
# Nature of Science through Problem-Based Learning: Effects on science epistemological and biology conceptions of students

Cristina M. C. Sousa
Ensino e Divulgação das Ciências
Unidade de Ensino das Ciências
2020

**Orientador**
Isabel Chagas, Professora Auxiliar, IE-ULisboa

**Coorientador**
João Paiva, Professor Associado com Agregação, FCUP

PhD

*está conforme - O Orientador*
Assinado por : **JOÃO CARLOS DE MATOS PAIVA**
Num. de Identificação: BI07358283
Data: 2020.06.29 12:56:32 +0100

“the origin of thinking is some perplexity, confusion, or doubt”
(Dewey, 1910, p.12)

## Acknowledgments

Participating Master students/preservice teachers and their teacher and University.

Participating middle school students and their teachers and directors of participating schools.

Professor João Paiva and Professor Isabel Chagas for supervision of the preparation of the project and provided for its implementation and for supervision including decisions about the methodology used.

Professor Isabel Chagas for helpful suggestions to the research instruments.

Authors that authorized the use of their items in our questionnaires and use of checklists for textbook analysis.

Doutor Gil Nata for SPSS consultation and support in the confirmatory factor analysis of the questionnaire.

Several experts that validated the questionnaire.

Several teachers of the first year of the PhD and panel of evaluation of the Project of this thesis at FCUP.

Panel of evaluation of this thesis at FCUP.

Professor F. Abd-El-Khalick and Professor L. Leite for permission to use their checklists for textbook analysis. Professor J. Olson for permission to use her tables and for helpful methodological suggestions.

For helpful suggestions: ESERA Summer School 2019 colleagues and instructors, IHPST Summer School 2019 colleagues and instructors, anonymous reviewers and editors for helpful suggestions to parts of the thesis previously submitted as manuscripts.

Professor Conceição Santos and Professor Luís Calafate for supervision on the final thesis writing.

For helpful suggestions and for support and encouragement to: João Honrado, Rachel Askew, and Professor Roberto Salema.

To Professor Isabel Santos for mentorship and friendship.

To friends and parents for support and encouragement in the most difficult moments.

Financial support by Faculdade de Ciências, Universidade do Porto, Instituto de Educação, Universidade de Lisboa and International History, Philosophy and Science Teaching group.

# Resumo

Esta investigação teve como finalidade contribuir para caraterizar os efeitos da Aprendizagem Baseada em Problemas (PBL) enriquecida pela Natureza da Ciência (NOS) nas conceções epistemológicas da ciência e da biologia de alunos do 8º ano de escolaridade e de futuros professores, nomeadamente através de intervenções didáticas com situações-problema concebidas para o efeito. Com este objetivo foram efetuados seis estudos empíricos: nos dois primeiros obteve-se uma visão do papel da PBL enriquecida com NOS usando um assunto sociocientífico nas conceções epistemológicas da ciência e compreensão de conceitos de ecologia de alunos do 8º ano de escolaridade (n=34) e na avaliação do processo de aprendizagem por futuros professores (n=8); no terceiro avaliaram-se as conceções epistemológicas da ciência de alunos do 8º ano de escolaridade antes e depois de uma intervenção didática recorrendo a episódios de História da Ciência (n=34); no quarto foram caraterizadas as conceções epistemológicas da ciência de alunos portugueses do 8º ano de escolaridade (n=362) aplicando um questionário concebido para o efeito; no quinto estudou-se o efeito de uma intervenção didática usando um assunto sociocientífico e episódios de História da Ciência nomeadamente para promoção de conceções epistemológicas da ciência mais informadas de futuros professores (n=10); no sexto realizou-se um estudo quasi-experimental com alunos do 8º ano de escolaridade (n=36 grupo PBL e n=33 grupo controlo) com uma intervenção didática usando História da Ciência para promoção de conceções epistemológicas da ciência mais informadas e compreensão de conceitos sobre origem da vida. Nestes estudos os questionários foram o método principal de recolha de dados sendo complementados com entrevistas, observação e análise de documentos. Destes estudos realçamos os seguintes resultados: i) os alunos portugueses do 8º ano de escolaridade apresentam conceções epistemológicas da ciência pouco informadas em diversos itens, como por exemplo sobre a influência da dimensão cultural e social na ciência; ii) concebemos e implementámos materiais inovadores de PBL enriquecida por NOS que promovem conceções epistemológicas da ciência mais informadas e compreensão de conceitos de biologia em alunos do 8º ano de escolaridade; iii) concebemos e implementámos uma intervenção didática para futuros professores que foi eficaz na melhoria das conceções epistemológicas da ciência e na identificação de aspetos NOS e assuntos sociocientíficos por estes; iv) a PBL, comparada com o controlo, foi mais eficaz na mudança da conceção de que os cientistas em momentos diferentes, podem usar diferentes teorias e métodos para interpretar o mesmo fenómeno natural. Adicionalmente, realizaram-se dois estudos de revisão de manuais escolares portugueses de Ciências Naturais com o objetivo de identificar a eventual presença dos temas das intervenções didáticas nos mesmos e identificou-se a ausência de um conceito estruturante de nicho ecológico em três dos nove manuais analisados e da teoria do ancestral comum em todos analisados. Os resultados obtidos nesta tese sugerem a eficácia do ensino explícito de NOS, através da PBL com recurso a situações-problema enriquecidas com NOS, para alunos do 8º ano de escolaridade até à formação de professores. Adicionalmente, com o objetivo final de melhorar a literacia científica dos estudantes propomos instrumentos e um curso como forma de contribuir para a investigação futura e para a melhoria das práticas dos professores.

## Palavras-chave

Aprendizagem Baseada em Problemas, assunto sociocientífico, conceções epistemológicas da ciência, História da Ciência, Natureza da Ciência.

## Abstract

This investigation aimed to contribute to characterize the effects of Nature of Science (NOS)-enriched Problem Based Learning (PBL) in the epistemological conceptions of science and biology of 8th grade students and future teachers, namely through didactic interventions with problem-situations designed for that purpose. With this objective, six empirical studies were carried out: in the first two, a view of the role of the NOS-enriched PBL was obtained using a socio-scientific subject in the epistemological conceptions of science and understanding of concepts of ecology of students in the 8th year of schooling (n = 34 ) and in the evaluation of the learning process by future teachers (n = 8); in the third, the epistemological conceptions of science of 8th grade students were evaluated before and after a didactic intervention using episodes of History of Science (n = 34); in the fourth, the epistemological conceptions of science of Portuguese students in the 8th grade (n = 362) were characterized using a questionnaire designed for this purpose; in the fifth, the effect of a didactic intervention using a socio-scientific subject and episodes of History of Science was studied, namely to promote more informed epistemological conceptions of science of future teachers (n = 10); in the sixth, a quasi-experimental study was carried out with students from the 8th grade (n = 36 PBL group and n = 33 control group) with a didactic intervention using History of Science to promote more informed epistemological conceptions of science and understanding of concepts about the origin of life. In these studies, questionnaires were the main method of data collection, complemented with interviews, observation and analysis of documents. From these studies, the following results were highlighted: i) 8th grade Portuguese students present epistemological conceptions of science that are poorly informed on several items, for example on the cultural and social influence in science; ii) we designed an applied innovative materials of NOS-enriched PBL that promote more informed epistemological conceptions of science and understanding of biology concepts in 8th grade students; iii) we designed and applied a didactic intervention for future teachers that was effective in improving the epistemological conceptions of science and in identifying NOS aspects and socio-scientific issues by them; iv) PBL, compared to control, was more effective in changing the conception that scientists at different times can use different theories and methods to interpret the same natural phenomenon. Additionally, two studies were carried out to review Portuguese school textbooks on Natural Sciences in order to identify the possible presence of the themes of the didactic interventions in them and we identified the absence of a structuring concept of ecological niche in three of the nine analyzed and of the theory of the common ancestor in all analyzed. The results obtained in this thesis suggest the effectiveness of explicitly teaching NOS through PBL, using problem-situations enriched with NOS, for 8th grade students through teacher training. Additionally, with the ultimate goal of improving students' scientific literacy we propose instruments and a workshop as a way to contribute to future research and to improving teacher practices.

## Keywords

Epistemological conceptions of science, History of Science, Nature of Science, Problem-Based Learning, Socioscientific Issue.

## Index

# List of abbreviations

CBL – Case-Based Learning

DL – Discovery Learning

DNA – Deoxyribonucleic acid

EBB – Epistemic Beliefs in Biology

G.a. – Giga-annum (Billion years ago)

GIS – Geographic Information System

HOS – History of Science

IBL – Inquiry-Based Learning

K-12 – Kindergarten through 12th grade

K-U – Kindergarten through University

LUCA – Last Universal Common Ancestor

NOS – Nature of Science

PBL – Problem-Based Learning

PCA – Principal Component Analysis

PjBL – Project-Based Learning

PISA – Programme for International Student Assessment

RNA – Ribonucleic acid

rRNA – Ribosomal Ribonucleic acid

SECS – Students' Epistemological Conceptions of Science

SEV – Scientific Epistemological Views

SSI – Socioscientific Issue

STS – Science-Technology-Society

SUSSI – Student Understanding of Science and Investigative Process

UCA – Universal Common Ancestor

VASI – Views About Scientific Inquiry

VNOS – Views of Nature of Science

VOSI – Views of Scientific Inquiry

VOSTS – Views on Science-Technology-Society

## List of figures

## List of tables

# Chapter 1

# Introduction

# Chapter 1 - Introduction

## 1.1. Personal background

What is the Nature of Science? According to Lederman et al. (2013) consists in the "epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge" (p. 140). Why Nature of Science? Two of my favorite disciplines as a High School student were Biology and Philosophy, and I thought they were related… Recently this has been defended by an Opinion article entitled "Why science needs philosophy" in the Proceeding of National Academy of Sciences, in which they define that the contribution of Philosophy is "at least four forms: the clarification of scientific concepts, the critical assessment of scientific assumptions or methods, the formulation of new concepts and theories, and the fostering of dialogue between different sciences, as well as between science and society" (Laplane et al., 2019, p3949).

I pursued a Biology course, and, in fact, Philosophy of Biology has been always present, when studying biological theories, in planning and teaching practical classes and when doing Biomedical research and Science Education research for my Master thesis (Sousa, 2015) and for my PhD thesis. Since Nature of Science (NOS) is fundamental for Science Education, and due to my experience and interests, we decided that the focus of my thesis should be to propose learning strategies and resources to be used in regular Kindergarten through University (K-U) education, facilitating the inclusion of NOS in Biology disciplines.

Why Problem-Based Learning? In the start of my professional life, teaching practical/laboratory classes at this Faculty, upon the frequent discussions with the discipline coordinator, Professor Isabel Santos, about the pedagogical methods I should use with the students in the practical classes I started reading about pedagogical methods, we also produced innovative resources to promote discussion with the students. In fact, we were using several features of PBL! And in 2006 I wrote a description of my experience in doing so and presented at a conference (Sousa, 2007). Afterwards, I also had some experience in implementing PBL in K-12 education with success (Sousa, 2013, 2014, 2015, 2016a).

As a K-U student I was very curious about the origin of life and evolution and I considered these themes fundamental and try to find disciplines/courses/seminars that address them in order to attend. So, when challenged by my PhD supervisor, Professor Isabel Chagas, to choose any subject to teach while integrating Nature of Science for my PhD thesis I choose these.

## 1.2. Theoretical context and relevance of the study

Presently, K-U Science Education faces several challenges such as the need to engage a large number and diversity of students in the classroom and achieve this in a short time frame. We, as other Science Education researchers, aim to overcome these challenges by developing teaching strategies to improve learning and motivation of students.

The goal of science education is the development of scientific literacy (Lederman et al., 2013) that is the “knowledge and understanding of scientific concepts and processes in order to make personal decisions, participate in civic and cultural affairs, and enter science and technology careers” (Wood, 2014, p.92). Understanding Nature of Science (NOS) has an important role in the development of scientific literacy (Holbrook & Rannikmae, 2007). Therefore, one of the main obstacles to the promotion of scientific literacy is the lack of informed conceptions about NOS of both students (Deng et al., 2011; Lederman et al., 2019) and teachers (Kartal et al., 2018). Additionally, within science education, we consider that biology education, for K-U and preservice science teachers’ education, aims to promote multidimensional biological literacy, as defined by Uno and Bybee (1994), including knowledge of nature and history of biology, so this was included in this thesis and will be discussed in a specific section II of Theoretical Background.

NOS has a long history of controversy (Matthews, 1998), has no consensus definition and according to McComas et al. (2002) constitutes a theoretical construct of “what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors” (p.4)

Active teaching methods are student-centered methods that enhance questioning, communication, argumentation and collaboration, such as Problem-Based Learning, the method of choice in the scope of this thesis, since we hypothesize that students' analysis of the designed resources, including the problem situation, can induce the cognitive conflict between their prior conceptions and the more informed conceptions of NOS (Loyens et al., 2015) and because PBL is also described as developing skills such as communication and collaboration, decision making, problem solving, critical thinking and autonomous learning (Wilder, 2015). We can find a rather consensual opinion that active, student-centered, learning strategies are superior to traditional or lecture-based strategies in promoting K-U students’ learning, and this is evidence-based as shown by a meta-analysis of 225 studies that indicate an increase in the average examination scores and a reduction of the probability of failure, comparing active methods with lecturing in STEM undergraduate students (Freeman et al., 2014).

The evaluation of the science epistemological knowledge of the students, as well as the identification and description of their epistemological conceptions has been object of study in the framework of a wide range of research projects in several countries worldwide. The results of such investigations have been a valuable contribution to the clarification of the Nature of Science, its teaching-learning practices and their effects on the involvement and achievement of students in science. Portugal is not included in several worldwide projects about the subject (e.g. Lederman et al., 2019), therefore the research in this thesis is of particular relevance as a contribution to knowledge in the field of NOS.

## 1.3. Research problem, objectives and questions

Since NOS understanding is fundamental to promote the scientific literacy (Holbrook & Rannikmae, 2009), NOS aspects should be addressed during K-U education and in preservice and in-service teachers' training.

We focused in some structuring themes of Biology, such as the origin of life and the ecological niche. Therefore, upon the review of the Portuguese and some international guiding documents and having in mind that, in Portugal, the Middle School (Portuguese 3$^{rd}$ cycle of Basic Education) corresponds to the last stage of schooling in which all the students attend Natural Sciences disciplines, we defined the 8$^{th}$ grade, as the K-U grade of interest for further study. Since students are the last beneficiaries of preservice and in-service training we also performed further studies with preservice teachers.

We addressed the following **research problem**: What are the effects of a Nature of Science enriched PBL process in both epistemological conceptions of science and biology conceptions of 8$^{th}$ grade students and preservice science teachers?

We propose to attain two main **objectives**:

1) to propose novel strategies and resources using PBL containing NOS aspects, for K-U Biology classes and preservice and in-service teachers' training, after testing their efficacy,
2) to contribute to the proposal of a questionnaire for characterizing science epistemological conceptions and to characterize Portuguese 8$^{th}$ grade students' conceptions.

We formulated the following **research questions** to address the research problem and attain the objectives:

➢ **Question 1 -** How to design and implement an innovative strategy, using NOS-enriched PBL, in the themes of origin of life and ecological niche to promote NOS and Biology learning in 8$^{th}$ grade students?

➢ **Question 2 -** What differences are observed in the science epistemological conceptions and performance about Biology concepts of 8$^{th}$ grade students, upon a short length NOS enriched PBL unit about the ecological niche?

➢ **Question 3 -** What differences are observed in the science epistemological conceptions and performance about Biology concepts of 8$^{th}$ grade students, upon a short length NOS enriched PBL unit about the origin of life?

➢ **Question 4 -** What are Portuguese 8$^{th}$ grade students' science epistemological conceptions? Are there gender differences in Portuguese 8$^{th}$ grade students' science epistemological conceptions? Are there correlations between Portuguese 8$^{th}$ grade students' science epistemological conceptions and other factors (e. g. favorite discipline, performance score at the discipline)?

➢ **Question 5 -** What differences are observed between PBL and non-PBL 8$^{th}$ grade students' science epistemological conceptions and biology conceptions upon an origin of life unit?

➢ **Question 6 -** What are the preservice science teachers' perceptions about the PBL environment during NOS-enriched PBL units?

➢ **Question 7 -** What differences are observed in the epistemological conceptions of preservice teachers, before and after a didactic intervention of NOS using PBL about the ecological niche concept and an insular biogeography model?

To target these research questions, several empirical studies were developed, each corresponding to a scientific abstract accepted in an international meeting and/or as manuscript published or under consideration in peer-reviewed international journal.

