number of research participants, as well as to develop methodologies with a higher degree of reliability and validity to understand how teachers conceptualize evolution and its importance in biodiversity education and the challenges and possibilities Brazilian teachers find when approaching cladograms in their classrooms.

Conclusions

In Study 1, we sought to assess how teachers conceptualize evolution and its importance in biodiversity education. We found that the concepts with the least emphasis by teachers are those related to macroevolution and phylogenetics. In order to explore in more detail teachers' approaches to phylogenetics, we sought to, in Study 2, explore what challenges and possibilities Brazilian teachers find in their classroom practices and the teaching materials they use when approaching cladograms while teaching about the diversity of organisms, as well as the experiences they had with cladograms during their education. Although most of the participant teachers in Study 2 reported using cladograms in the classroom, less teachers confirmed using the representation in classes about biodiversity. Teachers reported using different approaches to use cladograms in the classroom, such as using textbooks, building teaching materials, and using playful activities. They reported that their own conceptual challenges, students' difficulties, and alternative conceptions, as well as the insufficient approach by textbooks, were the main challenges found.

Therefore, we recommend that education of biology pre-service and in-service teachers approach this theme with consideration of the particularities regarding teaching and learning about cladograms. Hence, it is important that content knowledge is considered, but it should also be considered the pedagogical content knowledge about the topic, something that teachers reported that it was not approached enough. Furthermore, it is important that pre-service and in-service teacher education about this topic considers the reported challenges and possibilities presented by this research, searching for ways of building teacher education courses and teaching materials that could help their classroom practices. It is also important to develop teaching materials that approach the interpretation and construction of cladograms, in a way that would support the teacher and their students to learn about it. Most participant teachers also recognized the importance of cladograms to understand the kinship among organisms, connecting themes regarding biodiversity education. Therefore, it is important that the Science and Biology Brazilian curricula incorporate this transversal approach, enabling this perspective, recognized by teachers, to be implemented by them.

Future research can look into the changes in the cladogram classroom approach after teachers participate in teachers' in-service courses about this theme. Furthermore, future research can also look into the content of the pre-service and in-service education courses, how teacher educators approach this topic and what are their practices in the classroom, as well as other aspects regarding teacher education about cladograms. It is also important that future investigations look into the classroom practices and educational experiences of teachers that are in other contexts and, thus, may not be that interested in evolutionary topics.

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Author contributions

LALA conducted Study 1. CMBS and FF conducted Study 2. All authors contributed to the writing of the final manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Available from authors upon request.

Declarations

Ethics approval and consent to participate

In Study 1, the teachers provided their informed consent and answered questions under absolute anonymity, following all the applicable ethical procedures in compliance with Brazilian legislation at the time. Study 2 was approved by the Research Ethics Committee of the Federal University of ABC (CAAE: 67968217.5.0000.5594), and participant teachers provided informed consent. All participants signed terms of informed consent, agreeing to participate in the research, and the identities of the participants were kept anonymous.

Competing interests
The authors declare they have no competing interests.

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