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ARTIGOS

Analysis of the conceptions of future Biological Sciences teachers about concepts of Evolutionary Theory [1 2 3]

Análise das concepções de futuros professores de Ciências Biológicas sobre conceitos da Teoria Evolutiva

Análisis de las concepciones de los futuros profesores de ciencias biológicas sobre los conceptos de la teoría evolutive

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Abstract

Evolutionary theory is considered the integrating axis of Biology. Therefore, concepts related to Evolution are needed for an adequate understanding of other explanatory models. The present work aimed to analyze the conceptions about themes related to Biological Evolution (BE), through the application of questionnaires among pre-service teachers in a Biological Sciences undergraduate degree. After analyzing the data, we noticed that, besides misconceptions on the concepts, a significant portion of the respondents is not confident enough to discuss the topics about biological evolution. Defending the idea that the conceptions of future teachers are not an end in themselves, we articulate this with discussions about teacher education.

Keywords: Biological Evolution, evolution teaching, teacher education, initial training, Biological Sciences

Resumo

A teoria evolutiva é considerada o eixo integrador da Biologia, e, sendo assim, os conceitos relacionados à Evolução são necessários para uma adequada compreensão de outros modelos explicativos. O presente trabalho buscou analisar as concepções acerca de temas relacionados à Evolução Biológica (EB), por meio da aplicação de questionários entre os professores em formação em um curso de Ciências Biológicas. Após análise dos dados, percebeu-se que, além de equívocos relacionados a conceitos, uma parcela significativa dos respondentes não se sente segura para se manifestar a respeito dos tópicos sobre EB apresentados. Defendendo a ideia de que as concepções de futuros docentes não constituem um fim em si, foi feita uma articulação com discussões sobre formação de professores.

Palavras-chave: *Evolução Biológica, ensino de evolução, formação de professores, formação inicial, Ciências Biológicas*

Resumen

La teoría evolutiva se considera el eje integrador de la biología y, por lo tanto, los conceptos relacionados con la evolución son necesarios para una comprensión adecuada de otros modelos explicativos. El presente trabajo buscó analizar las concepciones sobre temas relacionados con la Evolución Biológica (EB), mediante la aplicación de cuestionarios, entre los docentes en formación en un curso de Biología. Después de analizar los datos, se observó que, además de los conceptos erróneos relacionados con los conceptos, una parte importante de los encuestados no se siente seguro para expresarse sobre los temas presentados en EB. Finalmente, defendiendo la idea de que las concepciones de los futuros docentes no son un fin en sí mismas, articulamos discusiones sobre la formación docente.

Palabras clave: *Evolución biológica, enseñanza de la evolución, formación de profesores, entrenamiento inicial, Ciencias biologicas*

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Introduction

Biological Evolution (BE) is the most important theory in the biological sciences. Without it, the various biological disciplines would be a catalog of facts and descriptions, unrelated to each other. Its relevance is highlighted not only by theorists of Biology, such as Dobzhansky (1973), Meyer and El-Hani (2005), and Mayr (2005, 2009), but also by official documents which have long guided K-12 Education, such as *Parâmetros Curriculares Nacionais para o Ensino Médio* (National Curriculum Parameters for Secondary Education- PCNEM, 2000), and studies in the Teaching area (Oleques et al., 2011).

Studies on teachers' conceptions have pointed out numerous difficulties in understanding scientific concepts related to evolutionary theory, either due to the degree of abstraction needed to work with concepts such as adaptation, natural selection, etc., or conflicts with personal beliefs (Coimbra & Silva, 2007; Gastal et al. 2009; Licatti & Diniz, 2005; Tidon & Lewontin, 2004). These works report situations that almost always associate the ideas related to evolution with the progress or improvement of organisms, or by the fact that EB is a content that can often clash with religious, such as the creationism ideas.

In addition to the aspects already mentioned, research with teaching materials, especially textbooks, indicate problems, relating EB with the notion of progress (Alfaya-Santos, 2013) or, despite all legal and theoretical recommendations, relegating EB as just another content of a specific year of high school (HS), and not as the integrating axis of other Biology knowledge, as it should be (Silva-Porto et al., 2007).

Moreover, as highlighted by Tidon and Lewontin (2004) and Dorvillé and Teixeira (2015), the growth of creationism in Brazil has occurred on numerous fronts. For instance, through the mobilization of organizations such as the *Sociedade Criacionista Brasileira* (SCB-Brazilian Creationist Societyhttps://s3.scb.org. br/), founded in 1971, and the *Associação Brasileira para a Pesquisa da Criação* (ABPC- Brazilian Association for Creation Research https://abpc.impacto.org/), founded in 1979. Both organizations are responsible for the dissemination of an apologetic material, aiming to discredit Darwinian Theory. Another front

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is the increasingly significant political participation of politicians connected to some religious group[4].

Although EB is an extremely significant theory for Biological Sciences, its relevance is not limited to this specific field. For Mayr (2005), Darwinian Theory undeniably promoted the secularization of natural sciences, replacing a "divinely controlled world by a secular world, operated according to natural laws" (p. 101). The impact of evolutionary theory was not limited to the natural sciences, but also influenced the leading social theory thinkers of the 19th century. In a letter to Marx (December 1859), Engels states: "Darwin, by the way, whom I'm reading just now, is absolutely splendid. There was one aspect of teleology that had yet to be demolished, and that has now been done ", to which Marx replies (December 1860) that Darwin's book on natural selection "contains the basis in natural history for our view" (Marx & Engles, 1973, p. 22).