Additionally, as textbooks have been described as the main element that determines the content and discourse of middle and high school science classes (Abd-El-Khalick et al. 2017) we studied the presence or absence of the biological themes that are the focus of our didactic interventions, addressing the following research questions:

➢ **Question 1 -** What are the Biology contents in the Portuguese guiding documents and textbooks for K-12 education about structuring areas of Biology, such as the ecological niche concept?

➢ **Question 2 -** What is the importance attributed to Nature and History of Science in the Portuguese guiding documents and textbooks about the ecological niche concept?

➢ **Question 3 -** What are the theories in the Portuguese textbooks for K-12 education about the origin of life?

To address the previous questions, we performed reviews corresponding to a scientific abstract accepted in an international meeting and as manuscript under preparation in a peer-reviewed international journal.

As this thesis aims to contribute to improve teachers' practices we propose novel strategies and resources using PBL containing NOS aspects, for K-U Biology classes and preservice teachers' training, research instruments such as the questionnaire of students' epistemological conceptions of science, and guidelines to improve the content of textbooks, with the ultimate goal of improving students' scientific literacy.

## 1.4. Thesis structure

This thesis includes six chapters, starting with a general introduction (Chapter 1) that contextualizes the thesis, presenting its relevance, the research problem, questions and objectives of the study, as well as the thesis structure.

Then, the Chapter 2 includes a revision of the literature and it is divided in 2 sections: i) Science Education and ii) Biology and Philosophy of Biology.

In the Chapter 3 the Methodology used in this thesis and in each study is presented.

Furthermore, the results of each study and their discussion are presented in Chapter 4 – Results and Discussion.

Then, Chapter 5 provides conclusions of the thesis with an integrative discussion of all the results obtained and future perspectives.

In Appendix it can be found relevant educational resources produced (not included in the main text, due to space limitations) and a proposal of a mini-course for K-U teachers (workshop approved proposal for PAN-PBL 2019 Immersive Virtual International Conference entitled "Nature of Science through PBL for K-U science professionals").

# Chapter 2

# Theoretical background

# Chapter 2

# Theoretical background

Part of this chapter was already published or is in preparation for publication:

- Sousa, C. (2019). The potential of Problem-Based Learning to promote NOS understanding: using a History of Science enriched problem In P. Lindholm (Ed.), Understanding the Nature of Science (pp. 109-138). New York, USA.: NOVA Science Publishers. [section 2.2]
- Sousa, C. (ABT, submited). Origin of life: An Update on New Evidences and Theories that can Highlight Teaching-Learning About Nature of Science [sections 2.1. and 2.6]
- Sousa, C. (Science & Education, submitted) NOS-enriched Problem-Based Learning using History of Science combined with a Socioscientific Issue in preservice science teacher education [sections 2.7 and 2.8]

# Chapter 2 - Theoretical background

## Section I – Science Education Section

## 2.1. Nature of Science (NOS)

### 2.1.1. Controversial concept

The concept of Nature of Science (NOS) has a long history of controversy (Matthews, 1998). NOS refers to the values and conceptions inherent in scientific knowledge and its development (Lederman et al., 2002) and to the relationships between science, technology and society (Abd-El-Khalick et al., 1998). According to McComas et al. (2002) NOS is a theoretical construct that includes what science is and how it works, as well as sociological aspects of how scientists work and how society is involved in scientific research. Recently it is discussed whether there is only one or more than one NOS, whether to consider one Science or several, whether or not there are methods common to all scientists in various disciplines (Kampourakis, 2016a).

Despite the controversy in defining NOS, there is some consensus on defining aspects of NOS that are common to various scientific disciplines; as well as proposals for developing NOS aspects that are specific to each scientific discipline that coexist (Abd-El-Khalick, 2012). The most consensual NOS aspects, accessible to students from kindargarten to secondary education (K-12) and fundamental to all citizens are related to scientific knowledge (Lederman et al., 2002) which: is mutable, it is based on observations of the natural environment (empiricism), is composed of theories, is related to human actions, such as inference, imagination and creativity, and is dependent on the society and culture in which it operates. Two more generally included aspects are the distinction between observations and inferences and the relationship between theories and laws (Lederman et al., 2002). Later Abd-El-Khalick (2012) proposed the addition of one more aspect about the social negotiation of science, referring to the peer review processes of scientific publications.

These NOS aspects have been included in curriculum documents on U.S. Science Education (States, 2013). However, there is some controversy surrounding the NOS aspects commonly referred to as consensual, but several authors state whether it is necessary to replace or enrich with other aspects (Allchin, 2013, 2017; Allchin et al., 2014; Deng et al., 2011; Hodson & Wong, 2017; Matthews, 2015). Allchin (2017) proposes to consider 3 epistemic dimensions of science: observational (e.g. including aspects of precision in observations and measurements), conceptual (e.g. including aspects of verifiable information versus values) and sociocultural (e.g. including peer review aspect). This NOS approach, in accordance with these dimensions of science, is called, by the author Whole Science.

According to Matthews (2015) the 7 aspects of NOS described by Lederman et al. (2002) should be referred to as Features of Science and complemented by other features such as experimentation, idealization, models, values and socio-scientific subjects, mathematization, technology, explanation, worldviews and religion, choice of theories and rationalism, feminism, realism and constructivism.

Dagher and Erduran (2016) propose an expanded Family Resemblance Approach by defining the following aspects: scientific values and objectives, scientific knowledge, scientific practices, scientific methods and methodological rules, professional activities, scientific ethos, dissemination and social certification and social values. According to these authors, this approach promotes an understanding of holistic and contextualized science that is subdivided into a cognitive-epistemic system and a socio-institutional system (Dagher and Erduran, 2016).

Following another theoretical line, Osborne (2017) considers that NOS teaching should focus on teaching the following six styles of scientific reasoning: mathematical deduction, experimental exploration, hypothetical modeling, categorization and classification, probabilistic and statistical thinking, and evolutionary accounts of origins.

Considering that there are major differences between scientific disciplines, namely in the type of questions posed, Hodson and Wong (2017) use the concept of understanding scientific practice to propose the replacement or enrichment of the consensus view of NOS and suggest the inclusion of aspects of scientists' daily practice. According to these authors the fundamental aspects to consider are the distinct language of Science, the characteristics of the scientific inquiry (including variants related to the various scientific disciplines), the role and state of scientific knowledge, the construction of scientific theories, the social and intellectual context. from new developments, the way scientists work as a social group, the values and conventions related to scientific practice, the ways science impacts and is subject to impact from the social context. The authors add that the various aspects of NOS that should be addressed in teaching are organized into 3 categories: learning about scientists, learning from scientists, and learning with scientists, and also refer to the distinction between science and pseudoscience as a key aspect to be addressed. be included in the teaching.

Lederman and Lederman (2019) proposes that the term 'nature of science' be replaced by the term 'nature of scientific knowledge' in order to distinguish it from the scientific inquiry. Separating it from NOS Lederman et al. (2014) explain that the scientific inquiry includes investigative procedural capacities, general scientific capacities, creativity and critical thinking. In VASI ("Views About Scientific Inquiry") questionnaire primary to secondary students are supposed to understand the following aspects (Lederman et al., 2014): scientific research usually starts with a question and does not necessarily test a hypothesis; there is not just one scientific method; the investigative process is guided by a question posed; different scientists using the same procedures may not find the same results; research procedures may influence results; research findings must be consistent with the results obtained; observations are not the same as evidence and scientific explanations are developed from the results obtained and what is already known about the subject.

In the continuation of this discussion Kampourakis (2016b) suggests that NOS teaching should begin with the characteristics of scientific knowledge and scientific inquiry, according to the consensus view, and then gradually move towards NOS aspects within family resemblance approach, such as values and practices and social organizations and interactions.

### 2.1.2. Our teaching framework

Our proposal consists in 12 aspects of NOS within 3 dimensions (Figure 2.1) based on relevant existent literature, including a well stablished McComas's model of 9 NOS aspects.

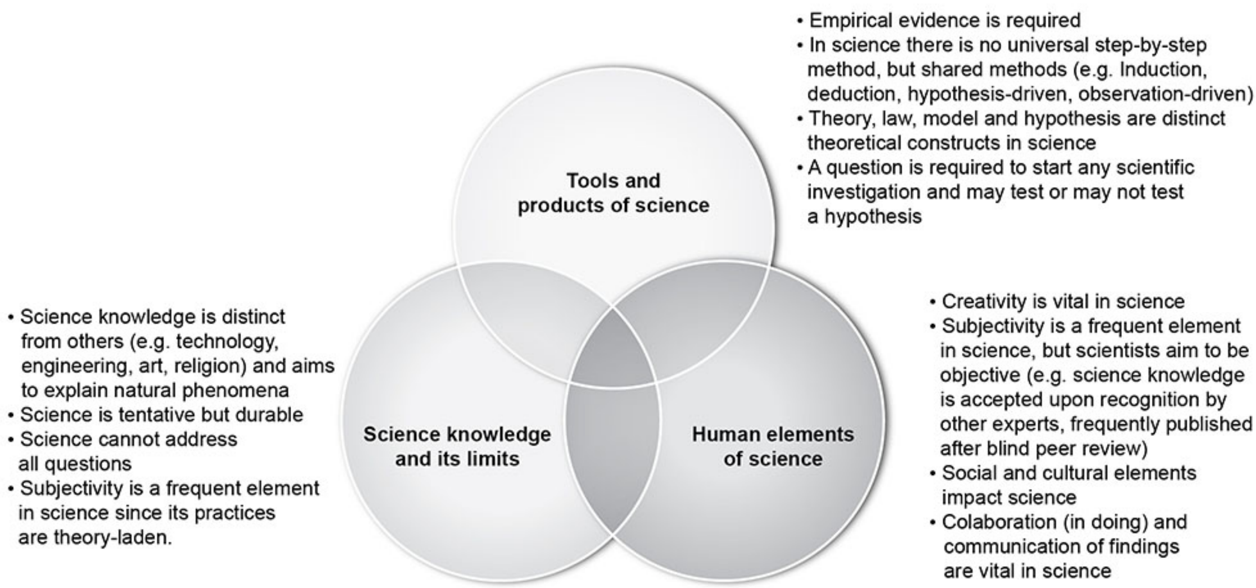


**Figure 2.1.** A dozen of main aspects of NOS for Science Education within 3 clusters (adapt. McComas, 2017): tools and products of Science, Science knowledge and its limits and human element of Science. Note: elements in each cluster are found written outside, nearby.

Briefly, according to McComas (2017) NOS aspects are grouped in 3 clusters (with elements present in the intersection portions of the Venn diagram): Tools and products of Science; Science knowledge and its limits and Human elements of Science). The background for this proposal is present in the literature at least since 2002 (McComas, 2002): theories, laws and models are different forms of scientific knowledge that are not related in any developmental sequence and have equal importance. Science relies on empirical evidence (McComas, 2002) - observations as descriptive statements about natural phenomena that are directly perceived, by human senses, for example using specific instruments, and inferences that are statements about natural phenomena that are not directly perceived by human senses (Lederman et al., 2002) - as well as on scientific arguments (Allchin, 2011). Scientific knowledge does not provide any absolute proof and is mutable, is tentative and subject to change, this idea of "progress" of science has been considered fundamental (Espinoza, 2012, p7). According to McComas (2004) scientific knowledge is one type of knowledge that explains natural phenomena and it distinct from others (e. g. Religion, Art) and its methods cannot answer all questions. Closely related one can find scientific predictions related with some level of uncertainty (Kampourakis, 2020), that are possible for some explanations (e.g. in some cases in Meteorological Sciences), but not for most explanations of descriptive sciences (e. g. Paleontology, origin of life). For these last sciences one can simulate similar conditions in a laboratory and, for example, compare genomes of different species. Additionally, in Science there are several scientific methods and not a single method and a scientific investigation may be observation- or hypothesis-driven, depending on the question to be addressed (Sousa, 2016b) so I additionally included this aspect in the dimension of the diagram "Tools and Products of Science".

We consider to be important to bridge Nature of Scientific Knowledge (NOSK) and Nature of Scientific Inquiry (e. g. any investigation starts with a question) and not all scientific practices (generally named Scientific Inquiry). Our proposal of these NOS aspects is supported in additional literature that propose "general aspects of NOS" (Kampourakis, 2016b) and Science demands for creative and imaginative scientists (Allchin, 2011) and is influenced by historical, cultural, and social contexts (Allchin, 2011) as any other human activity. Another relevant aspect of NOS is theory-laden that is part of the subjectivity frequently found in science (McComas, 2017) for example in the collection and interpretation of data, although some natural scientists and science education researchers consider Science to be objective if considered as a "collective knowledge" (Galili, 2019). Overall our proposal is a consistent but a simplified version of the Family Resemblance Approach by Erduran and Dagher (2014).

### 2.1.3. Assessing NOS

Regarding the identification and eventual evaluation of students' NOS conceptions, there are several methods described since the 1950s (Lederman, 2007), namely: questionnaires (with open and/or closed answer items), interviews and observation. Allchin (2011) proposes prototypes of integrated issues in contemporary cases that require students to make an informed analysis based on the dimensions of Whole Science (using resources such as newspaper and magazine news).

Lederman and Lederman (2014) have proposed open-ended questionnaires, such as their VNOS (Views of Nature of Science) questionnaire, with various versions (A, B, C, D, E) for different levels of education, the Views of Scientific Inquiry (VOSI), which has been improved, giving rise to the Views About Scientific Inquiry (VASI).

Other authors consider the epistemological conceptions of science by proposing the SEV (Scientific Epistemological Views) questionnaire, with Likert scale, and 18 items (Tsai & Liu, 2005) or 25 items (Liu & Tsai, 2008). This questionnaire was given to high school students (Tsai & Liu, 2005) and Taiwanese teachers (Tsai, 2007). It is organized according to 5 dimensions (Liu & Tsai, 2008; Tsai & Liu, 2005): the role of social negotiation, the imaginative and creative nature of science, the exploration of theory-based knowledge, the cultural impacts and the changing characteristic of the scientific knowledge.

Tsai (2006) created a questionnaire on the views on biology and physics, namely on the changing nature and creative characteristics of both sciences.

Dogan and Abd-El-Khalick (2008) administered the VOSTS questionnaire (Views on Science-Technology-Society), which consists of 114 multiple-choice items, or adaptations using only 14 items. The chosen items include various aspects of NOS, such as: scientific observations based on theories, mutability of scientific knowledge, relationship between scientific constructs and reality, epistemological status of different types of scientific knowledge, myth of a single scientific method, non-linearity of scientific investigations and the role of scientific reasoning in the development of scientific knowledge.

The Epistemic Beliefs in Biology (EBB) Questionnaire (Lee et al., 2016) was designed on the basis of the Epistemological Beliefs Questionnaire for 5$^{th}$ grade (Conley et al., 2004) and is subdivided into 4 dimensions: source, certainty, development and justification.

Other authors propose questionnaires that include aspects of the Nature of Science and the investigative process (Liang et al., 2006; Park et al., 2014). The Student Understanding of Science and Investigative Process (SUSSI) questionnaire includes 24

Likert scale items and 6 open response items and is subdivided into 6 dimensions (Liang et al. , 2006): observations and inferences; change of scientific theories, laws versus theories; social and cultural influence on science; imagination and creativity in scientific research and methodology of scientific research. Park et al. (2014) developed a questionnaire based on others, namely SUSSI, for students of 8$^{th}$ grade, with 15 closed items and 5 open response items, subdivided into 5 dimensions: mutability of scientific theories, observation in Science, knowledge based on empirical evidence, socio-cultural aspects included in science and diversity of scientific methods.

The different instruments mentioned also allow the assessment of the students' conceptions to guide the researcher to define the student profile that can be naive (also called positivist, traditional and empiricist) or informed (also called sophisticated and constructivist) regarding each aspect NOS and the profile is considered transient if the student has a naive profile with respect to some NOS aspects and an informed profile with respect to others (Lederman et al., 2015; Tsai, 2007). The notion of conceptions as a continuum of naive - transient - informed profile is useful for assessing design changes in a given aspect (Lederman et al., 2015).

In this subchapter we present a variety of instruments suitable for students, namely for the 8$^{th}$ grade, from which items were selected (Liang et al., 2006; Liu & Tsai, 2008; Tsai & Liu, 2005) for our questionnaire.

Different authors refer to students' knowledge of NOS (focus of this project) as epistemic beliefs, views, perceptions, beliefs; our choice for the term "epistemological conceptions of science" is based on the fact that we consider them as curriculum content, requiring specific strategies for their identification and conceptual change.

### 2.1.4. Students' conceptions about NOS

In general, studies conducted over the years have described low levels of knowledge about Nature of Science in students and teachers (Lederman et al., 2014; Lederman, 2007) and about scientific inquiry in students (Lederman et al., 2019).

Tsai and Liu (2005) describe that 613 Taiwanese high school students have a wide range of views on the impacts of culture on scientific knowledge over a range of values from 1 (minimum) to 5 (maximum), an average of 4.22 was observed for the mutability dimension of scientific knowledge, but also for a response range of 2.33 to 5, an average of 3.77 for the role social negotiation, and 4.05 on the inventive and creative nature of science; regarding the theory-based knowledge exploration dimension, the average student response is 3.96 (Tsai & Liu, 2005). In the scope of that study was also given the questionnaire to the teachers of these students and significant differences, with greater value for teachers, were observed in the dimensions related to the impacts of culture on scientific knowledge and the mutability of scientific knowledge (Tsai & Liu, 2005).

Tsai (2006) describes, based on the results of his study, that high school students show higher values relative to the changing nature of biology compared to values relative to the changing nature of physics; while the values for the creative characteristics of both sciences are identical. The author concludes that epistemological beliefs about biology are different from those of other sciences, namely, according to Taiwanese high school students, biological knowledge is more changeable than physical knowledge.

Khishfe and Lederman (2007) report that between 0 and 29% of the 129 high school students participating in their study have informed views about NOS (using the VNOS questionnaire).

In a national study in Turkey, an adaptation of the VOSTS questionnaire was given to 10th grade students. For the different items there was a percentage of students with informed views from 0 to 68.2%; there was also a positive relationship between students' informed views and the socio-economic conjuncture of the region where their schools are located (Dogan & Abd-El-Khalick, 2008).

In their study of 227 8th grade students in the U.S. A. Lederman et al. (2014) describe that students' views on the investigative process, using the VASI questionnaire, are mostly traditional, or poorly informed or naive (e.g. views that do not agree with accepted knowledge for one aspect, they do not agree with the statement that scientific investigations begin as a question, but do not necessarily test a hypothesis) or transient, or mixed, regarding the 8 aspects related to the investigative process considered by the authors in their study. Only 0% to 26% of students revealed informed views. After the teaching-learning process their views improved from naive to transient or mixed to transient to informed.

In the qualitative study by Kuçuk and Çepni (2015) with 17 students 7th graders from a Turkish school with an average age of 13 years, using a questionnaire with open questions about the nature of science and interviews, it is reported that 65% of students have a traditional NOS view, and only 12% of students revealed informed view (to classify the view as informed students had to justify their answer in the questionnaire) regarding the changeable nature of scientific knowledge. The traditional NOS view is 41% on the differences between observation and inference, and 47% on the role of information gathered in the construction of scientific knowledge and 71% on the question of creativity and imagination in the Nature of Science. In conclusion, they say that 78%

of students (including average traditional visions and 22% of students with transient vision) were found to have an inadequate understanding of the Nature of Science (Kuçuk & Çepni, 2015). These authors also conclude that the results of their study support the notion that learning through investigative activities is not sufficient to teach NOS.

The conceptions about Nature of Science of 214 students from 4 schools in Toronto (Canada) and 307 students from 3 schools in Busan (South Korea) from 8th grade, with an average of 14 years, were studied by Park et al. (2014), in a mixed study, which described the lowest values (approximately 2.5 on a scale of 1 to 5), related to questionnaire items, obtained by students from both countries, regarding the subjectivity dimensions and possibility of empirical tests. There was a significant difference between the two groups regarding the dimension of scientific observation and subjectivity, with the more informed perception of Canadian students (3.27 on a scale of 1 to 5) and poorly informed perception of Korean students (2.46) (Park et al., 2014). Canadian students turned out to be more relativistic and multiculturalist in their conceptions of science than Korean students, who are more realist and universalist (Park et al., 2014).

Understanding of NOS aspects can also be assessed by students' ability to reason about NOS aspects (Deng et al., 2011; Khishfe et al., 2017). These authors conclude that the 11th grade students from Saudi Arabia who participated in their study who produced good arguments about socioscientific issues also demonstrated more informed views about NOS (Khishfe et al., 2017).

Lee et al. (2016) describe in their article that students with less sophisticated NOS perceptions, namely with a belief in the certainty of biological knowledge, use more superficial and memorization-based learning strategies. The authors conclude that students' epistemic perceptions allow them to predict their attitudes, effectiveness, motivation, metacognition and performance.

A more informed view of students' NOS is associated with better learning and better attitudes towards science (Tsai & Liu, 2005) as well as the development of more integrated science knowledge structures (Tsai, 2007).

Recently, an international collaborative investigation of 7th grader students using the VASI questionnaire showed a worldwide (not including Portugal) average regarding each scientific inquiry aspect of less than 50% of students with informed conceptions and 54.4% of naïve conceptions on the aspect of existence of multiple methods and 39.7% of naïve conceptions on the aspect conclusions must be consistent with data collected (Lederman et al., 2019).

Misconceptions about NOS have also been described in preservice biology teachers (Adedoyin & Bello, 2017) and in Portuguese prospective science teachers (Torres & Vasconcelos, 2016).

In summary, the studies described in this subchapter identify students' conceptions mostly as traditional or naive, which served as background for the design and implementation of this project on the epistemological conceptions of Portuguese students. The analysis of these studies also served as the basis for the construction of data collection instruments.

### 2.1.5. Strategies to teach about NOS

Strategies for teaching about NOS aspects have been classified as implicit or explicit. Advocates of implicit strategy consider students to develop more sophisticated views of NOS through teaching-learning processes that use investigative activities, while explicit strategy (also called explicit reflective strategy) is based on identifying NOS aspects as cognitive goals of the NOS. teaching-learning process in which students discuss and reflect on NOS by developing their own understanding of the various NOS aspects addressed in class (Lederman, 2007).

The literature has revealed some debate among advocates of each of these strategies, although several studies have shown that explicit teaching is more successful than implicit (Khishfe & Abd-El-Khalick, 2002; Khishfe & Lederman, 2007; Lederman & Lederman, 2014).

According to Lederman et al. (2014) using the investigative process in class and classroom is not enough to understand the investigative process or the Nature of Science. Students may participate in investigative activities, but the characteristics of the investigative process must be explicitly addressed in order for students to understand and apply them.

NOS has been recognized as a cognitive goal (Lederman et al., 2015), so students are expected to be able to: distinguish observation from inference, and also distinguish theory from law; understand that scientific knowledge, in part, is empirical, but includes human imagination and creativity; understand that scientific knowledge is subjective and theory-laden; to know that science is a human endeavor dependent for example on its culture, philosophy and religion and to understand that scientific knowledge is neither absolute nor right, but is subject to change.

Allchin et al. (2014) consider 3 distinct classroom strategies that promote learning about NOS. Such strategies allow the necessary contextualization of the NOS in the themes covered within the program of a given science discipline: historical cases, contemporary cases and investigative activities. Mulvey and Bell (2016) propose another strategy centered on the discussion of socio-scientific issues, also leading to the learning of specific scientific content.

In this thesis we used an explicit NOS teaching-learning strategy, since, as previously described, this strategy has shown positive results in students' learning about NOS.

## 2.2. Problem-Based Learning

### 2.2.1. Background

Active learning environments, under the constructivist epistemology, such as Inquiry-Based Learning (IBL), Project-Based Learning (PjBL), Case-Based Learning (CBL), Discovery Learning (DL) and Problem-Based Learning (PBL) are student-centered. Since these require students to use higher order thinking skills (e.g. analysis, synthesis, and evaluation) and promote several skills, such as questioning, critical thinking, argumentation and, if performed in group, also collaboration and communication (Wilder, 2015), are considered adequate to Science Education and 21st century competencies learning. Active learning has also been described to increase student performance, comparing with traditional lecturing, in Science, Engineering and Mathematics (Freeman et al., 2014) and Biology (Brigati, 2018).

A summarized comparison of five active learning pedagogies student-centered is presented (Table 2.1).

**Table 2.1.** Comparation of five active learning environments.

| | PBL | PjBL | IBL | CBL | DL |
|---|---|---|---|---|---|
| Learner-centered | +++ | +++ | +++ | +++ | +++ |
| Process | +++ | +++ | +++ | ++ | +++ |
| Content | + | +++ | ++ | +++ | + |
| Interdisciplinary | + | + | + | +++ | ++ |
| Methods | +++ | ++ | ++ | +++ | ++ |
| Reflection | +++ | +++ | +++ | +++ | + |
| Assessment | +++ | +++ | +++ | ++ | +++ |
| Collaboration | +++ | ++ | ++ | ++ | + |
| Teacher support | Facilitator | Guide | Guide | Guide | Guide/+ |
| Learning driven | Problem | Output | Question | “Real-life" case | Experiences and questions |

Source: Cattaneo (2017); Hammer (1997); Oguz-Unver & Arabacioglu (2014).

Note: +++ = aspect considered important; ++ = aspect discussed; + = aspect usually not important or not mentioned.

All of these active learning environments can be implemented with varying degrees of teacher support, according to learners' experience in an active environment, using higher student guidance and scaffolding with inexperienced students.

In active learning environments if the students do not have sufficient conceptual background to perform the investigation, the new concept should be introduced by the teacher (e.g. with a lecture) or through a textbook, a video or a website.

While DL is based on Jerome Bruner (1915-2016)'s ideas, PBL, PjBL, IBL and CBL are based on John Dewey (1859-1952)'s ideas (Hammer 1997, Oguz-Unver & Arabacioglu 2014).

### 2.2.2. Characterization

Problem-Based Learning (PBL) is an "instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2006) or to provide a description of a phenomena that needs to be explained (Wijnia, Loyens, & Rikers, 2019).

PBL was proposed by Howard Barrows (1928-2011) and started in medical education in 1969, at McMaster University, in Canada (Barrows 1996). It is also called Context-Based Learning (Murie, 2014) and is characterized by (Wijnia et al., 2019): being a student-centered approach in which students work in collaborative small groups, that uses ill-structured problems (i.e. with multiple solutions or solution paths) to initiate the learning process, includes teachers as tutors that guide the learning process and includes self-study. It has been said that Barrows considered that John Dewey had PBL in mind (McCaughan, 2013) and, in fact, the idea of *problem* seems to be central in Deweyan philosophy as he considered "the origin of thinking is some perplexity, confusion, or doubt" (Dewey, 1910, p.12).

Since the 1970s PBL has been implemented in different disciplines and on several educational levels (Ertmer & Simons, 2006), so it is not possible to identify one single model of the PBL process as several approaches on how to apply it have been described. PBL was first introduced as a simulation of professional practice, yet other approaches to PBL have been suggested, such a mental model construction, in which the problem is a description of a phenomena that needs to be explained (Wijnia et al., 2019).

PBL is the learning method proposed, in this chapter, since it has been described as constructive, self-directed, collaborative and contextual (Dolmans et al., 2005), activating prior knowledge (Schmidt et al., 2011), able to promote conceptual change (Loyens et al., 2015) and longer-term knowledge retention (Strobel & Barneveld, 2009). It has also been described to be able to develop several skills in students, adequate for Science and NOS teaching, such as (Wilder, 2015): communication and collaboration skills, decision-making, problem-solving, critical-thinking, and self-directed learning.

In PBL students work, in small teams, on problems, before they have received any other teaching input about the subject and are expected to propose a solution or an explanation to the problem (McComas & Hayward, 2014).

The teacher, as a PBL tutor, and a metacognitive coach (Savery, 2006), facilitates learning by helping students to monitor their own learning and providing feedback (Dolmans et al., 2002), therefore teaching students how to learn.

### 2.2.3. PBL cycle

The most commonly used approach for the PBL "as mental model construction" is the Seven Step method, proposed by the Maastricht University, in The Netherlands, and this number of steps in the PBL cycle has been either reduced or extended in several other methods (Wijnia et al., 2019). The PBL method presented in this chapter, previously used by the author, at the University level (Sousa, 2007) and in K-12 education in Life and Earth Sciences classses (Sousa, 2014), was adapted from DiCarlo (2006), including the following five steps, performed by students in small collaborative groups, teams of 3 to 5 students (Figure 2.2): *step 1)* starts with students' clarification of the problem-situation and what they already know; *step 2)* brainstorm (small-group discussion during which the students question the issues in the problem-situation, activate former knowledge, and hypothesize possible solutions); *step 3)* students identify, discuss and distribute the themes/questions to study either individually or in group; *step 4)* individually or in small-group perform the search in different sources and/or perform investigative activities.; *step 5)* students communicate the findings to the small group and discuss possible solutions to the problem, then students communicate their proposed solution to the class, and may or may not carry out assessment of the progress and self-evaluation. Then students are expected to propose a new problem. This sequence is not strick since any of these steps can be repeated at any time-point.

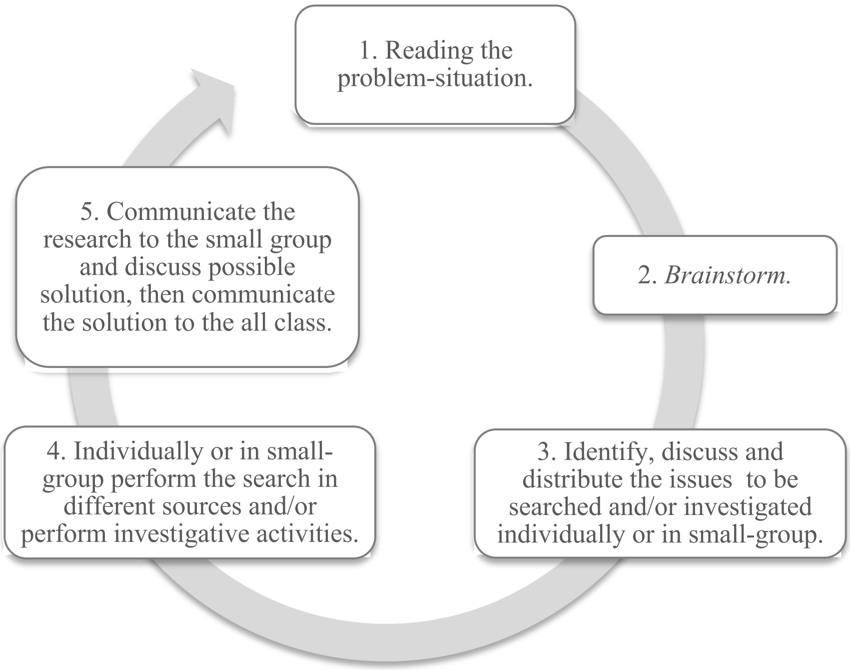


**Figure 2.2.** The Problem-Based Learning cycle, adapted from DiCarlo (2006).
Source: Sousa (2007, 2015).

### 2.2.4. Evidences of effectiveness compared with traditional teaching

Recent meta-analysis studies, in medical education, have showed that PBL is more efficient than traditional lecture teaching in promoting several skills such as problem solving, self-directed learning and collaboration (Ding et al., 2014) and one of these studies quantified a standardized mean difference of 1.46 in improving knowledge and skills comparing with traditional teaching (Wang et al., 2016).

A meta-analysis of the impact of PBL on students' achievement in High-School comparing with lecture-based methods showed that only 7 of the 10 articles studied demonstrated that PBL was more efficient and in 1 of these 10 studies the students's scores were lower in the PBL condition (Wilder, 2015). This author argued that the assessment of students' achievement in all the studies was based on recall conceptual and factual knowledge, while PBL is described to develop other skills (Wilder, 2015), what may explain the results observed.

A recent systematic review of the literature about Kindergarten to Middle School Science Education, showed that PBL is as effective as traditional teaching in promoting students' achievement and knowledge retention and in the majority of the articles studied PBL has positive effects on students' achievement, knowledge retention, conceptual application and attitudes (Merritt et al., 2017).

A quasi-experimental study has showed the efficacy of PBL in student's ability to apply the novel concept in new contexts comparing with traditional lecture/discussion method, in undergraduated physics students (Pease & Kuhn, 2011). These authors also described that there are no significant differences between PBL-individual condition and the PBL-team condition in students' assessments, showing that the engagement with problem is the defining component of PBL and not the social interactions (Pease & Kuhn, 2011).

Wirkala and Kuhn (2011) studied Middle School students, in a classroom setting, using a quasi-experimental, crossed within-subjects design, showing that the number of concepts defined by students after the intervention in PBL-team and in PBL-individual conditions were not statistically different, and the number of concepts defined by students in the PBL-team condition was superior to the lecture/discussion condition.

### 2.2.5. Role in NOS teaching

Naïve conceptions or misconceptions (or alternative conceptions) about NOS (e.g. empiricist/ positivist views, considering that hypotheses and theories can be proven, and that theories upon testing and confirmation mature into laws) are usually found in students (Lederman, 1992, 2007; Lederman et al., 2019; Deng et al., 2011) and in Science preservice and in-service teachers, before any NOS instruction (Lederman, 1992; Kartal, 2018) – so how can we address this?