EB-related research, whether on teaching, learning, didactic materials, etc., becomes increasingly more necessary in the troubled Brazilian political scenario. Besides the growth of the evangelical political group, the presidency of one of the main funding agencies for scientific research- *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (Capes)-, was chaired (as of January 2020) by an open supporter of creationism[5].

Considering the theoretical assumptions previously discussed, the present research aims to investigate the understanding of students in the first and final stages of the Biological Sciences undergraduate degree at *Universidade Federal de Santa Catarina* (UFSC- Federal University of Santa Catarina), about concepts and themes related to EB. First, we analyze the data collected on the knowledge of future Science and Biology teachers about evolution. Later, in the final part of this paper, we will articulate this information with some curricular changes that took place in teacher education in recent years.

[4] In the 2018 elections, Brazil elected 84 deputies and 7 senators connected to evangelical churches. (http://agenciabrasil.ebc.com.br/politica/noticia/2018-10/em-crescimento-bancada-evangelica-tera-91-parlamentares-no-congresso). (Brazilian Communication Company).

[5] See more at: https://www.redebrasilatual.com.br/educacao/2020/01/criacionista-e-indicado-do-governo-bolsonaro-para-presidir-a-capes/ (Rede Brasil Atual).

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Methodological procedures

This is a qualitative research, which, according to Oliveira (2007), constitutes "a process of reflection and analysis of reality using methods and techniques for a detailed understanding of the object of study in its historical context and/or according to its structure" (p. 37).

For the proposed investigation, we applied a two-part questionnaire. The first part was related to the student's profile. The second part was composed of 16 questions of different types: Likert scale multiple choice questions, in which the respondent must answer by giving his/her level of agreement to a statement, varying from totally disagree to totally agree; open questions, in which the respondent must answer in his/her own words; and questions to relate rows and columns. The questionnaire is available in Appendix A.

Data collection took place between August and November 2018, with undergraduates in the first and last semesters of the Biological Sciences degree at UFSC. The professors gave time from their classes so that students could answer the questionnaire. Participants also filled the 'Free and Informed Consent Form' for joining the research. 55 students participated, 21 from the beginning and 34 from the end of the course. The respondents were identified with numbers from 1 to 55.

Results and discussion

To profile the respondents, we asked students which semester they were studying, which evolutionary theory concepts they had contact with during high school (HS), and which of them they had already changed their perspectives during higher education (HE). The concepts chosen were: evolution, adaptation, natural selection, Lamarckism, Neolamarckism, Fixism, mutation, ancestry, competition, evolutionary biology, and Intelligent Design. We found that a large part of the students had contact with important concepts of evolutionary theory in HS: 37 (66.7%) of the respondents had contact with the concept of adaptation and 49 (88.89%) with the natural selection. Figure 1 shows students' contact with evolutionary theory concepts in HS. Only 3 (5.45%) said they did not know the mentioned concepts.

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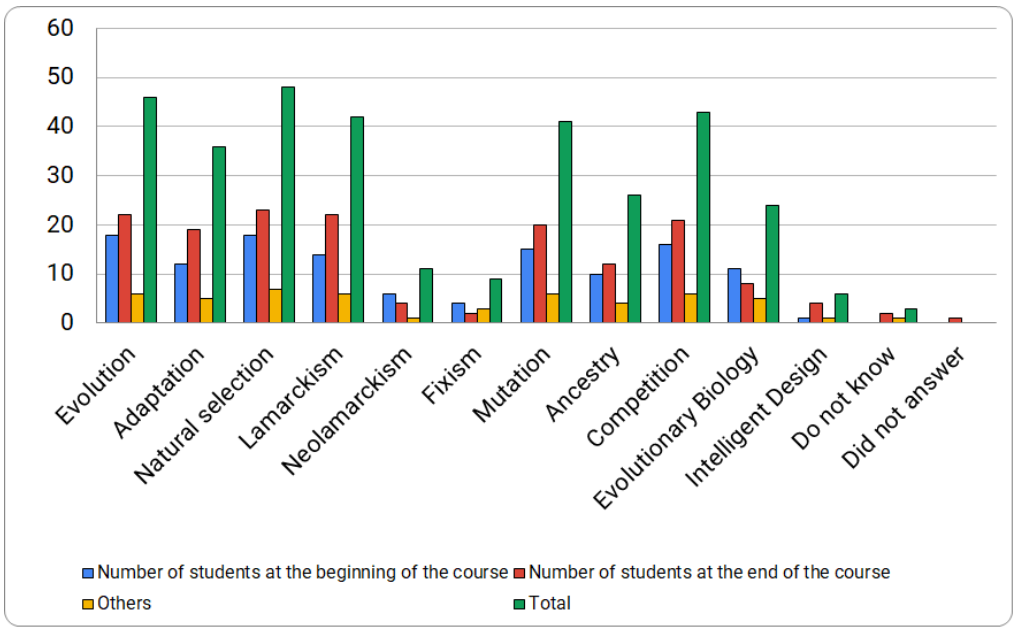

Figure 1: Number of students who had contact with the themes during HS

Source: Authors' data

Regarding a change in the understanding of the concepts previously mentioned, 50 (90.91%), 38 (69.09%), 43 (78.18%) of the respondents changed their conceptions about the topics Evolution, Adaptation, Natural Selection, during HE. Figure 2 illustrates this change:

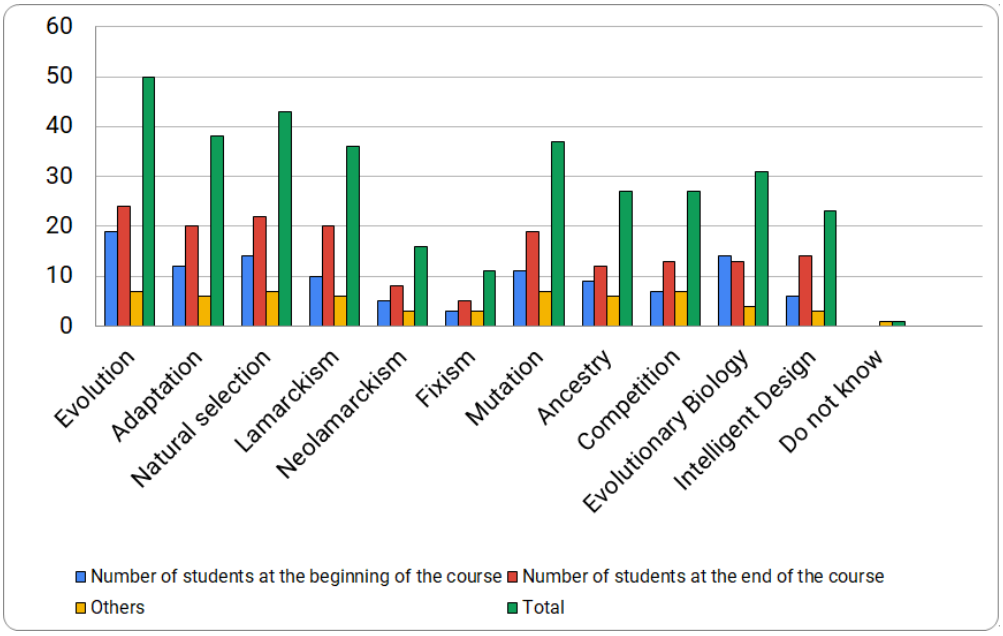

Figure 2: Number of students who changed their perception about the themes during their undergraduation

Source: Authors' data

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Question 5 asked students to correlate rows to columns. There were evolutionary factors in the rows, while in the columns there were two options: directional and non-directional. The evolutionary factors were migration, mutation, natural selection, recombination, and genetic drift. We highlight here that 14 (25.45%) respondents stated that genetic drift is a directional process; 50 (91%) respondents stated that mutation is a process that occurs randomly; 41 (74.54%) and 23 (41.8%) of respondents that genetic recombination and natural selection are random processes, respectively. We will further detail each of these points.

According to Futuyma (2002), genetic drift is a random process of change in gene frequencies. More than a quarter (25.45%) of the respondents stated the opposite, i.e., that the process is directional. Regarding the processes of mutation[6], genetic recombination[7] and natural selection, we refer to Mayr (2009): natural selection is a process in two stages, the first corresponds to a moment in which chance predominates, in which the processes of mutation and genetic recombination prevail[8]. In the second stage, the selective process itself consists predominantly in the exclusion of the individuals less fit or in the lower fertility rate of adult individuals. Therefore, the selection process, regarding the differential reproductive rate of individuals, is not simply random, although elements of chance may be present.

If 50 (90.90%) of the respondents understand that the processes of genetic variability are predominantly stochastic, almost half of them claim that natural selection is predominantly random. Considering that, for Mayr (2009), understanding the process of natural selection implies these two moments, the randomness, production of genetic variability, and the selection, which consists in the exclusion of the less fit, we can see that almost half of the respondents do not have a clear understanding of natural selection.

When we say that the selective process is not random, no teleology is established to the process. Given certain initial conditions, we cannot say which direction evolution will take, since stochastic factors operate over it. However, this does not prevent the observer to attribute a

[6] Mutation, as Futuyma (2002) points out, is a vague term that can refer to a change either in the sequence of base pairs of a gene or in the number and structure of chromosomes.
[7] By genetic recombination we understand the random exchange of genetic material during meiosis.
[8] We use the verb "prevail" because there are factors that interfere with the rate and direction of mutations, although a large proportion of mutations occur at random.

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directionality of what remained and what was excluded after the result of the selective process. This aspect will be clearer when we talk about progress in the next question.

The sixth question, an open-ended question, concerned students' general understanding of the concept of evolution. Some answers directly associated the concept of evolution with the idea of organismal improvement, as seen in the following excerpts:

> "Series of natural or directed events that pressure the individual to "change" for the perpetuation of the species." (Respondent 14)

> "Evolution is the changing of species' characteristics for better survival and reproduction and perpetuation of the species." (Respondent 28)

> "Adaptive forms acquired when different conditions arise, leading to the development of some structures for better adaptation." (Respondent 34)

> "Genetic improvement and phenotype based on natural selection." (Respondent 47)

The seventh question asked students to express their degree of agreement or disagreement to the statement: "Evolution is synonymous with adaptation/progress". Of the 55 students, 17 (30.91%) agreed to some degree; 4 (7.27%) had no opinion, and 34 (61.82%) disagreed to some degree. To better analyze this question, we separated the students from the beginning and the end of the course. We observed that among the students from the first semesters, 8 (38.10%) agreed, in some level, with the statement, 4 (19.05%) had no opinion and the other 9 (42.86%) disagreed in some level. As for the final-year students, 7 (20.58%) agreed and the remaining 27 (79.41%) disagreed. Here we notice a big difference in disagreement between students at the beginning and the end of the course.