One approach when planning a NOS learning environment, is to use Kuhn's thoughts about scientific concept formation (Kuhn, 1993):

> "Four essential elements of my developed position are, in any case, to be found there [referring to his mentor's book]: scientific terms are regularly learned in use; that use involves the description of one or another paradigmatic example of nature's behavior; a number of such examples are required for the process to work; and finally, when the process is complete, the language or concept learner has acquired not only meanings but also, inseparably, generalizations about nature."
>
> (Kuhn, 1993, p.312)

Therefore, to promote students' learning about the concepts of theory and hypothesis these can be introduced using "paradigmatic examples" (Kuhn, 1993, p. 312), that is, the examples of specific theories and hypothesis.

Different approaches used to teach about NOS have been used and are commonly classified into 3 categories (Lederman, 1999):

- implicit approach - suggests that by doing science (e.g. participating in authentic scientific investigations) will allow students to develop more informed views of NOS and scientific inquiry,
- historic approach - employs episodes from the history of science to enhance students' views of NOS and
- explicit approach - specifies that instructional goals related to the NOS should be planned as any other subject learning objective.

According to Lederman (1999), learning about NOS and scientific inquiry is best enhanced through an explicit reflective approach, and he emphasizes that it is important to spend some time, at the conclusion of any learning activity, to explicitly discuss and point out to students the aspects of the NOS and scientific inquiry present.

Upon comparison of implicit (engagement in research activities), reflective (includes additionally reflective seminar on NOS) and explicit (additionally includes participation on NOS activities) approaches, in the context of a summer authentic research experience with secondary school students, it has been suggested that an explicit approach promotes the increase in NOS understandings more frequently than the other two approaches (Burgin & Sadler, 2016).

NOS instruction has also been categorized regarding the science component (Bell et al., 2011):

- contextualized - NOS learning is integrated within specific science content,
- non-contextualized - NOS learning is the primary focus of instruction, without connecting it to a scientific subject.

A study with preservice elementary teachers by Bell et al. (2011) suggests that NOS instruction is most effective using an explicit approach and that teaching NOS in a contextualized way (within global climate change issue teaching) was as effective as teaching in a non-contextualized way (using only activities specifically designed to promote particular aspects of NOS). These findings corroborate previous studies, such as Khishfe & Lederman (2007) that showed that explicit NOS instruction improves 9$^{th}$ and 10$^{th}$/11$^{th}$ grade students' views of NOS whether integrated within content or through generic NOS activities.

In summary, we find several studies in a continuum in one end with explicit and reflective highly contextualized NOS teaching and in the other end implicit and non-contextualized NOS teaching.

According to Abd-El-Khalick & Lederman (2000) NOS should be treated as a cognitive domain and explicitly taught like any other component of the science curriculum and this can be achieved by integration into a framework of teaching for conceptual change (Abd-El-Khalick & Akerson, 2004). Conceptual change is the “process by which people’s central, organizing concepts change from one set of concepts to another set, incompatible with the first” (Posner et al., 1982, p. 211). Posner et al. (1982) suggested 4 necessary, but insufficient conditions for conceptual change: dissatisfaction with a currently held idea, and the perception of existence of a new conception that is intelligible, plausible and fruitful. The conceptual change model assumes that “ontogenetic change in an individual’s learning is analogous to the nature of change in scientific paradigms that is proposed by philosophers of science” (Pintrich et al., 1993, p.169).

Given the ubiquitous misrepresentation of NOS in everyday life, out-of-school settings (e.g. television, internet), and most school settings, a consistent image of NOS that resists efforts of conceptual change is created, so it is necessary to design instructional contexts that persuade students to reexamine their naïve NOS conceptions, for example by questioning, drawing students’ attention to NOS aspets they may have missed and discussing students’ ideas (Clough 2006). According to Clough (2006, p474) NOS teaching is more efficient if done in a reflective/explicit and contextualized way since “efforts to improve students’ understanding of the NOS and science content are complementary with each reinforcing the other”, however NOS teaching can also be performed during time in a decontextualized/ contextualized NOS continuum using appropriate scaffolding.

It was shown that upon a conceptual change intervention with preservice elementary teachers the percentage of learners with informed conceptions increased significantly (Abd-El-Khalick & Akerson, 2004).

Regarding teaching about NOS using PBL we can find a small number of studies that in fact implement it and present data regarding quantification of its outcome. A study that showed an efficient PBL intervention with 7$^{th}$ and 10$^{th}$ grade students (Sousa, 2013, 2014), by the author, in improving NOS and Biology and Geology conceptions. Also, in 2014 another study was published by Akerson et al. that showed that PBL increased the percentage of adequate views about NOS of preservice science and mathematics teachers during an undergraduate elementary science methods course. More recently, Maeng et al. (2018) claim to use PBL for NOS instruction, and being the first to implement this, in their study using a professional development program of elementary teachers, that I think constitutes an example, according to the informations included, of Project-Based Learning, PjBL not PBL. They showed that elementary teachers’ ability to incorporate NOS in their classes upon completing their programme was higher comparing with a control group not experiencing the same programme (Maeng et al. 2018).

In fact, according to Loyens et al. (2015) PBL has several features that are likely to enhance conceptual change, such as activation of prior knowledge (when students try to explain the problem with their preliminary ideas), group discussion and a critical analysis of arguments (problems that enhance high quality discussion are the ones that provide cues for opposing viewpoints), and encouraging a deep comprehension of the information by promoting accommodation of new information in a way that allows them to apply it in future new situations. These authors, studying undergraduate students in a physics discipline, showed higher scores in a problem-solving task in the PBL-group compared with both participants in the lecture-based and in the self-study group on both the immediate post- and the delayed post-test.

### 2.2.6. Guidelines used for implementation

It is important that the learning environment designed by the tutor allows students to understand the scientific knowledge as interconnected, meaningful, and useful, using a context similar to the one they will encounter and in which they will apply the knowledge in the future, such as an ill-defined problem that requires evaluating scientific findings and arguments (e.g. presented by the media), determining the benefits and risks of health and environment policies, using research and investigative skills and constructing scientifically-based explanations of everyday phenomena (Hmelo-Silver et al., 2007). It has been described that the students’ learning is to a large extent dependent on the quality of the learning environments they encounter, therefore I suggest following the principles previously proposed to design effective PBL environments. The learning environment should (Dolmans et al., 1997): be well adapted to students' prior knowledge, contain several cues that stimulate students to elaborate, provide a context that is relevant to the student (e.g. real-life, future profession), present relevant basic sciences concepts in an adequate context to encourage integration of knowledge, stimulate self-directed learning by encouraging students to generate learning issues and conduct literature searches, enhance students' interest in the subject-matter, by sustaining discussion about possible solutions and facilitating students to explore alternatives and match one or more of the learning objectives defined by the teacher.

PBL includes direct instruction as a strategy just-in-time when students show the need of a concept to pursue their learning (Hmelo-Silver et al., 2007). For inexperienced learners in selecting literature, the tutor can provide a set of resources, such as a list of articles, books, websites and webquests.

Although some authors claim PBL is a minimally guided approach (Kirschner et al., 2006), it includes scaffolding and guidance to facilitate student learning (Hmelo-Silver et al., 2007). Soft-scaffolds (provided orally, e.g. asking students to explain their thinking) and hard-scaffolds (digital or in paper support, e.g. a webquest) provide students with the information of how to do the task as well as why the task should be done in a certain way, constituting similar forms of guidance recommended also by the Cognitive Load theory defenders (Hmelo-Silver et al., 2007).

Frequently, during PBL, students take roles such as reading the problem or taking notes, so it is important that the tutor encourages the students to try all of the roles and be always actively involved in the group work.

## 2.3. History of Science for NOS teaching

History of Science constitutes one way to illustrate key aspects of NOS to students, providing “a context for or example of” (McComas, 2008, p.251). Using History of Science in the classroom “can humanize science by raising instruction from the mere recitation of facts to its exploration as an authentic and exciting human adventure” (McComas 2008, p.262).

James B. Conant (1893-1978), a scientist, professor and president of Harvard University, taught undergraduate courses and wrote books about History and Philosophy of Science, and suggested that all necessary knowledge about science for any citizen, in a college level course on ‘Understanding Science’ (Conant, 1947, p.98), could be obtained from studying a few historical examples (Conant, 1947). He considered that almost all historic episodes should be chosen from the “early days in the evolution of the modern discipline. Certain aspects of physics in the 17th and 18th centuries; chemistry in the 18th and 19th; geology in the early 19th; certain phases of biology in the 18th; others in the 19th” (Conant, 1947, p. 17-18), due to the advantage of smaller factual knowledge content. These historical examples promote the understanding of what science is by studying how difficult it was its start (Conant, 1947). With the selected historical episodes, in which the new concepts have arisen from observations and experiments, he expected to stimulate the learner to read further about History of Science and to follow current scientific developments through articles and books in the future (Conant, 1957).

According to Clough (2006) highly contextualizing NOS strategies needs integration of historical and contemporary science examples, connected to the fundamental ideas that should be included in the curricula of particular science subjects, since these examples enhance understanding of science content and exemplify important epistemological lessons that are central to understanding about NOS.

The purpose of using historical episodes is to include the humanistic subject matter and not to teach history as the primary goal, that could decrease the interest by the science content (Clough, 2006).

The historical episodes chosen, in this thesis, are further explored in the Biology Section.

## 2.4. Socioscientific Issues for NOS teaching

Socioscientific issues (SSI) are "complex societal issues with conceptual, procedural, and/or technological associations with science" (Sadler et al., 2016, p.1622). SSI include Science-Technology-Society (STS) education and also the ethical dimensions of science and the moral reasoning of the student (Zeidler et al., 2002).

According to Zeidler et al. (2019) learning SSI help students to be better prepared to decision-making about SSI, mainly due to the development of socioscientific reasoning competencies.

One of the main focus of SSI research is learning about Nature of Science and it was shown that the nature of these SSI (social, tentative and subjective) facilitate the role of teachers in engaging students in a discussion that includes many aspects of NOS (Zeidler et al. 2002). Instruction using SSI has been shown to promote gains in most of NOS aspects in 11$^{th}$ and 12$^{th}$ grade students (Eastwood et al., 2012).

Tidemand and Nielsen (2017) showed that several teachers do not use SSI due to small recognition of their potential for teaching, lack of available classroom resources, and teachers' insufficient knowledge of science subject matter and lack of confidence in being able to promote discussion.

One of the focus of my teaching interventions, both with 8$^{th}$ grade students and preservice science teachers, is the impact of invasive species in the extinction of native species which constitutes a socioscientific issue (Sousa & Chagas, 2018) and a controversial issue informed by societally accepted science (Borgerding & Dagistan, 2018). This has two objectives: developing NOS learning in both populations and prepare preservice teachers to use SSI in their future profession.

# Section II – Biology and Philosophy of Biology Section

## 2.5. Some epistemological notes and NOS

According to Kuhn (1993, p.312) "… scientific terms are regularly learned in use; that use involves the description of one or another paradigmatic example of nature's behavior…", so examples of each concept - model, law, hypothesis, inference and observation – related to the theme of origin of life, ecological niche and insular biogeography were provided to the students and are presented in the next sub-sections.

Laws and theories are "both very important kinds of scientific information but they explain different types of phenomena" (McComas, 2014, p107). A theory is an explanation of natural phenomena (such as events, observations and relationships), constructed by scientists, based and supported by several facts and scientific investigations (McComas, 2014). A law is a generalization that is spatiotemporally unrestricted (Hull, 1992), a pattern in nature (Godfrey-Smith, 2014), that is tentative and are not hierarchically related with theories (Lederman et al., 2002). Therefore, to address the common myth about theories becoming laws, we consider important to give examples of laws to students, as previously suggested by Williams and Rudge (2015) using the historical episode of Mendel. Regarding the origin of life, the example of law of Biology is "all known properties of life are obedient to the laws of physics and chemistry" (Wilson, 2006, p.111). However, it is important to note that Biology cannot be reduced to physics and chemistry, since there are emerging properties in living organisms (Mayr, 2004).

A model is a theoretical construction that "abstracts and simplifies a system by focusing on key features to explain and predict scientific phenomena" (Schwarz et al., 2009, p.633) which is consistent with data obtained about phenomena (Schwarz et al., 2009).

Differences between inference and observation constitute one NOS aspect to teach students and the origin of life subject constitutes a good context for this distinction since the last universal common ancestor (LUCA) is an inferred evolutionary intermediate and its existence is an example of an inference highly relevant in Biology and constitutes an example of an inference that supports the theory of common ancestry.

## 2.6. Origin of life and common ancestry

### 2.6.1. Background

Since the conditions for the occurrence of the origin of life on Earth may have happened only once, billions of years ago, the study of this subject is limited to the examination of historical evidences, such as fossils, that are rare, poorly preserved and difficult to interpret. Moreover, the replication of the events in the laboratory, even if possible, in the future, does not guarantee that the methods used are similar to the ones under which life has originated.

There is consensus, among biologists, that all organisms share a common ancestor (Mayr, 2004) as proposed by Darwin's theory of common ancestry or theory of common descendent in 1837 (Mayr, 2004; Glansdorff et al., 2009). This theory, according to Mayr (2004), is one of Darwin's five theories of evolution which is independent from the other four theories (evolution, gradualism, multiplication of species and natural selection), and explains that "every group of organisms descended from an ancestral species" (Mayr, 2004, p.100).

The concept of common ancestor bridges the gap between the abiotic phase of the early Earth and the biotic phase.

It is still under debate which is the better model of the evolutionary history of all the known species in Earth, however the tree of life model, is widely accepted, if considered a tree-like structure, and constitutes a perfect example of the mutable nature of Science.

Historical episodes and contemporary episodes, selected in the following subsections, are relevant to discuss a present lack of consensus on a theory about the origin of life, although notion that life arose from non-life to a complex system of organic molecules is well accepted by biologists. Subjectivity can be discussed since one gets to know scientists supporting each one of the theories and hypotheses based on different evidences or making different interpretations of the same evidences.

Several ideas about the characteristics of LUCA coexist, by different scientists, such as the cellular status (prokaryotic or not), unicellular or a community status and the homogeneity level (Glansdorff et al., 2009) and contemporary examples of theories and hypotheses about the origin of life were selected for this sub-section, including the main contributions of several scientists from different nationalities and specialists in different disciplines and both genders. Another social aspect that we addressed is gender equity (Sousa, 2016c) or feminism as defined by Matthews (2012) as a NOS feature, by selecting both female and male scientists working on the subject to be presented to the students.

In summary, the problem of characterization of the universal common ancestor is relevant for Biology and the focus of the problem-situation presented to the students.

### 2.6.2. Darwin's theory of (universal) common ancestry

Since the theory of common ancestry (Theobald, 2010; Sober, 2008) or the theory of common descendent (Mayr, 2004) explains that "every group of organisms descended from an ancestral species" (Mayr, 2004, p.100) and it is "central […] to evolutionary reasoning" (Sober, 2008, p.264), we consider that it has a central role in Biology learning. As we will see in the following sections the idea of common descent, from one or a population of ancestors, is generally more accepted than the idea of a single organism ancestor.

We can trace the theory of universal common ancestry back to Darwin, in 1837, when he drew a tree-like diagram with one single species at the base of the tree (Darwin, 1837-8, p36), based on his study of evidences of similarities among different organisms on Earth (Figure 2.3.).

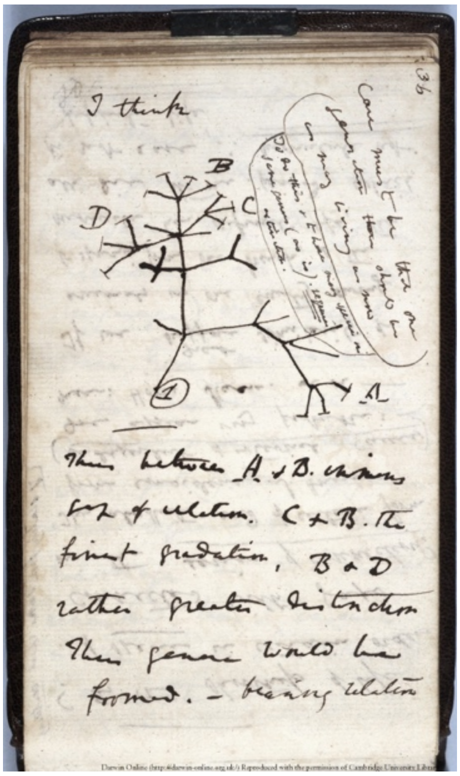


**Figure 2.3.** Tree of life model. Source: http://bit.ly/2S2K3dj.

Darwin, in his book *The Origin of Species*, stated that all the organisms descend from an organism existing very early in the history of Earth. In the first edition of his book Darwin (1859, p.484) wrote "[…] Therefore I should infer from analogy that probably all the organic beings which have ever lived on this earth have descended from some one primordial form, into which life was first breathed". Less than two months after, in the second edition, Darwin (1860, p.484) added "(breathed) by the Creator''. In 1861 and during the rest of his life several editions were published, all of them with the sentence ending this way "[…] we must admit that all the organic beings which have ever lived on this earth may have descended from some one primordial form." (Darwin, 1861, p.519). This historical episode reflects the influence of the Victorian society and Christianism on Darwin's ideas; therefore, it can be used to discuss the embeddedness of society and religion on scientific knowledge.

In 1977, Carl Woese (1928-2012) and George Fox (1945-) performed a phylogenetic analysis sequencing ribosomal RNA (16S and 18S rRNA), a molecule with wide distribution, which allows comparison of very distant species. The authors found evidences in support of Darwin's theory, and suggested the existence of a common ancestor to all organisms on Earth, that wasn't a prokaryote but a "far simpler entity" (Woese & Fox, 1977, p.5090). They proposed the archaebacteria, as the oldest primary grouping, including methanogenic bacteria (anaerobes that reduce carbon dioxide to methane) and hypothesized it has existed since 3-4 billion years ago (Woese & Fox, 1977) and extremely thermophilic archaebacteria (Woese et al., 1990). Woese et al. (1990) proposed a universal phylogenetic tree and hypothesized that the most recent common ancestor of all life existed 3.5-4 billion years ago and emphasised this proposal was possible due to "the sequencing revolution, by making accessible the vast store of historical information contained in molecular sequences" (Woese et al., 1990, p.4576).

Theobald (2010) performed the first formal test of universal common ancestry that does not assume that a similarity in DNA sequence indicates a genealogical relationship. Applying a model selection theory to molecular phylogenies he found that universal common ancestry is the most accurate and parsimonious hypothesis, more probable than the competing hypotheses of independent or parallel origins of different taxa in the three domains of life (Theobald, 2010). For further discussion we suggest Sousa (2016b) but be aware that the universal common ancestry is "at least $10^{2,860}$ times more probable than the closest competing hypothesis" (Theobald, 2010, p.220).

In summary, the theory of common ancestry is, at the present, the best scientific explanation of the molecular phylogenies observed. Accordingly, we consider it as a good example of the explanatory feature of a theory.

### 2.6.3. The (universal) Tree of Life model

The Tree of Life is one of the most important organizing models in Biology as an image unifying all living organisms through their common origin that explains their evolutionary history (Woese, 2000). Its meaningfulness makes it highly relevant to Biology learning.

Darwin explained, about the tree of life (Figure 2.3), that:

> Thus genera would be formed, — bearing relation to ancient types, — with several extinct forms, for if each species as ancient is capable of making recent forms. […] There would be great gap between birds and mammalia, […], still greater between animals and plants.
>
> (Darwin, 1837 *in* de Beer, 1960, p.46).

Figure 2.3 is Darwin's model of tree of life, and he is considered a forerunner, since Lamarck, an evolutionist before him, defended a form of Chain of Being (Ruse, 1997). Upon the advances of Molecular Biology, in the 1960s, specially 16S (18S) ribosomal RNA sequencing, Carl Woese and George Fox stated, in the 1970s, that living organisms are divided into 3 domains (domain as a monophyletic taxon above the level of kingdom): Archaea, Bacteria and Eucarya, and proposed a novel idea that the prokaryotes constitute a paraphyletic group (Woese & Fox, 1977). All domains are subdivided into several kingdoms, for example Archaea is divided into kingdoms comprising methanogens and extremely thermophilic archaea (Woese et al., 1990). Later, the authors proposed a universal phylogenetic tree of life that has a first node representing the most recent common ancestor or last universal common ancestor (LUCA) with two branches, one that is common to Eucarya and Archaea and the other one corresponding to Bacteria (Woese et al., 1990). Eucarya and Archaea are sister domains (Figure 2.4) since their molecules resemble more between themselves than with the Bacteria's molecules and the Eucarya result from the evolutionary radiation of Archaea (Woese et al., 1990).

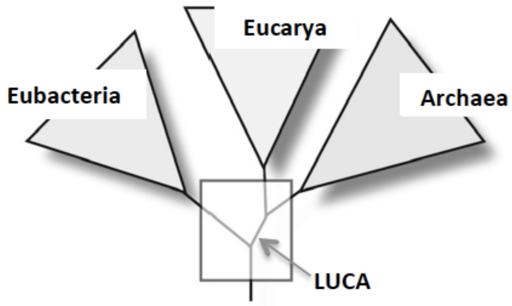

**Figure 2.4.** The 3-domain tree of life model as first proposed by Woese et al. (1990); tree obtained by using rRNA genes (adapted from Weiss et al., 2018).

Recently other authors have suggested a 2-domain tree model (Figure 2.5), that is based upon the appearance of eukaryotes from within the Archaea domain, such as Raymann et al. (2015) that used a novel strategy (two-step strategy) that analyses separately the markers shared between Archaea and eukaryotes and between Archaea and Bacteria.

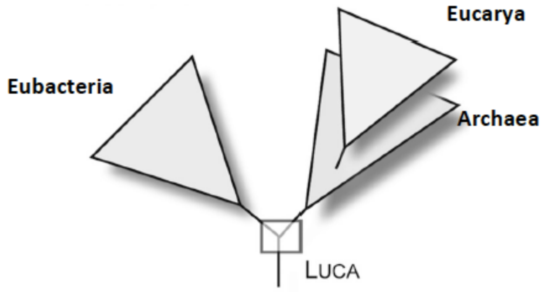

**Figure 2.5.** The 2-domain tree of life model, showing an archaeal origin of eukaryotes; tree obtained by using cytosolic ribosome genes (adapted from Weiss et al., 2018).

Both teams of scientists describe LUCA as the common ancestor of Bacteria and Archaea, considered as two monophyletic groups (models in Figures 2.4 and 2.5).

Presently, there is no consensus about the specific structure of the tree of life, despite the wide acceptation of the 3-domain view of life and evidences supporting this view recently published (Hug et al., 2016).

It is consensual that Eucarya, a more recent group, has its origin in both Bacteria and Archaea with some genes common to Bacteria (e. g. many enzymes involved in eukaryotic cytosolic metabolism), some common to Archaea (e. g. use of peptidoglycan in cell walls, present in Bacteria and not used by Eucarya or Archaea), and some unique to eukaryotes originated by gene transfers from Bacteria and Archaea, including the endosymbiotic progenitors of mitochondria and plastids (Doolittle, 1999; Raymann et al., 2015). Weiss et al. (2016, 2018) suggest a tree of life with 2 primary domains highlighting this endosymbiosis idea (Figure 2.6).

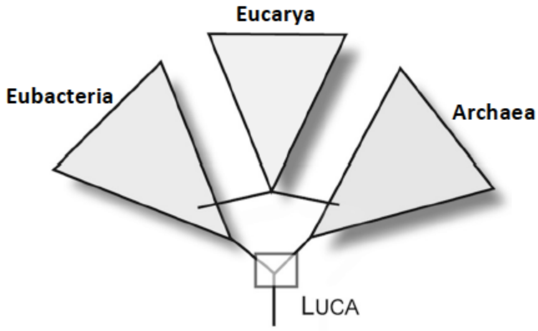


**Figure 2.6.** A 2-domain and endosymbiosis origin of eukaryotes tree of life model that highlights the endosymbiotic origin of eukaryotes; tree obtained by using nuclear and mitochondrial genes (adapted from Weiss et al., 2018).

Due to the importance in evolution of the interspecific lateral gene transfer of DNA and since (plant) trees have branches that split but never join (as in Figure 2.6), there is some opposition, by some authors, to use as the name of the model an analogy to a tree, suggesting, instead, a net or a reticulated tree model (Doolittle, 1999).

Others suggest a statistical tree of life model that represents a significant statistical pattern that consists in the dominant genetic history (Puigbò et al., 2013).

Recently, Betts et al. (2018) using multiple lines of evidence, including fossils, biomarkers, new molecular clock analyses, and isotope geochemistry, produced two different phylogenies (through independent runs using PhyloBayes with a GTR+G model) one supporting Woese's model (Fig. 2.4) and another supporting the eocyte tree (Fig. 2.5).

In summary, the model of universal tree of life is one of the most mutable theoretical constructions in Biology, so it constitutes a perfect example for students to understand the mutable nature of Science, presently changing mainly due to novel phylogenetic methods being used. However, it is important to mention to students that the mutable nature of this model is not part of the definition of model and that not all the models in Biology are in on-going changes (e. g. the DNA structure model is durable).

### 2.6.4. Darwin's hypothesis of the origin of life in a warm little pond

A hypothesis is a tentative explanation of a natural phenomenon with "two primary features […] falsifiability and testability, which are reflected in an 'If…then' statement summarizing the idea and in the ability to be supported or refuted through observation and experimentation" (Rogers, 2018, online).

Charles Darwin tried to avoid the theme of origin of life publicly, but he discussed this subject in several letters (Peretó et al., 2009). One of his most famous letters was sent to Joseh Hooker, in 1871, in which he hypothesized about the origin of life upon thinking about Louis Pasteur's experiments:

> "[…] how on earth is the absence of all living things in Pasteur's experiments to be accounted for? […] It is often said that all the conditions for the first production of a living being are now present, which could ever have been present. But if (and oh what a big if) we could conceive in some warm little pond with all sort of ammonia and phosphoric salts, light, heat, electricity present, that a protein compound was chemically formed, ready to undergo still more complex changes, at the present such matter would be instantly devoured, or absorbed, which would not have been the case before living creatures were formed […]" (Darwin, 1871, online).

This excerpt shows that Darwin's hypothesis of the origin of life in a warm little pond is based on experimental evidences from another scientist. It is important to mention to students that testing his hypothesis at that time was not possible due to the lack of scientific and technological knowledge available and that was one of the reasons for Darwin not to include this subject in his book, as he stated in a letter in 1882 (Peretó et al., 2009). The fact that Darwin avoided discussing this issue publicly and including it into print can be addressed with the students as a historical example of the influence of Society and Religion in Science (NOS social aspect).

Darwin's hypothesis is supported by recent experimental evidences by Pearce et al. (2017) who describe that the synthesis of nucleotides (probably from nucleobases delivered by meteorites), and their polymerization into RNA occurred, before 4.17 billion years ago, in one or a few wet-dry cycles in warm little ponds. Another interesting NOS aspect to discuss is the difference between a hypothesis and a theory and the ways a hypothesis may become a theory, since several scientists (Damer, 2016; Pearce et al., 2017) said their experimental and paleontological evidences support Darwin's hypothesis, we suggest that we may now refer to it as a theory. However, is a theory with a significant lower level of consensus than the theory of common ancestry, in a clearly Kuhn's pre-paradigm stage (according to Ruse, 1997), while others due to the lack of current consensus prefer to maintain the classification of hypothesis.

## 2.6.5. Theories of the origin of life before Darwin

Aristotle (384-322 BC) explained living organisms' organization as a scale from lower to higher forms (Godfrey-Smith, 2014). The *scala naturae*, from inanimate things to the human being, the angels and God, was the dominant idea through the Middle Age. Implicit to this idea was the continuous creation of simple organisms from lifeless matter. This theory of spontaneous generation has been accepted up until the eighteen century thanks to the absolute authorities of Aristotle and the Church, as well as scientists whose experiments supported the theory despite the lack of adequate control of variables. Jean-Baptiste Lamarck (1744-1829) described spontaneous creation of simple organisms from mud by action of electricity, originating independent lineages (Ruse, 1997), Félix-Archimède Pouchet (1800-1872) "claimed to have accomplished spontaneous generation using hermetically sealed flasks and pure oxygen gas" (Ben-Menahem, 2009, p.276). Over the years an increasing number of scientists questioning the theory has discovered evidences contradicting it, such as Francesco Redi (1623-1698), Anton van Leeuwenhoek (1632-1723), Lazzaro Spallanzani (1729-1794) and Louis Pasteur (1822-1895) who used more reliable observation instruments and experiments with more accurate controls. In 1862, Pasteur, designed an imaginative experiment: he used swan-necked flasks containing water, boiled it for a few minutes, and left the flasks to cool. While cooling, the air entering the flask deposited dust and germs in one of the flasks but not in the other in which the germs could not get through (Institute Pasteur, 2017). These observations contradicted the spontaneous generation theory but supported the biogenic theory proposed by Pasteur. Other scientists rapidly accepted this theory and the Church adopted the doctrine that the creation of life took place once by divine intervention (Deichmann, 2012). So, this constitutes an example of how the outcome of controversies and the advancement of the scientific knowledge was influenced but not decided by institutions, such as Church (Deichmann, 2012). Therefore, the relationship between science and religion is not one of conflict, as some historians of science suggest (Glass & McCartney, 2014), since these two subjects constitutes different forms of knowledge and answer different questions. It is important to note that scientists' preconceived ideas against spontaneous generation (e. g. Redi, Spallanzani and Pasteur), whether due to past observations or experiments, guided their experiments (Deichmann, 2012), so these constitute examples of theory-laden nature of Science. Pasteur's episode is also an example of subjectivity nature of scientific knowledge since he is described as a conservative Catholic, which for religious reasons aimed to oppose the spontaneous generation theory defended by the radical materialist physician Felix Pouchet (McComas & Kampourakis, 2015).

It is possible to promote a discussion about the relevance of experiments in Science methodological procedures through these historical episodes such as the importance of using controls in experiments (Allchin, 2011), comparing Pasteur's experiments and spontaneous generation defenders. Moreover, one can explore the social aspect of Science (political, philosophical and religious dimensions) in designing experiments and interpreting data, throughout the episodes of the historical controversy of spontaneous generation theory. The role of imagination and creativity in designing experiments and interpreting results (e. g. Pasteur) is also a clear NOS aspect present in these historical episodes.

### 2.6.6. 20th century history of science episodes about the origin of life

In 1903, Svante Arrhenius suggested the theory of panspermia explaining that meteors or cosmic dust might have brought to Earth spores of "germs" (Arrhenius, 1908, p.226), starting the evolution of life on Earth. New analyses to the Murchison meteorite, that fell in 1969, in Murchison, Australia, identified several organic compounds (Schmitt-Kopplin et al., 2010). In a recent study, scientists describe evidences of several organic compounds, such as hydro-carbons and N-rich organic compounds, e. g. amino acids, and water in the composition of two meteors, one that fell near Morocco and another one in Texas, in 1998 (Chan et al., 2018). These evidences – in salt crystals within the meteors – might represent the early solar system's organic composition (Chan et al., 2018). Francis Crick, molecular biologist and Nobel prize winner, and Lesli Orgel (1973) proposed the theory of directed panspermia, according to which the origin of life on Earth was due to the intentional dispersal of life, microorganisms, from another place in the universe by intelligent beings; they proposed this theory based on the evidences of the universality of the genetic code used by all organisms on Earth and the enrichment in molybdenum in the chemical composition of current organisms while this element is rare in Earth (Crick & Orgel, 1973). This episode is relevant as an example of different interpretation of evidences by different scientists, since the universality of the genetic code is both used as evidence of theory of panspermia and the theory of common ancestor on Earth and that, in accordance to Crick and Orgel (1973), there are no experimental evidence that rejects either one of them, at the present – this constitutes an example of the subjectivity aspect of NOS (Lederman et al, 2002).

In his book "The Origin of Life" published in 1938, Aleksandr Oparin (1894-1980) describes a primitive atmosphere with no oxygen but enriched in water, methane and ammonia. After rainfall interactions among these initial molecules gave rise, in the primitive hydrosphere, to increasingly complex organic compounds such as proteins, constituting colloidal solutions in the primitive ocean, the so called "coazervates" – microscopic spheres with a "more or less distinct membrane" (Oparin, 1938, p. 249), which evolved to the anaerobic and heterotrophic primordial living organisms. Oparin's theory known as the heterotrophic theory was originally published in Russian "Proiskhozhedenie Zhizni" in 1924. It is also designated Oparin-Haldane's theory of the primordial soup because a similar proposal about the early atmosphere, was given independently, in 1929, by John Haldane (1892-1964) who defended that the primitive atmosphere was devoid of oxygen but enriched in carbon dioxide promoting the emergence of organic compounds in a primordial soup (Fry, 1995). Haldane also hypothesized the viruses as the first organisms in the history of Earth (Harold, 2014).

## 2.6.7. Contemporary episodes about the origin of life

The existence of a universal common ancestor is the example of an inference in Biology and its characterization is still under intense investigation, corresponding to a Kuhn's pre-paradigm state (Ruse, 1997).

The present concept of last universal common ancestor (usually referred as LUCA) combines the Darwin's concept with the universal ancestor concept proposed by Woese (1998). It refers to the organism at the first node of the tree of life, the most recent common ancestor of all organisms alive (Harold, 2014).