The intent of the question was twofold. We intended, on the one hand, to see if students associated evolution with improvement/progress. There is an extensive literature on this subject (Alfaya-Santos, 2013; Gould, 2001; Mayr, 2008; Meyer & El-Hani, 2005, 2006; Nitecki, 1988; Rosslenbroich, 2006). Gould's (2001) book *Full House: The Spread of Excellence From Plato to Darwin* is entirely devoted to the topic. The author's position is radically opposed to any idea of progress or improvement in the evolutionary process. To some extent, Meyer and El-Hani (2005)

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endorse this understanding, defending the idea that natural selection does not result in perfect or optimized organisms. For the authors:

> Adaptive characteristics, in the evolutionary history of a species, only allowed the organisms who presented them to be more successful, compared to other organisms in the same population, in surviving and reproducing in a given environment. They would be perfect, and their carriers would be optimal organisms, only if all possible variation were present in a given population at a given moment in evolutionary history, but this, of course, never happens. Thus, the selected characteristics are always the most favorable ones within a spectrum of variation available in a population, and not characteristics that prove to be perfect in the face of challenges presented by the environment to organisms. (pp. 68 – 69)

However, whether or not there is progress in evolution is an open and controversial issue. Mayr (2008), while agreeing with the statement that organisms, however well adapted they are, are not perfect, also points out that it is possible to see an appearance of progress as an inevitable result of the Darwinian principle of variation and selection, i.e., a consequent result of the natural selection process, without any kind of teleology or progressivism.

The second intent was to relate evolution and adaptation. It is true that the adaptationist program, proposed by Mayr (1984), is and will continue to be fruitful for quite some time to explain the different adaptations of organisms to the environment. However, not all traits of organisms are explained by adaptation, and if the 'adaptationist program' is successful in many cases, it has its critics, as we see in Lewontin (1978), Gould and Lewontin (1979), and Gould and Vrba (1982). The last work is particularly interesting. The authors explain the term 'exaptation' as a trait of living things, whose origin did not derive directly from natural selection, but as a co-opted trait that shows a certain aptitude for the organism, i.e., traits that evolved for other purposes, functional or not, but which are currently useful, having been co-opted for different uses than the original ones. As the authors state adaptations have functions, exaptations have effects (Gould & Vrba, 1982, p. 6).

The eighth question asked respondents to explain, in their own words, how natural selection occurs. Of the 55 students, only 2 did not answer the question. Among the replies, the terms fitness and selection frequently appeared, as can be seen in some students' answers:

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"By selecting the best adapted individuals." (Respondent 3)

"Certain genes are favored by the environment; the individuals that possess it have an easier time surviving if they reproduce in that location, this ends up selecting the individuals of the species." (Respondent 12)

"NS is an evolutionary force that 'selects' populations according to their characteristics, allowing for the extinction or evolutionary success of those populations." (Respondent 26)

"According to changes in the environment, traits can be negatively or positively selected, thus individuals with the positively selected trait tend to reproduce more." (Respondent 29)

"Through evolutionary pressures that select individuals who present themselves, for whatever reasons, more adapted to the environment and situation." (Respondent 35)

"Selection would act by leaving individuals best suited for a given environment or situation. In other words, it favors the individual." (Respondent 40)

Some answers associated natural selection with other evolutionary factors, such as mutation:

"Organisms experience environmental pressures that can condition mutations and evolution." (Respondent 4)

"Natural selection is, in brief words, how the individual can adapt to survive the environment. With those being more 'well prepared' their lineage is more likely to survive." (Respondent 6)

"Due to environmental pressures and changes, coupled with gene recombination, the predominant genotype may change in a population over the course of many years." (Respondent 38)

"Natural selection generates change." (Respondent 43)

We focus on these answers, especially those of students 3 and 6, considering that the natural selection mechanism is key to understand the selective process. For student 6, the individual can adapt to survive the environment. Here, clearly, the respondent confuses

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individual physiological adaptation with evolutionary adaptation. For example, when a person is exposed to the sun and gets a tan, we say that his/her organism adapts to a condition of greater sunlight incidence. But even if we use the term adaptation here, it is not an adaptation in the evolutionary sense.

First, because to consider an organismic trait as an adaptation, we must see it in a historical perspective, placing its emergence in time, and how this trait came to perform the role it plays today (Meyer & El-Hani, 2005, p. 75). Second, because there is in these cases and in the answers of all respondents, except 26 and 38, an imprecision between typological thinking and population thinking[9]. It is interesting to see how almost all respondents attributed the action of natural selection to individuals.

Natural selection can act on single individuals, but its evolutionary result is in populations. Individuals do not evolve biologically, but populations can evolve to the point of becoming distinct species. This distinction between typological and population thinking, initiated by Darwin with the publication of *The Origin of Species*, later developed by Mayr (1984), is extremely important for understanding the evolutionary process. While typological thinking understands life forms as ideal types, with deviations being abstractions from these types, population thinking considers types (or averages) as abstractions, while variety is real. In the words of Meyer and El-Hani (2005):

> Population thinking, on the other hand, treats each species as a collection of populations of individuals with many genetic differences. Populations change from generation to generation, depending on the combinations of traits that are generated and the greater or lesser success of each combination. (p. 65)

We also see in the answers, some quite inconsistent ones, such as those of the participants 40 and 43. The first, for stating that selection acts leaving the fittest individuals and the second, for stating that selection is the cause of change, since selection only acts leaving a greater number of descendants of those individuals that, for whatever reason, have characteristics that allow a differentiated reproductive rate. It does not cause changes, but selects them.

[9] See Mayr (1984).

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Question number 9 stated that adaptive characteristics become frequent in a population because they favor the survival or reproduction of the individuals that possess them. Of the 55 students, 46 (83.64%) agreed, to a greater or lesser degree, while the other 9 (16.36%) disagreed, also to a greater or lesser degree. Analyzing the responses separately for students at the beginning and the end of the course: 20 (95.24%) of the students at the beginning of the course agreed to a greater or lesser extent with the statement, while only 1 (4.76%) student disagreed. Among the students at the end of the course, 25 (73.08%) agreed, while the other 9 (26.92%) disagreed.