Different approaches have been used to address the question of the origin of life, such as the "from Geochemistry up" (e. g. studying the environmental conditions that would occur in the beginning, studying the biochemical reactions involved in the increase of complexity up until the first cell) and the "from Biology down", such as studying the simpler components of any complex cellular entity and phylogenetic studies that compare organisms with different level of complexity (Sutherland, 2016, p.105). A date of last universal common ancestor or LUCA's appearance cannot be precisely determined. Some authors consider that LUCA existed 3.5 to 3.8 Ga or billions of years ago (Weiss et al., 2016), others consider 3.95 Ga using evidences of carbon isotope signatures in Eoarchean rocks (Tashiro et al., 2017).

Recently, Betts et al. (2018) proposed a novel timescale of life, using multiple lines of evidence, including fossils, biomarkers, new molecular clock analyses, and isotope geochemistry suggesting that the last universal common ancestor of cellular life appeared before the end of late heavy bombardment, > 3.9 Ga (4.519 to 4.477), and the emergence of Eubacteria and Archaebacteria occurring < 3.4 Ga.

Of course, the origin of life is constrained by the age of Earth itself – approximately 4.56 Ga (Arndt & Nisbet, 2012) - and the time point of about 4.4 Ga when the temperatures were still very high, the mantle was largely molten, upon the event Moonforming impact (Arndt & Nisbet, 2012). Additionally, according to some authors, the time point of 4.2 to 4.3 Ga is the last constraint regarding the presence of liquid water (Mojzsis et al., 2001).

Regarding panspermia, new analyses of the Murchison meteorite, that fell in 1969, in Murchison, Australia, revealed several organic compounds (Schmitt-Kopplin et al., 2010). In a recent study, scientists described evidences of several organic compounds, such as hydro-carbons and N-rich organic compounds, e. g. amino acids, and water in the composition of two meteors, one that fell near Morocco and another one in Texas, in 1998 (Chan et al., 2018). These evidences – in salt crystals inside the meteors – might represent the early solar system's organic composition (Chan et al., 2018).

Stanley Miller (1930-2007) tested the ideas of his mentor, a chemistry Nobel laureate, Harold Urey (1893-1981), regarding the composition of early atmosphere, and the Oparin's primordial soup theory, which states that the early Earth atmosphere was composed of hydrogen, carbon dioxide, methane and ammonia (Harold, 2014). Miller constructed an imaginative and creative experimental apparatus in which he introduced the gases of the early Earth atmosphere (hydrogen, water, methane and ammonia), subjected them to electric discharges, simulating lightning, and collected the products in a water container, simulating the ocean (Harold, 2014). Over a few days, organic matter was accumulated and then analyzed. Several small molecules were found including glycine, alanine, glutamic and aspartic acids (Harold, 2014). In 2011, a research team headed by one of Miller's former students identified – in Miller's original samples archived since 2007 and stored in the Scripps Institution of Oceanography in La Jolla, CA - a higher diversity of amino acids (total of 23 amino acids) and 4 amines (Parker et al., 2011). According to these data scientists stated that life arose in the ocean in areas adjacent to volcanoes where the proposed early Earth gases could be found. A NOS aspect, concerning human elements, referred by Harold Urey that is relevant to be mentioned is the "fastest gun in the West" syndrome, that he explains that sometimes happens with young scientists that want to prove the older scientists wrong (Urey in Sagan, 1996). Another NOS aspect, a human element, is that, presently, frequently (e.

g. Parker and colleagues), scientists work in teams, with the senior author, usually with habilitation and tenure, resolve any conflicts of authorship and supervise decisions of methods to be used. Usually, scientists published their findings in scientific journals upon peer review, which is the process of evaluation of the research by peers, that exists since the 17$^{th}$ century (The Royal Society, 2018), that contributes to increasing the quality of the published work and It is consensually accepted that peer review is the better way, available, to validate research results therefore making science more objective.

In 2010, a biochemistry Helen Hansma suggested the muscovite mica hypothesis for the origin of life according to which the confinement between muscovite sheets, constitutes an entropy reduction, and since molecules between mica sheets are able to interact forming biopolymers these are selected, through a Darwinian evolutive process, while molecules outside the mica sheets are lost in solution (Hansma, 2010). This hypothesis is supported by evidence from atomic force microscopy that mica is able to interact with biomolecules, such as proteins, lipids, and short length DNA molecules (Hansma et al., 1996), and the description of some samples of mica about 3.8 billion years in age (Hansma, 2010). This hypothesis is included in a larger hypothesis of origin of life on mineral surfaces, first suggested in 1951 (Hansma, 2010). This hypothesis is also supported by the research team headed by Peter Coveney who using supercomputers to perform simulations of interactions of DNA molecules with clay minerals suggesting that strong electrostatic forces act between mineral sheets and intercalated DNA (Thyveetil et al., 2008). They also tested conditions of temperature and pressure increasing in the simulations and conclude that the variations observed support the theory of origin of life in hydrothermal vents (Thyveetil et al., 2008). These examples are relevant to show the NOS aspect that scientific research uses a variety of methods.

John Sutherland, in 2009, reported that simple precursor compounds (acetylene and formaldehyde) could produce two of RNA's nucleotides in the primordial soup under ultraviolet light (Service, 2015). According to Service (2015) this evidence supports the theory of panspermia, since HCN is abundant in comets, as well as the theory of the primitive soup. Recent results by Sutherland's team (Xu et al., 2019) found strong evidence that RNA and DNA could have arisen, about four billion years ago, from the same set of precursor molecules. Sutherland's results support that life likely arose on the surface or in shallow water. He added that the presence of UV radiation was important to assemble monomers in an interview (Marco-Casanova & Peretó, 2015). This interview can also be used as a great starting point to discuss the role of Society in Science, in special research funding procedures, since he said, "Nowadays, we are in hands of people obsessed in balancing the books. This impacts directly on considering funding research only if it yields short-term results and it is immediately profitable." (Marco-Casanova & Peretó, 2015, online).

Additionally, an international team of researchers, including NASA's researchers, was responsible for a recent study that constitutes evidence that meteorites may have contributed to the synthesis of important prebiotic molecules such as RNA, since they found ribose and other sugar in 3 primitive meteorites (Furukawa et al., 2019).

Allen Nutman and collaborators, studying metacarbonate rocks in the Isua supracrustal belt in southwest Greenland, published the evidence of the oldest known stromatolites (macroscopically layered structures produced by microbial activity) with a date of 3.7 billion years (Nutman et al., 2016). They suggest that the origin of life occurred in shallow marine environments and that ancient organisms were responsible for an autotrophic $CO_2$ inclusion in the ocean (Nutman et al., 2016). In Labrador, Canada Tashiro et al. (2017) found evidence of the oldest of biogenic graphite with at least 3.95 billion years corresponding to autotrophic organisms in seawater mixed with hydrothermal fluid. This team led by a Japanese geologist Tsuyoshi Komiya, in 2017, studied carbon isotope values of graphite and carbonate in metasedimentary rocks. Recently, Nutman has been challenged by another team of scientists who studied the same structures present in rocks of Greenland, using a sample close to the original sample site. They concluded that these structures are abiogenic, probably deformed metasediments (Allwood et al., 2018). Recently Nutman et al. (2019) presented additional examinations supporting the conclusions in their previous study. The main NOS aspects to be discussed with this example is that Science relies in empirical evidence and is tentative.

Weiss et al. (2016) analysed 355 genes in bacterial and archaeal phyla. They conceptualized a tree of life as a protein tree that represent monophyly of Bacteria and Archaea from which they were able to infer that the proteins probably present in LUCA, such as reverse gyrase, an enzyme specific of hyperthermophiles, and the Wood-Ljungdahl pathway. Therefore, they suggested that LUCA was an anaerobic autotroph, $H_2$-dependent, from geological source, using $CO_2$ and $N_2$, and that existed in a hydrothermal environment. Others such as Matthew Dodd et al. (2017) presented evidences supporting this theory of origin of life in submarine hydrothermal vents, which occurred at least 3.77 - 4.28 billion years ago. The evidences are fossils of tubes and filaments, and remains of iron-oxidizing bacteria embedded in rocks of the Nuvvuagittuq belt in Quebec, Canada. More evidence may be found in the fact that in modern hydrothermal Si-Fe vents one can find microorganisms that form distinctive tubes and filaments like the fossils found (Dodd et al., 2017). This idea of the hydrothermal origin of life was first proposed by Corliss et al. (1981) after the discovery of modern submarine hydrothermal vents. NOS can be explored with this example highlighting that this hypothesis was suggested in 1981 and that now is considered a theory due to the several lines of evidence found that support it.

New evidence found in the Dresser Formation, Pilbara Craton, Australia, are hot spring deposits within a low-eruptive volcanic caldera (Djokic et al., 2017). Several "biosignatures" were found such as evidences of gas bubbles, microbial filaments and stromatolites (Djokic et al., 2017). The authors proposed a view of the origin of life as occurring in pools that repeatedly dry out and get wet (Djokic et al., 2017; Van Kranendonk et al., 2017). They also performed an experiment using compounds probably available in the prebiotic Earth (nucleic acids) that were put through wet and dry cycles in conditions similar to the hot springs and obtained longer polymers, similar to RNA, encapsulated in protocells (Van Kranendonk et al., 2017). These authors suggest an early environment similar to Darwin's hypothesis having their work included in "Revolutions in Science", "a collection of articles [. . .] Kuhn called 'paradigm Shifts' in his 1962 book" (Gawrylewski, 2018). Regarding Darwin's 1871 contribute they say, "A number of scientists from different fields now think [he] had intuitively hit on something important" (Van Kranendonk et al., 2017, p.31). Facing these arguments, we consider that their evidences support Darwin's hypothesis. Could this constitute a paradigm shift (concept proposed by Kuhn) promoted by Darwin?

Tara Djokic commented on the Mars 2020 project and said: "The deposits in the Pilbara [formation of Australia] are about the same age as the deposits on Mars [Columbia Hills], so if life ever developed on the red planet, there is a strong possibility that it would be preserved in hot springs just like here on Earth." (Zoric, 2017, online). This sentence highlights the theory-driven NOS aspect regarding the choice of the place to look for life.

Recently, evidence provided by Djokic et al. (2017) have been challenged by another team of scientists (Wacey et al., 2018) since they suggest that at the same geological formation some microstructures might be vesicular volcanic rocks, non-biological, pseudo-fossils. A NOS aspect to be explored is that different scientists, upon similar evidences/observations interpret them in different ways.

These examples constitute contemporary science stories that can efficiently contextualize NOS, according to Clough (2006), because they are examples of present-day scientific literature and also examples of media reports (e.g. interviews) that represent Science in the making and with NOS aspects that can be highlighted.

It is important to involve students in discussions about these theories since they are supported mainly by fossil evidences, and not by experiments, what may promote the understanding of the wide range of scientific methodological procedures either experimental or naturalistic ones, such as non-manipulative descriptive studies (Sousa, 2016b). It is possible to trace the recent theories approached in this section back to the theory of common ancestry first stated by Darwin in 1837. The processes of construction of scientific knowledge usually by multidisciplinary teams of female and male scientists across continents are social aspects of NOS that can be discussed.

The date when and the environment where the LUCA has occurred is not fully agreed to by all scientists and one cannot discard the possibility that there may have been multiple origins in various environments that have contributed to the ancestral genotype.

### 2.6.8. Summary: the problem of characterization of the universal common ancestor

The focus of this problem-situation (How do you characterize the universal common ancestor?, Appendix 1) is the phase of unicellular entity and the first three transitions of the origin of life - of the eight major transitions, from replicating molecules to human societies - proposed by Maynard-Smith & Szathmáry (2000, p16-17): "replicating molecules -> populations of molecules in compartments, independent replicators -> chromosomes, and RNA as gene and enzyme -> DNA and protein." Additionally, we discuss some historical episodes and theories about the early prebiotic phase before the first replicating molecules.

Therefore, the problem in the problem-situation has several possible solutions such as these characterizations for the universal common ancestor:

- early organisms would be unicellular anaerobic and heterotrophic existing in a primitive soup (according to Oparin's theory),

- early organisms were viruses (according to Haldane),

- first organisms were microorganisms that came from another place of the Universe (according to the theory of panspermia),

- first entities were bubbles produced by underwater volcanoes (according to Lerman's theory),

- last common ancestor lived in hydrothermal vents and was a unicellular autotrophic organism (using $CO_2$ and $H_2$ to produce organic compounds), anaerobic, hyperthermophilic and environmental $H_2$-dependent (in accordance with the theory of origin of life in hydrothermal vents),

- ancient life forms were cyanobacteria, autotrophic beings dependent on sunlight (according to the theory of origin of life in shallow marine waters),

- last common ancestor was unicellular autotrophic dependent on sunlight and energy sources such as hydrothermal fluid rich in hydrogen and heated by volcanoes (according to the theory of the origin of life in land hot springs),

- a reasonable combination of theories/evidences (e.g. panspermia and theory of the origin of life in land hot springs).

## 2.7. Ecological niche and biological invasions: concepts and theories

### 2.7.1. Background

Ecological niche is an "important organizing idea" (Griesemer 1992, p231) or a "core concept" in ecology (Pocheville 2015, p.547) and "represents a major heuristic tool for our understanding of nature" (Polechová and Storch 2019, p.72).

We consider that when describing an ecosystem, the concepts of habitat, niche, species, population and variety are fundamental, as well as when teaching about this subject. The concept of species is connected with both the, commonly taught, concept of habitat, and the concept of ecological niche, and should be taught together. This has been proposed previously by Thomas Kuhn, in 1993, when he mentioned this inter-relation:

> What permits the closer and closer match between a specialized practice and its world is much the same as what permits the closer and closer adaptation of a species to its biological niche. Like a practice and its world, a species and its niche are *interdefined*; neither component of either pair can be known without the other.
>
> (Kuhn 1993, p.337, my italics)

Recently, the concept of ecological niche has been defined as the "position of a species within an ecosystem, describing both the range of conditions necessary for persistence of the species, and its ecological role in the ecosystem" (Polechová & Storch 2019, p72).

The problem-situation prepared for 8$^{th}$ grade students and preservice science teachers (Appendix 2) is focused on the impact of invasive plant species in the extinction of native plant species and constitutes a socioscientific issue (Sousa & Chagas, 2018), that is, a problem that require students to consider scientific issues of social significance and that includes the evaluation of several concepts and considerations in order to arrive at an informed solution (Sadler, 2004). And I agree with Borgerding & Dagistan (2018) that it is an issue informed by societally accepted science.

### 2.7.2. Ecological niche and invasive plant species

Our focus is one of the main problems in Ecology – how species diversity is maintained. In order to understand it the concept of niche, or ecological niche, is fundamental. Miller (2007) defines this concept as including abiotic (e. g. humidity) and biotic (e. g. competition) factors, as well as all the aspects related to survival and reproduction of a species, and a species' way of life or role in an ecosystem. The niche theory was first proposed by Joseph Grinnell (1877-1939) in a study, in 1917, about 3 subspecies of *Toxostoma redivivum*, a Californian bird with common name California Thrasher, upon which he described that each occupied its own niche.

Currently, the niche theory provides several propositions (Chase, 2011, p.101), such as "for two or more species to coexist regionally, they must trade off the ability to compete for different limiting resources, and those resources must be heterogeneously distributed in space."

The niche theory is not consensual since certain scientists explain biodiversity according to Hubbell's neutral theory in which random dispersal is the main controlling factor of ecosystem structure so none of the species shows advantage over the others (Hubbell, 2001). While niche theory explains diversity according to species' ecological and functional differences; the neutral theory of biodiversity claims that much of the diversity we observe can be explained without invoking species' differences (Wennekes et al., 2012).

Referring to Hutchinson's work about the niche, Holt (2009) highlights that the species' distribution can be constrained by competition, so the realized niches (environmental conditions where a species is found) are usually less than fundamental niches (environmental conditions that would allow the existence of a species).

A recent field experimental study with 18 annual plant species quantified the stabilizing niche differences and concluded that these differences are due to 11 functional traits, such as rooting depth, maximum height and leaf area, that are related to the predicted outcome of competition (Kraft et al., 2015). These authors suggest that the stable coexistence and diversity between species and within a species are due to functional trait differences between competitors' niche that reduces the interspecific competition relative to intraspecific competition, favoring any species when at low relative abundance (Kraft et al., 2015; Levine & HilleRisLambers, 2009).

According to Valladares et al. (2015) the framework of niche differences should be used to understand biological invasions. Usually, invasive plants (species that can survive and reproduce distant from the site of introduction) are threats to native plants since they have broader and overlapping niches (Higgins & Richardson, 2014). Examples of invasive plants are Australian Acacia species, Australian eucalypts and the Hottentot Fig (scientific name *Carpobrotus edulis*, in Figure 2.7).

**Figure 2.7.** *Carpobrotus edulis*, common name Hottentot Fig, with succulent leaves and yellow to purple flowers (in https://www.inaturalist.org/photos/2956638).

Currently it is considered that the exotic plants may became invasive since they have an ecological and evolutionary history different from the native plants, they may have advantageous traits not present in native species, that promote success in competition. According to the “enemy release hypothesis” the invasive plants don’t have the enemies that are present in their original location and this facilitates their propagation; while the “human release hypothesis” suggests that invasive plants are introduced due both to human activity and the lack of human control, facilitating their propagation in new areas (Kueffer, 2017; Zimmermann et al., 2014).

The Hottentot Fig (Figure 2.7) is a perennial plant native of South Africa that has a worldwide geographic distribution and is described as an invasive plant and a threat to several rare and endangered species in Mediterranean regions, Australia and California (USA).

*Carpobrotus edulis* was introduced both as an ornamental plant in gardens and to stabilize sand dunes, in Europe, Australia and USA, in the beginning of the 20th century. It forms impenetrable mats up to 200cm wide and over 40cm deep and reproduces by seed or vegetatively by cutted branches (Novoa et al., 2013). It was shown a statistically significant reduction of the pH and increase of salinity and organic matter content in the invaded area of sand dunes, when compared with non-invaded area by *Carpobrotus edulis* (Novoa et al., 2013).

Experts describe the action of *Carpobrotus edulis* in the carbon, phosphorus and nitrogen cycles, interfering mainly with soil microbial communities and consequent change in nutrient cycling processes (Novoa et al., 2013; Novoa et al., 2014). Invasive plants can form symbiosis with mycorrhizal fungi, which contributes to their survival in the invaded ecosystem (Travest & Richardson, 2014).

Annual costs in Europe due to biological invasions are at least of 12.7 billion euro (Novoa et al., 2013), so one NOS aspect that can be addressed is that research projects on invasive species, such as on ways to eliminate these species and the restoration of the invaded areas, are considered important by the society and, in consequence, financing is available for these lines of research.

There are several examples of native plant species that compete with *Carpobrotus edulis*, such as the *Malcolmia littorea* (Fig. 2.8), a perennial, herbaceous, 2-4 cm, multicaule plant, native of the Mediterranean region.

**Figure 2.8.** *Malcolmia littorea*, common name “goiveiro-da-praia”, (in https://flora-on.pt/#/heSrP).

Studies of interaction of invasive plants, such as *Carpobrotus edulis*, in seed germination of native plants have been conducted, using *Malcolmia littorea* as a model species, by Novoa and collaborators that showed a statistically significant reduction, of about 50%, in the germination index of the native species in soil from invaded area, when compared with non-invaded area (Novoa et al., 2013). It was shown a statistically significant reduction of the pH and increase of salinity and organic matter content in the invaded area of sand dunes, when compared with non-invaded area by *Carpobrotus edulis* (Novoa et al., 2013). In this context some NOS aspects that can be discussed are: any research starts with a question, the importance of publishing and the precision of measurements and several scientific methods may be used to conduct investigations.

In natural ecosystems we can find several native species that are able to coexist with invasive ones meaning that any equilibrium must exist between interspecific and intraspecific competition (Levine & HilleRisLambers, 2009). Two or more interacting species that coexist in an ecosystem, are usually associated with different niches, and frequently involved in coevolution. The coevolution principle, or Red Queen principle, explains that a species must evolve as fast as it can just to keep up with all the others, so "running at least as fast as it" (Morris & Lundberg, 2011). Coevolution is a process of reciprocal evolutionary change driven by natural selection (Thompson, 2010). Coevolution may occur between mutualists, competitors, predators and prey, and parasites and hosts. In this paper emphasizing the relevance of coevolution Thompson (2010) states that all complex organisms are the result of coevolution between at least two species. Human induced changes in any of these interactions will have a huge impact in ecosystems. One such human-induced changes is the invasion by alien plants that often cause the extinction of native plants they outcompete them. A recent research and conservation approach has focused on the intraspecific genotype variability as the core issue concerning coexistence (Valladares et al., 2015).

Some invasive plants disrupt forest ecosystems facilitating fire, such as *Eucalyptus globulus* that sheds bark, leaves and twigs putting a lot of fuel in the ground. The fallen bark can be carried by the wind spreading flames, and in intense fires, volatile compounds in foliage cause explosive burning. Scientists involved in land management, suggest this species substitution by "firefighter trees" that are more resistant to fire, such as oak and chestnut tree.

Invasive plants usually respond to changes in the environments more quickly than do natives (Nijhuis, 2013), so upon a climate change scenario, the invasive plant species, that usually have an earlier blooming than natives, will be favored shading out competitors and capturing a larger share of nutrients, water and pollinators if native plants are not able to adjust their flowering (Nijhuis, 2013; Valladares et al., 2015).

Ecosystems, as supporting systems of all life, are considered to provide services that contribute to the biosphere's regulation, and consequently to humans' benefit such as (CICES, 2019): provisioning (e. g. fresh water; plants as sources of energy), regulation and maintenance (e. g. climate regulation, water cycle) and cultural (e. g. recreational, tourism). Therefore, ecosystems can be associated to a monetary value, which reduces if biodiversity decreases (Turnbull et al., 2016).

### 2.7.3. Niche theory

Niche theory explains that differences between species allow them to coexist (Wennekes et al., 2012) and predicts the competitive exclusion of the less fit competitor by the more fit competitor.

The niche theory is not consensual, and it has been challenged by an alternative theory, the neutral theory of biodiversity, that describes that, at least in some cases, different species of competitors are equivalent, and the competition is driven by stochastic processes and due to differences between competitors (Wennekes et al., 2012). However, according to some authors it is possible to unify them (Tillman 2004). The stochastic niche theory has been proposed as a unifying theory "that resolves many of the shortcomings of both classical trade off theory and neutral theory" (Tillman 2004, p.10854).

### 2.7.4. Ecological niche and history of science

Although, Greek philosophers have used niche-related concepts such as habitat (e.g. Aristotle 4$^{th}$ century BC, p37 in Book IX), the first mention of the idea of ecological niche was as by Charles Darwin (1859). It is clear the distinction, made by Darwin between habitat and niche, as "place in nature" meaning a form of life or role in the ecosystem of a given species:

> "It would be easy to show that within the same group carnivorous animals exist having every intermediate grade between truly aquatic and strictly terrestrial habits; and as each exists by a struggle for life, it is clear that each is well adapted in its habits to *its place in nature*."
>
> (Darwin, 1859, p.212, my italics)

The first time, the word niche was used I think it was in 1910, by Roswell H. Johnson in a study about beetles of the family Coccinellidae (that includes the ladybugs):

> One expects the different species in a region to *occupy different niches* in the environment. This at least is a corollary of the current belief that every species is as common as it can be, its numbers being limited only by its food-supply, a belief which is the result of the strong Malthusian leanings of Darwin. The major species of the coccinellids do not seem to be so distributed. With certain exceptions which we have given, the species of Hippodamia and Coccinella are in quite general competition. They are

characterized for the most part by very wide distribution and extensive overlapping of other species.

(Johnson, 1910, p.87-88, my italics)

However, I think Johnson (1910) considered the niche as the spatial distribution occupied by the species and not as is presently accepted and proposed by Darwin with a broader meaning as the role in the ecosystem. Therefore, I tend to agree with Griesemer (1992) that describes the niche concept as being introduced by Joseph Grinnell in 1913 in his PhD thesis.

In 1917, Joseph Grinnell (1877-1939), mentioned as one of the most important ornithologists of the first half of the 20th century (Smith 2017), by the time of the centenary of one of his most important articles, performed a study about a Californian bird, California Thrasher, with scientific name *Toxostoma redivivum* (Grinnell 1917), characterizing three subspecies in California and their geographic distribution (Figure 2.9).

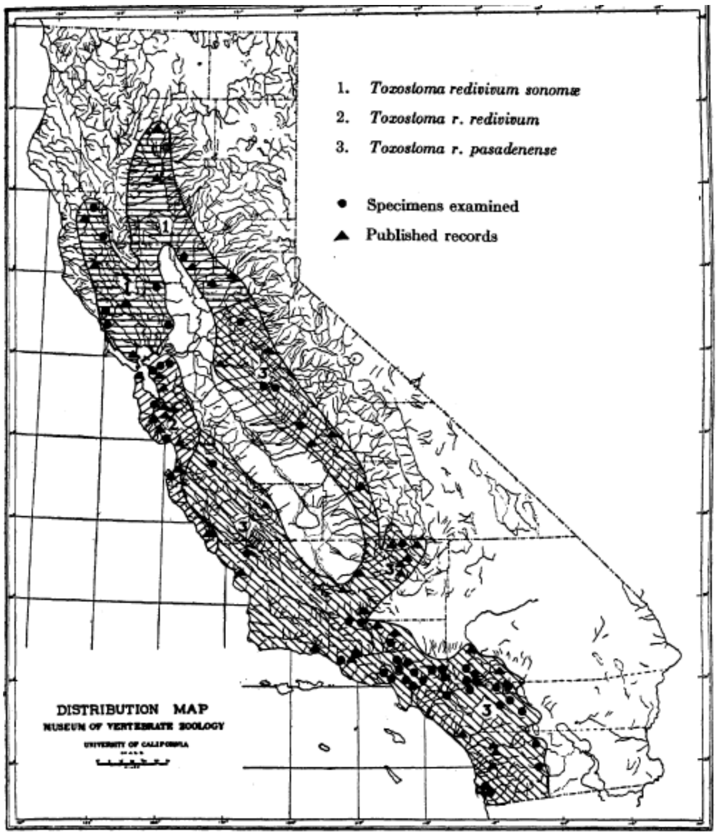


**Figure 2.9.** Geographic distribution of the 3 subspecies of *Toxostoma redivivum* (Grinnell, 1917): *Toxostoma redivivum sonomae* (identified as 1 in the above figure), *Toxostoma redivivum redivivum* (as 2) and *Toxostoma redivivum pasadenense* (as 3).

Temperature and atmospheric humidity were identified by Grinnell (1917) as abiotic factors responsible for the geographic distribution of the three subspecies of California trasher: “The California Trasher is unquestionably delimited in its range in ultimate analysis by temperature conditions” (Grinnell 1917, p.430) and “Comparing the map of the ranges of the subspecies of T. redivivum [...] with a climatic map of the State, direct concordance is observed between areas of stated rainfall on the latter and the ranges of the respective subspecies.” (Grinnell, 1917, p.431).

The *Toxostoma redivivum pasadenensis* occupies an area of relatively low atmospheric humidity, *Toxostoma redivivum sonomae* occupies an area of higher humidity and *Toxostoma redivivum redivivum* is present in an area of highest humidity (Figure 2.9). Dependent on chaparral type vegetation the California Trasher is, omnivorous having ants and seeds as predominant diet. Grinnell (1917, p.432) explains that “The bird’s most conspicuous structural feature, the long curved bill, is used to whisk aside the litter, and also to dig, pick-fashion, into soft earth where insects lie concealed”.

This article by Grinnell is quite relevant for the scientific literature since it is currently cited at a considerable rate, especially for a paper with more than 100 years, of more than 90 times per year, in average (Smith 2017). In terms of using this full article, and not only the selected sections presented, in Biology teaching it is important to contextualize the study, in the beginning of the 20th century, and that the word “race” (Grinnell, 1917, p.431) is used as synonymous of subspecies, which is currently commonly referred as variety.

Another Grinnell’s contribute is the ecological niche theory that according to Griesemer (1992), consisted on his idea of competitive exclusion that is, commonly, wrongly attributed to G. F. Gause (1910-1986). In fact, Grinnell described that each of the 3 subspecies he studied has its own niche leading to his proposed generalization - the niche theory - that explains that any two species cannot have the same niche: “It is, of course, axiomatic that no two species regularly established in a single fauna have precisely the same niche relationships.” (Grinnell, 1917, p.433).

Johnson (1910) when referring to the idea that different species, in a region, occupying different niches, uses the expression “is a corollary of the current belief” (Johnson, 1910, p.87) and not a theory, although he mentioned the “theory of warning coloration” (Johnson, 1910, p.9) regarding the mechanisms of coloration that evolved in the insects he studied with the advantage of avoiding capture by birds.

So, what is either called “Gause’s Law” (Justus, 2013, p.356) or “Volterra-Gause principle” (Polechová & Storch, 2019, p.74) I think it constitutes a theoretical construct, based on solid experimental work (e.g. Gause, 1932), within the niche theory, first proposed by Grinnell, based on his descriptive studies.

## 2.8. Insular biogeography and applied biogeography: model and theory

### 2.8.1. Background

The use of History of Science (HOS) constitutes one way to illustrate key aspects of NOS to students, providing "a context for or example of" (McComas, 2008, p. 251) and "can humanize science by raising instruction from the mere recitation of facts to its exploration as an authentic and exciting human adventure" (McComas, 2008, p. 262). Some historical episodes about insular biogeography were selected for the PBL session to construct the problem-situation (Appendix 3) for preservice science teachers and are described below.

The theory of island biogeography, also called equilibrium theory of island biogeography, can be applied to various environmental problems, such as habitat fragmentation and to the design of protected areas, such as shape and size of the areas (Brown & Lomolino, 2000; Triantis & Bhagwat, 2011). The application of this theory allows the design of protected areas, for example the option for a large reserve than for a small one and for corridors between reserves to increase migration/dispersal (Triantis & Bhagwat, 2011). Due to the importance of this theory and applications we consider that it constitutes an important theme to be taught in K-U education.

### 2.8.2. MacArthur-Wilson's 1963 historical episode

In 1963, ecologists Robert H. MacArthur (1930-1972) and Edward O. Wilson (1929-) observed the number of bird species in some Pacific islands and related it with the area of the island where these species are found (MacArthur & Wilson, 1963). One NOS aspect to be explored is the existence of a diversity of scientific methods that can be used (Sousa, 2016b), since a common myth is the idea of a single method (McComas, 2002), in this case a descriptive approach was used. Another NOS aspect is that any investigation starts with a question, so in order to promote learning of this aspect the teacher can ask students to formulate the question that guided MacArthur-Wilson research.

In 1963, they published their evidences in the scientific peer-review journal Evolution (Figure 2.10).

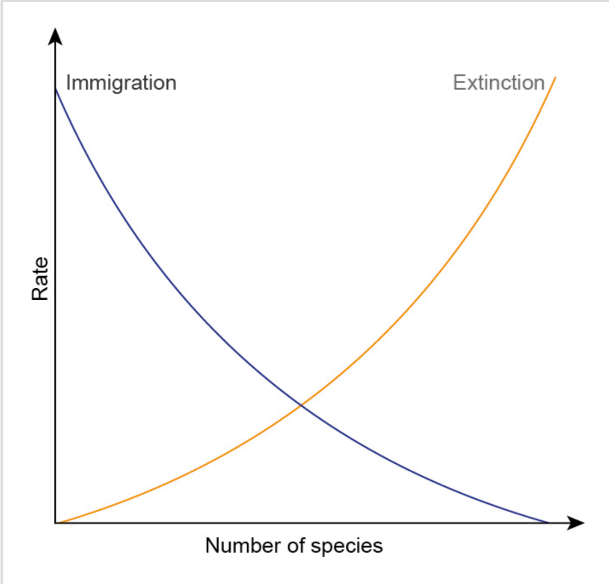


**Figure 2.10.** MacArthur-Wilson insular biogeography model (Adapt. MacArthur-Wilson, 1963).

This HOS episode allows the discussion of NOS aspects, such as the importance of publishing and about the peer-review process and the concept of model and theory.

In their article, of 1963, MacArthur and Wilson propose the model of dynamic balance between the number of bird species that migrate to a given island and the number of extinct bird species on that island.

The MacArthur-Wilson model allows predicting the number of bird species on an island. This model considers factors such as the island area and the distance between the island and mainland in the biodiversity balance, which is different for groups of species (taxa) and different islands. According to the authors the model only applies to bird species of Pacific islands.

## 2.8.3. MacArthur-Wilson's 1967 historical episode

In 1967, these scientists expanded their ideas to all islands and all species when proposing the theory on the equilibrium of biodiversity in islands in their book "The Theory of Island Biogeography" (MacArthur & Wilson, 1967). This theory explains the geographic distribution of species on islands, including oceanic islands and more or less uniform geographical areas around them, and various factors that influence it such as: immigration, extinction, speciation and ecological interactions between resident species and colonizers (MacArthur & Wilson, 1967).