With this question we wanted not to confirm or invalidate the statement, but to highlight that not all characteristics present in a population become frequent because of their adaptive character. Many of these traits may simply have become frequent in a population by simple genetic drift, as in the evolutionary model proposed by Kimura (1979) having that trait does not necessarily indicate a reproductive favoritism of these individuals. However, we should say that from a strictly Darwinian view of the evolutionary process there would be nothing to oppose the statement. Possibly, the fact that a greater number of students at the end of the course disagreed with the statement shows that they have already had contact with different theories about the evolutionary process.

Questions 10 and 11 concerned the evolutionary theory proposed by Lamarck. The first question stated that the varieties of life forms are explained by Lamarckian theory by two main laws, that of the use and disuse of characters and the law of heredity of acquired characters. Question 11 asked students to justify their answer from the previous question. Of the 55 students, 37 (67.27%) disagreed to a greater or lesser degree; 13 (23.64%) agreed to a greater or lesser degree, and the remaining 5 (9.09%) had no opinion about it. Among the 37 who disagreed with the statement, 30 only disagreed while another 7 strongly disagreed and of these, 5 were from the early stages. When asked to justify their marking on the previous question, 12 respondents (21.8%) were not confident to give any opinion on the matter.

For Martins (1997), although the two laws mentioned are present in the Lamarckian theory, it is unfair to summarize the theory only to these aspects. In fact, the Lamarckian theory would have four main laws, namely: the tendency to increase complexity; the emergence of organs according to the needs that are felt and maintained; the development or atrophy of the organ according to its employment (traditional use and disuse); and, finally, the inheritance of

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what has been acquired. Although the belief in the use and disuse of organs, as well as the hereditary transmission of what has been acquired was generalizable in the 19th century, even strongly present in Darwinian thought, therefore, to consider these statements wrong and exclusively as Lamarckian is not historically accurate. In Darwin, who textbooks usually represent as an antipode of Lamarck, we see that the use and the transmission of what is used both play a role in his interpretation of the living world:

> Habit also constitutes a decisive influence, as in the flowering period of plants when transported from one climate to another. In animals there is a more marked effect; I have found, for instance, that in the whole skeleton of the domestic duck the wing-bones become less heavy and the leg-bones heavier than the same bones in the wild duck; and I presume that this change can be safely attributed to the fact that the domestic duck flies much less and walks more than its wild ancestor. The increase - large and inherited - of the udder of cows and goats in countries where they are habitually milked, as compared with the condition of these organs in other countries, is another example of the effect of use. (Darwin, 2018, p. 34)

Questions 12, 13, and 14 addressed their understanding about mutation. Question 12 stated that mutation is a concept associated with changes in nucleotide sequences, (which may or may not be beneficial to the organism or cause no advantage or harm). 53 out of 55 respondents (96.36%) agreed with the statement.

Question 13 stated that, considering the previous question, any and all changes in the sequence of nucleotides lead to the evolution of the species. Question 14 asked students to justify their answer to the previous questions. 46 students (83.64%) disagreed to some degree with the statement in question 13. When asked to justify the previous question, only 2 respondents cited mutations in germ cells and another 7 brought up, in some way, the importance of mutations being heritable, as we see in the responses below:

> "They only lead to evolution if the environment favors them." (Respondent 12)

> "Many mutations - the greatest majority of them, are neutral and make no difference at all on an evolutionary level. Still, mutations in gamete cells are the only ones that can cause any difference for evolution." (Respondent 26)

> "No, because mutations are usually deleterious and a good part of these nucleotide sequences are not transcribed into proteins, and for it to be passed from one generation to another it needs to take place in a region that is passed on to the gametes." (Respondent 44)

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> "First this modification in the base sequence can happen in places that do not directly interfere with the manifestation of traits, representing no change in the individual. Secondly, a mutation in a single individual does not mean that it will be carried forward leading to a significant change in the species." (Respondent 48)

> "The change must be inheritable by the offspring to be an evolutionary process." (Respondent 53)

Among the justifications of agreement with the statement in question 13, we got answers such as the following:

> "Regardless of the change that has occurred, the individual is no longer the same, so it has evolved." (Respondent 24)

> "I agree, because I believe there is evolution whenever evolutionary forces operate - mutation is one of them." (Respondent 25)

Although few students (9 out of 55 respondents) stated that any and all mutations leads to evolution, we can see that among them it is not yet clear that, to justify the evolution of the species, the mutation needs to be inheritable. We can again turn to the example of physiological adaptation. The fact that someone is exposed to the sun can cause the DNA of his/her epidermal cells to change, to mutate. This mutation, as it occurred in the epidermal cells, is not heritable to his/her descendants, so it does not interfere in the evolutionary process.

Question 15 asked students to briefly explain what they understood by competition. Many answers presented words like dispute and resource, as we can see in the following excerpts:

> "It is the dispute between two individuals (Ex: for food, territory) over the same resource." (Respondent 3)

> "Competition - when the same or different species compete with each other for food, habitat, females." (Respondent 7)

> "If two organisms use the same resources and coexist, when that resource is limited there will be a dispute (competition)." (Respondent 28)

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Only two respondents somehow related competition to the evolutionary process:

> "It is a process that constitutes natural selection, competition for food, habitat, and a mate for reproduction, among others. It makes beneficial characteristics in these interactions to be selected in the species. According to Darwin it is one of the main factors or pressures that lead to evolution." (Respondent 22)

> "Competition is an ecological relationship that for a long time was considered the most important evolutionary factor, in a social relationship of science, which reproduces societal values within it (as was when capitalism was reinforced)." (Respondent 31)

Again, this is not about the falsehood or veracity of the answers. In a strictly Darwinian view of evolution, competition plays a major role in the evolutionary process, but there are authors who advocate theories in which competition would not be the predominant agent, such as the natural drift, proposed by Maturana and Mpdozis (1995) and Maturana and Varela (1995), and the theory of mutual support by Kropotkin (2012). We do not want to discuss the controversies on such theories, but only to point out that there are attempts to explain the diversity of life by mechanisms that are not predominantly competition and exclusion.

The sixteenth question stated that the bacterial flagellum is composed of an interaction of about 50 protein parts, and that in the absence of any one of these proteins, the flagellum becomes dysfunctional. Considering this, we asked the students how they could explain the appearance of the bacterial flagellum through natural selection. This was the question with the highest number of abstentions, so we did not distinguish between the answers from the beginning and the end of the course: altogether 15 (27.27%) students did not answer and another 7 (12.73%) could not justify it, representing 40.00% of the respondents.

Some answers, however, were quite satisfactory based on the currently established scientific knowledge:

> "Since not every mutation needs to be beneficial or useful, it could be that the proteins just kept coming together until one day it worked." (Respondent 2)

> "The structure found in recent bacteria was the result of successive mutations until they resulted in the conformation found today." (Respondent 16)

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> "EXAPTATION. That is, the process by which a structure is expropriated for another, possibly more complex, function." (Respondent 25)

> "The emergence of complex structures happens gradually over thousands or millions of years. I don't know much about it, but probably some earlier stage of this structure was different (maybe less nimble). There is also the hypothesis that maybe other proteins previously replaced the proteins in the current structure. I haven't read on the subject, but I think these are possibilities. Talking about the eyes and making a parallel, today there are animals with various levels of complexity, from photosensitive cells, ocelli, compound eyes, etc. The human eye is quite complex, for example, but if it were something so unique and absolute, there wouldn't be so many levels of complexity." (Respondent 46)

Some respondents, however, attributed a progressive character to the emergence of the scourge:

> "We could say, in basic terms, that the structure went through many mutations during the time, it has gone from a simpler form to a more complex one, the gradual evolution 'moves' to increasingly more complex and differentiated characteristics from the other species". (Respondent 22)

> "Billions of years of little trials and errors, selecting the most efficient and less harmful structure, less wasteful" (Respondent 53)

Only two students related the question to the "theory" of Intelligent Design, although they did not develop an answer:

> "That is one of the main questions raised by Intelligent Design. I wouldn't know how to explain the genesis." (Respondent 43)

> "Intelligent Design?" (Respondent 55)

Other students, while not citing the "theory" of Intelligent Design, gave answers that are based on the idea of irreducible complexity:

> "It took the generation of (approximately) 50 proteins for the bacterial flagellum. That is, when one protein is missing, the function of the bacterial flagellum is corrupted." (Respondent 3)

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> "I would say that changing the structure of the bacteria may not kill it, but it needs that combination to work properly. So do many things in our body. So that modification to 50 protein parts is a form of evolution." (Respondent 6)

> "Missing one protein will make another one not work; if that one doesn't work, another one may also stop working, and so on and so on." (Respondent 15)

> "I see it as something similar to a building, if there is something missing in the structure the building may even stand, but with flaws." (Respondent 37)

Our intention with this question was to bring an example of how certain critical strands of evolutionism, in particular the "theory" of Intelligent Design, seek to present objections to the evolutionist thesis that structures endowed with high complexity, such as flagella or eyes, could not evolve gradually. The "theory" of Intelligent Design, proposed by the American biochemist Michael Behe in the book *Darwin's Black Box* (1997), resurrects objections that Darwin himself had already foreseen in the formulation of his theory, namely the difficulty of gradually forming complex structures. The supposed innovation of Behe's argument is that now we are no longer talking about the difficulty of the formation of new organs, but that evolutionism would not be able to explain molecular structures and biochemical processes, since, in the absence of any of the molecules or biochemical steps for the functioning of the system, the whole structure or biochemical cascade would become dysfunctional. Among the examples cited by the author in the mentioned book is that of the bacterial flagellum. Behe called such structures complexly irreducible.

It is worrisome to note that this was the question with the highest level of abstention and even the admission that they would not know how to answer it. In the sixth chapter of *The Origin of Species*, Darwin (2018) had already raised objections that could hinder the acceptance of his theory, and among these difficulties was precisely the formation of complex organs, such as the eye. Two arguments serve to dispel these objections, whether they apply to the complex eye or the bacterial flagellum. The first argument consists in being clear that, when it comes to investigating the origin of an organ, the simple description of its functioning, however important it may be, is unable to reveal its genesis. For this it is necessary to investigate the organism's ancestors or collateral descendants of the original form and to ascertain there what gradations would be possible " , in order to see what gradations are possible, and for the chance of some

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gradations having been transmitted in an unaltered or little altered condition." (p. 198). We see a diversity of eyes in nature, from extremely simple ones, such as a simple optic nerve coated with pigment, present in some arthropods, to highly sophisticated eyes, such as those of eagles. Darwin (2018) draws an interesting analogy to explain the emergence of such structures through natural selection:

> It is scarcely possible to avoid comparing the eye with a telescope. We know that this instrument has been perfected by the long-continued efforts of the highest human intellects; and we naturally infer that the eye has been formed by a somewhat analogous process. (p. 199)

Of course the analogy is valid for the continuous improvement and for the temporal dimension, since the improvement of optical instruments is done by intentional agents, while the improvement of the eyes was done by non-finalistic natural processes, resulting from natural selection.

Darwin's second argument for the emergence of complex structures concerns structures that perform different functions at the same time. Natural selection could cause the structure, or a molecule, to specialize in only one function. This is interesting to explain the case of the bacterial flagellum and all the other objections Behe raises to evolutionary theory. The proteins present in the flagellum, as numerous as they are, might not be uniquely related to flagellum function, or even have no direct relation to flagellum function at all. The selective process co-opted these proteins to gradually perform, in an increasingly refined and specialized way, the function of the bacterial flagellum.

Behe's theses seek to disprove Darwinian Theory by means of a supposedly scientific discourse, as in the case of the bacterial flagellum. This was the example we brought in the questionnaire applied with pre-service teachers. However, as Martins (2001) points out, this refutation is driven solely by a religious background. The defenders of intelligent design are nothing more than concealed creationists.

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Final Considerations

In this article, we investigated elements related to the conceptions of BE in undergraduate students of the Biological Sciences degree at UFSC. We are aware of the immense heterogeneity in Brazilian territory, especially when it comes to education. We also know that, due to the sample of this research (55 respondents), our conclusions should be cautious about possible generalizations.

However, we believe that the scenario for future teachers at UFSC seems worrying. Our research allows us to corroborate part of the results already obtained by previous studies, such as that of Tidon and Lewontin (2004), who found a significant number of teachers who claim that evolution is an event that produces improvement, occurs at the individual level, and has direction (teleology).

We endorse that a possible and desirable way to change the current picture is the more widespread use of historical and philosophical elements in teaching and teacher education, as pointed out by Martins (1998) and Corrêa and collaborators (2010). In this case, besides demystifying the scientific activity, which is seen as an activity subject to failures and permeated by social and cultural factors, of gradual and slow development, we consider of utmost importance that future teachers read classic texts of their area of expertise, even if such texts are outdated considering current scientific advances.

There are many possible elements to justify this difficulty to understand evolutionary concepts for both entering higher education and those graduating it. The lack of didactic materials (Martins, 1998; Tidon & Lewontin, 2004), the deeply abstract concepts, such as adaptation and natural selection, the language barriers that lead students to confuse scientific concepts with their everyday use (e.g., adaptation), are just some of these complicating factors.

The difficulties in understanding Evolutionary Biology we highlighted in this research and its discussion are presented in detail in the results section. What we would like to emphasize in the conclusion of this paper concerns a more general aspect of teacher education, which, of course, also includes future teachers of Science and Biology. In the case of Biology, the statement that evolutionary theory works as a kind of integrating axis among the various contents (Dobzhansky, 1973; Meyer & El-Hani, 2005) is recurrent. Furthermore, the official

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documents that, for years, have guided the teaching of Biology, focused on EB as a structuring theme in the MS (PCNEM, 2000).

Dobzhansky's statement in the 1970s and the publication of the National Curricular Parameters for Secondary Education (PCNEM) in the early 2000s (PCNEM, 2000) seem to have had little effect on the training of science and biology teachers, at least regarding the content of Evolutionary Biology, since the difficulties of understanding raised here endorse the results of previous studies. However, in recent decades, there has been an investment of time, money, and endless studies on new models for teacher education.

These new models are all based on a criticism of the so-called technical rationality and the training model based on the 3+1[10] format, which consists of 3 years of theory, i.e. specific disciplines of each area and pedagogical theories, plus 1 year of practice, through school placement (Diniz-Pereira, 1999). These discussions and changes on the curricula of undergraduate degrees were consolidated after the promulgation of the National Guidelines for Teacher Education Courses in 2002 (Resolution CNE/CP no. 1, 2002). Since then, numerous opinions and resolutions have been issued, but all guided by the same agenda: criticism of the technical rationality model and valorization of the practical aspect of the teaching profession, of an epistemology of practice[11].

Considering that the environment in which the present research took place is in the training of future teachers, we raise the following issue: the UFSC, as well as several universities, reformulated its teacher training curriculum, guided by the criticisms towards the previous model (3+1) and by the defense of a kind of epistemology of practice, which claims that the previous proposal kept future teachers too far away from school practice. To this end, the 'pedagogical practices as a curricular component' (PPCC) were incorporated, which, in our understanding, established a change that, in fact, remained the same. They changed only the temporal dimension of the 3+1 model, divided into years, to adopt a model that divides each subject into a 3+1 form. In other words, the activity of a pedagogical practice at the end of the

[10] To better understand the aspects of the 3+1 model as well as historical aspects of teacher education in Brazil, see Saviani (2009).

[11] Although, in 2015, the National Council of Education has sanctioned the law that "Defines the National Curricular Guidelines for Initial Training at the Higher Level (degree courses, pedagogical training courses for graduates and second degree courses) and for Continuing Education" (Resolution No. 2, 2015), and this law revoked the resolutions of 2002. PPCC remains a mandatory curricular component with 400 hours in the curricula. Therefore, even with the new law, the challenges and issues posed by PPCC in the curricula are current and need to be understood and debated in teacher education courses" (Mohr & Cassiani, 2017, p. 64).

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disciplines only incorporated the old division of the course into the interior of each discipline[12]. In the case of UFSC, the curricular reformulation that implemented the PPCCs occurred between December 2002 and October 2005 (Mohr & Cassiani, 2017).

It is highly questionable that this model has made significant contributions to teacher education, and criticisms of the epistemology of practice are already widespread (Duarte, 2003). What we point out in this research, at least regarding the understanding of evolutionary theory, is that such a model of teacher training has not improved at all the understanding of what is considered the most relevant aspect of Biology.

Previous research on teacher education and the subject of BE, such as Goedert, Leyser, and Delizoicov (2006), pointed out flaws on teacher training to work on this subject, and that such insufficiencies were due, not exclusively, but mainly, to a curriculum that privileged theory over practice. This curriculum was clearly influenced by the 3+1 model and by technical rationality. Considering the problems observed, the authors suggested inclusion of pedagogical subjects in the early semesters of the course and the need for the scientific content to be worked together with the pedagogical content, without the prevalence of one to the detriment of the other (Goedert, Leyser, & Delizoicov, 2006).

The curricular change, which took years for UFSC to elaborate, incorporated such suggestions, with the inclusion of pedagogical practices in the largest possible number of course subjects (UFSC, 2005). What conclusions can we reach in terms of education improvement, at least regarding BE, the main subject of Biological Sciences, in face of the results we found through the questionnaires? In our opinion, improvement in these aspects definitely cannot be achieved through a reformulation of the curriculum, whatever it may be, if this reformulation is guided by an epistemology of a practical nature.

It is clear that more research needs to be done, both in relation to the understanding of future teachers about the main concepts of evolutionary theory, as well as aspects more directly involved with the teacher training model. However, it is worth raising a question, especially for those responsible for curricular reformulations: if knowledge, which is the main pedagogical tool for teachers, has not changed, and the same difficulties that existed before the curricular

[12] It is important to emphasize that each university could think its training models based on its interpretation of the official guiding documents for teacher training. This autonomy is materialized in the political-pedagogical projects of each institution. More about this new formative model and its application at UFSC can be found in Mohr and Wielewicki (2017).

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reformulation remain, at least on EB contents, should such curricular modifications, guided by an epistemology of practice that intends to increasingly make teacher training courses more "practice-oriented", be the way to improve teaching and training?

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Appendix A - Questionnaire used for data collection in the research 'Biological Sciences students' conceptions about evolutionary mechanisms'

You are invited to participate in a survey about science teaching and biological evolution at the Federal University of Santa Catarina. The questionnaire is anonymous. Please feel free to stop your participation in the survey at any time while completing the questionnaire. By submitting your answers, you declare to be aware that the results of this work may be disclosed in the academic and scientific environment and, because it is anonymous, the data obtained will be shown only as a whole, without revealing your name or any information related to your privacy.

*Obligatory

1. Please read the ICF, complete it, and send it by email:
"I, _____, understand my rights as a research participant and voluntarily consent to participate and give up the information provided in the questionnaire for this study.
Place and date: _____, ____ /____ /_____." in the response field of this question, filling in with the requested data. *

2. What undergraduation semester are you in? (Answer the one that represents the largest number of courses you are currently) *

Mark only one option.

( ) 1. st
( ) 2. nd
( ) 8. th
( ) 9. th
( ) 10. th
( ) Other

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3. During high school, did you have contact with any of these topics? If yes, select them*

Mark all that apply.

( ) Evolution
( ) Adaptation
( ) Natural selection
( ) Lamarckism
( ) Neolamarckism
( ) Fixism
( ) Mutation
( ) Ancestry
( ) Competition
( ) Evolutionary Biology
( ) Intelligent Design
( ) I do not know all the terms mentioned above

4. To date, have you changed your perception regarding any of the previously marked themes? *

Select it(s). Mark all that apply.

( ) Evolution
( ) Adaptation
( ) Natural selection
( ) Lamarckism
( ) Neolamarckism
( ) Fixism
( ) Mutation
( ) Ancestry
( ) Competition
( ) Evolutionary Biology
( ) Intelligent Design
( ) I do not know all the terms mentioned above

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Qualitative analysis

If you do not know or have not had contact with the term presented in the question, please inform it in the corresponding answer box.

5. Match Rows to Columns: *

Mark only one option per row.

	Random	**Directional**
Gene drift		
Migration		
Mutation		
Recombination		
Natural selection		

6. Briefly, answer: what do you understand by "evolution"? *

7. Evolution is synonymous with adaptation/progress. *

Mark only one option.

( ) Strongly agree

( ) I agree

( ) I have no opinion

( ) Disagree

( ) Strongly disagree

8. Explain, briefly, how natural selection acts to make evolution happen? *

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9. It is correct to say that adaptive traits become frequent in a population because they favor the survival and/or reproduction of the individuals that possess them. *

Mark only one option.

( ) Strongly agree
( ) I agree
( ) I have no opinion
( ) Disagree
( ) Strongly disagree

10. According to Jean-Baptiste de Lamarck, the variety of existing species can be explained by two laws: the Law of Use and Disuse and the Law of Heredity. What do you think about this? *

Mark only one option.

( ) Strongly agree
( ) I agree
( ) I have no opinion
( ) Disagree
( ) Strongly disagree

11. Justify your answer to the previous question.

12. In biology, mutation is a concept associated with changes in nucleotide sequences, (it may or may not be beneficial to the organism or it may not cause any advantage or harm). You: *

Mark only one option.

( ) Strongly agree
( ) I agree
( ) I have no opinion
( ) Disagree
( ) Strongly disagree

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13. Considering the previous question, it is correct to state that any and all changes in nucleotide sequences lead to the evolution of the species. *

Mark only one option.

( ) Strongly agree
( ) I agree
( ) I have no opinion
( ) Disagree
( ) Strongly disagree

14. Justify your answer to the previous question.

15. Briefly, answer: what do you understand by "competition"? *

16. The bacterial flagellum consists of a molecular motor interacting with about 50 complex protein parts. The absence of any of these proteins causes the flagellum to stop working, i.e. this structure is irreducibly complex because if we try to reduce its complexity by excluding any of these proteins, we will get a structure that does not work properly. Given this, how do you explain the genesis of the bacterial flagellum?