This HOS episode allows clarifying the difference between a model and a theory and how they relate, since a model may be proposed within a theory, therefore the concept theory is a broader concept than model. And promotes the discussion of the concept theory since according to the authors, a “good theory points to possible factors and relationships in the real world that would otherwise remain hidden and thus stimulate new forms of inquiry” (MacArthur & Wilson, 1967, p.5).

### 2.8.4. Simberloff-Wilson’s 1969 historical episode

In 1969 Edward O. Wilson and his student Daniel S. Simberloff (1942-) tested this theory in southern Florida on small mangrove islands. After fumigating the area with a pesticide in order to eliminate all arthropods, without affecting vegetation, they studied the diversity of arthropods over the years (Simberloff & Wilson, 1969). By using this episode, the teacher can ask students what their research question was and promote discussion to propose a response.

Another NOS aspect that can be discussed is about whether a theory can be tested or proved, by using, for example, experiments such as Simberloff and Wilson 1969 and introducing Popper’s statement “the criterion of the scientific status of a theory is its falsifiability, or refutability, or testability” (Popper, 1962, p.37).

Upon reading about the study by Simberloff and Wilson (1969), a Bioethics discussion can be promoted about whether in the present the studies can and/or should be conducted in more environmental-friendly ways. In fact, at the present due to the availability of satellite imaging, several ecological succession studies are currently being carried out using newly formed volcanic islands, such as Surtsey (del Moral & Magnússon, 2014) and other geographic areas, for example forest areas that have suffered fires. Then a discussion can be promoted about what type of ecological succession was studied and which one can be studied in recently formed volcanic islands, and the advantages and disadvantages of this use for ecological studies.

### 2.8.5. Darwin’s contribute to the understanding of insular biodiversity

The study of island biodiversity was also conducted by Charles Darwin (1809-1882) and his observations in the Galapagos Archipelago were central to his theory of evolution through natural selection. Darwin wrote in his notebook on finches that he observed there:

> “When I see these islands in view of each other, and possessing only a meager stock of animals, occupied by these birds, but slightly different in structure and filling the same place in the Nature, I must suspect that they

> are just varieties. (...) If there is the least foundation for these observations, it will be worth examining the zoology of the Archipelagos; as such facts would weaken the stability of Species."
>
> (Darwin, 1836, online).

Thus, Darwin considered that a species of finches on the continent dispersed to the Galapagos Archipelago, and on each island found different foods available providing the environmental trigger to speciation, and this is the central aspect of his theory of evolution by natural selection. Reinforcing the NOS aspect of diversity of scientific methods: this was an observation-driven, not a hypothesis-driven, investigation.

# Chapter 3

# Methodology

# Chapter 3
# Methodology

Parts of this chapter were already presented at international conferences and/or published, submitted to publication or are in preparation for publication:

- Sousa, C. & Chagas, I. (2018). Using Nature of Science enriched-PBL in pre-service science teacher education. In Conference proceedings "New perspectives in science education" (p592-595). Itália: Libreriauniversitaria edizione. ISBN: 978-88-6292-976-9. Online in: http://bit.ly/35fqUuo. [Section 3.5.1.]
- Sousa, C. & Chagas, I. (2019) Teaching the nature of science using problem-based learning in pre-service biology and geology teacher education presented orally at Winter Conference of Association for Teacher Education in Europe - Science and Mathematics Education in the 21st century (16/04/2019) [Section 3.5.2.]
- Sousa, C. (2019) Fostering Pre-Service Science Teachers' Learning About Nature of Science Using a Problem-Based Learning Activity on Biogeography presented orally at International History, Philosophy and Science Teaching Conference: Re-introducing science - Sculpting the image of science for education and media in its historical and philosophical background (17/07/2019) [Section 3.5.2.]
- Sousa, C. (Science & Education, submitted) NOS-enriched Problem-Based Learning using History of Science combined with a Socioscientific Issue in preservice science teacher education [Section 3.5.2.]
- Sousa, C. (IJPBL, submitted) Change of middle school students' Nature of Science and ecological conceptions upon a PBL intervention using a socioscientific issue [section 3.6.1]
- Sousa, C. (2019) Nature of Science-enriched Problem-Based Learning about the ecological niche concept using a socioscientific issue, presented orally at International Conference of European Ecological Federation & SPECO - Ecology across Borders (30/07/2019) [sections 3.6.1. and 3.7.1.]
- Sousa, C. & Chagas, I. (2019). Changes in Students' Nature of Science Conceptions upon a HOS and NOS-Enriched PBL Intervention. In New Perspectives in Science Education Conference Proceedings (p537-543). Italy: Filodiritto Editore. [section 3.6.2]
- Sousa, C. (2019) Characterization of students' scientific epistemological conceptions and development of a multi-dimensional instrument for the assessment presented orally at ESERA Conference "The beauty and pleasure of understanding: engaging with contemporary challenges through science education" (26/08/2019) [section 3.6.3.1.]
- Sousa, C. (in preparation) Changes of students' epistemological conceptions of science upon Problem-Based Learning through History of Science about the origin of life" [sections 3.6.3.2. and 3.6.4.]
- Sousa, C. (in preparation) Teaching Nature and History of Science in context with ecological niche: philosophical considerations and a review of Portuguese textbooks and curricular documents [section 3.7.1.]
- Sousa, C. (2019) History and Nature of Science about the Origin of Life: Analysing Textbooks and Guidelines for a Novel Teaching Approach presented orally at International History, Philosophy and Science Teaching Conference: Re-introducing science - Sculpting the image of science for education and media in its historical and philosophical background (18/07/2019) [section 3.7.2.]
- Sousa, C. (in preparation) Origin of Life as Context for Nature and History of Science teaching: A systematic analysis of textbooks, teaching guidance documents and a novel teaching proposal. [section 3.7.2.]

# Chapter 3. Methodology

## 3.1. Methodological general considerations

The focus of this thesis is on characterizing, describing, promoting learning about epistemological conceptions of science of 8th grade students and preservice teachers and studying the effects of a PBL teaching-learning process on these conceptions, which fits into an interpretative paradigm of qualitative orientation (Cohen, Manion, & Morrison, 2007; Coutinho, 2011). On the other hand, our research questions also reveal the focus on comparing, quantifying, correlating, which fits into a quantitative (Creswell, 2014) or positivist (Cohen et al., 2007) paradigm, essentially deductive.

This combination of qualitative and quantitative procedures, in the same investigation, reflects a mixed methodological approach (Creswell, 2014). According to this author mixed method research "involves the collection of quantitative and qualitative data, integrating both forms of data" (Creswell, 2014, p.32) to provide a higher-level understanding of a research problem than either approach alone would provide (Creswell, 2014).

According to the classification proposed by Creswell, given the diversity of mixed studies, the research in this thesis is parallel convergent, since qualitative and quantitative data were collected and analyzed separately and then compared. It is also of concurrent triangulation mixed type, according to Warfa (2016), that is, the qualitative and quantitative data were collected separately in the same phase and the objective is the cross validation of both data types.

## 3.2. Research design

Preliminary results (Sousa, 2014) of our action research project in which we implemented a NOS and HOS-enriched Problem-Based Learning environment at the middle (year 7 of the Portuguese National Curriculum) and secondary level (year 10) for teaching the origins of biodiversity and of continents and oceans (mobilism) constitutes the background to design the problem-situations in this PhD thesis.

In this thesis two populations (Figures 3.1. and 3.2) were used: i) preservice science teachers (master students attending the first semester discipline biology and geology didatics of the Master program in Biology and Geology Teaching for middle and secondary science teaching certification in Portugal) and ii) middle school students (8th grade students in Natural Sciences classes).

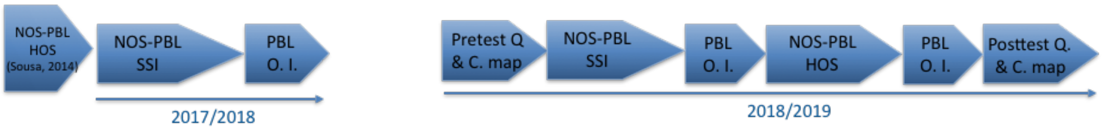


**Figure 3.1.** Main steps of research with preservice teachers: exploratory study in 2017/2018 using a NOS-PBL focused on SSI and one-group pretest-posttest design study in 2018/2019 using 2 sessions of NOS-PBL with SSI and HOS. Note: Observation instrument (O. I.), pretest and post-test questionnaire (pretest Q. and posttest Q.), conceptual map (c. map).

The exploratory study conducted in 2017/2018 allowed the improvement of the problem-situation about ecological niche for the next study with preservice teachers in 2018/2019 and with 8th grade students in 2017/2018.

Regarding the studies with 8th grade students we performed a one-group pretest-posttest design studies in 2017/2018 using SSI-PBL focused on NOS and the other HOS-PBL. These studies allowed the background to design and perform a quasi-experimental pretest-posttest design study using HOS-PBL focused on NOS.

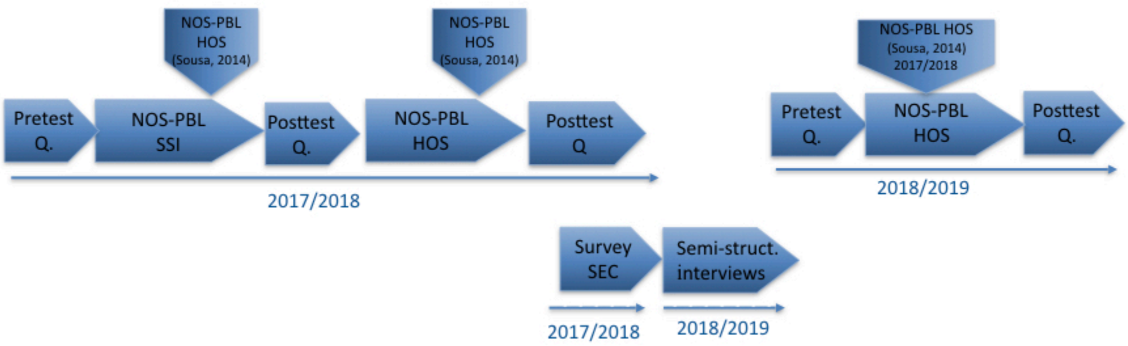


**Figure 3.2.** Main steps of research with 8th grade students: one-group pretest-posttest design studies in 2017/2018, a quasi-experimental pretest-posttest design study in 2018/2019 and in parallel a survey of students' epistemological conceptions of science of Portuguese 8th grade students. Note: pretest and post-test questionnaire (pretest Q. and posttest Q.).

The exploratory study of NOS-PBL with HOS conducted in 2017/2018 allowed the improvement of the problem-situation about the origin of life and the planning of the next study with 8th grade students in 2018/2019.

Since the guidance for teachers about the contents to include in K-12 Science classes is provided by curricular documents, that in Portugal are mandatory by law and textbooks have been described as the main element that determines the content and discourse of middle and high school science classes (Abd-El-Khalick et al. 2017) we also performed review studies on these documents about ecological niche concept and origin of life theories.

## 3.3. Ethical considerations

The protection of the participants is ensured since the results obtained were only used in the scope of this project, anonymity was respected, and informed consent was obtained for the use of the data in this research. For underage students, their parents or guardians were also contacted to obtain informed consent for the use of data obtained from this investigation.

Regarding the questionnaire some of the items are adapted from other questionnaires created by different authors who were contacted, authorizing their use.

All the studies were subject to authorization by the Portuguese Ministry of Education (authorization number 0613700001) and for the survey study interviews (authorization number 0613700002) were authorized with no video or audiotaping.

Regarding the quasi-experimental study (3.6.4.) the control group of students (non-PBL group) were offered, afterword, our PBL unit about ecological niche, so they would have the opportunity to experience PBL.

## 3.4. Validity considerations

The criteria of internal validity and external validity are fundamental to ensure the credibility of any investigation, regardless of the methodologies followed.

In general terms, internal validity refers to the degree to which the results of the study are, in fact, supported by the data, ensuring that such results accurately describe the phenomenon under study (Cohen et al., 2007). External validity refers to the possibility of generalizing the results of a study to other contexts (Cohen et al., 2007; Coutinho, 2011).

Regarding the eminently qualitative component, involving the different didactic interventions, we proceed to the methodological triangulation, using different instruments for data collection (observation, questionnaires, interviews), as well as different sources (teachers and students), in order to integrate different perspectives, ensuring internal validity (Cohen et al., 2007). Discussing the external validity in this context will involve research updated throughout the study with the aim of identifying other investigations with which it is possible to establish some comparison, that is, establishing a parallel between the results of the present investigation with those of other investigations that have involved the same type of participants in similar conditions (Creswell, 2014).

With regard to the quantitative component, that is, the questionnaire survey about the epistemological conceptions of 8th grade students we performed content validation by experts (four science education experts and a middle school teacher) of our pre-validation questionnaire (Appendix 4) and obtained adequate reliability of the questionnaire. With regard to external validity, it is expected to obtain some degree of generalizability of the sample of four school regarding Portuguese 8th grade students, according to the conditions provided.

## 3.5. Methodology of studies with preservice science teachers

### 3.5.1. Using Nature of Science enriched-PBL in pre-service science teacher education

This interpretative exploratory study was conducted in 2017 in a 120 minutes session of a Biology and Geology Didactics course of a Portuguese University Master's program in Biology and Geology Teaching (for middle and secondary science teaching certification). A qualitative and descriptive approach (Cohen, 2011) was implemented.

Participants: Eight Master students (5 females and 3 males) attending the course, accepted to participate in the study, and signed the informed consent form. They were in the first year of the two-year Master's program (2nd cycle Bologna).

Intervention: According to PBL methodology an ill-structured problem-situation (Appendix 2) was presented to the students by the investigator/teacher (C. Sousa) about the consequences of the introduction of invasive plants in ecosystems. This subject is included in the compulsory school, 8th grade, as essential learning "Explain how pollution, deforestation, fires and biological invasions can affect ecosystems." (DGE, 2018a, p.10).

After reading, brainstorming and discussing in small group (2 or 3 students) about the problem-situation, students searched for information on recommended websites. Finally, each group presented to the whole group their proposed solutions. All proposals were discussed. Students were also asked to identify aspects of NOS in the problem-situation. Students were also asked to fulfil a handout (that worked as a hard scaffolding designed for middle school students) while dealing with the problem-situation.

Data collection procedures: Students answered to an anonymous questionnaire assessing the learning process, adapted from Senocak (2009) and Garcia et al. (2017), with a scale 1 to 5 (1 – never to 5 – always). Students' answers identifying the NOS items present in the problem were analysed, and their comments about the handout were registered. Observation notes were also analysed.

### 3.5.2. NOS-enriched Problem-Based Learning using History of Science combined with a Socioscientific Issue in preservice science teacher education

Participants

Participants included a total of 10 preservice science teachers (n = 10 voluntary participants, corresponding to the total number of students enrolled in the discipline, 3 males and 7 females) enrolled in a biology and geology teaching methods course of the first year of a university master's program in biology and geology teaching (biology and geology didactics discipline required for middle and secondary biology and geology teaching certification, in Portugal). The unit was conducted in the first month of their studies. Some preservice science teachers (5 out of 10) held only a bachelor's degree, while 2 had a master's degree, 2 had completed a post-graduation and 1 had a PhD degree (all degrees non-related with education research or teaching, in a specific subdiscipline of biology).

Teaching intervention

This study included a teaching intervention: a PBL unit consisting in two PBL sessions (120 minutes each), by the author, within a biology and geology teaching methods course, that was conducted in 2018.

We designed a PBL unit to explicitly teach about NOS in a contextualized way (within Biology themes), through two different approaches (each one in one session):

(1) Using a socioscientific issue, such as the introduction of invasive plants in ecosystems and teaching about ecological concepts in this context (e.g. ecological niche), that is included in the compulsory school, 8$^{th}$ grade, as essential learning "Explain how pollution, deforestation, fires and biological invasions can affect ecosystems." (DGE, 2018a, p.10)

(2) Using history of science episodes, such as the MacArthur-Wilson's insular biogeography model (e. g. MacArthur & Wilson, 1963) and Darwin's contribute about insular biodiversity (Darwin, 1836), that is included in the compulsory school, 11$^{th}$ grade,

as essential learning “Explain biological diversity based on models and theories accepted by the scientific community” (DGE, 2018b, p.7).

The unit started with an individual activity that consisted of a conceptual map construction activity “what is science?” (description in detail in the following section Data collection and analysis). Then a short electronic presentation by the teacher/author to introduce preservice teachers to the way the sessions would occur and to the process of PBL, including existence of several modalities, with different number of steps (Wijnia et al. 2019), description of the method to be used adapted from DiCarlo (2006), concept of NOS as epistemology of science and SSI as issues with an ethical, political or religious dimension followed. Then preservice teachers were presented with two problem-situations designed to promote the discussion about NOS aspects (explicit teaching of NOS), one in each session. In the first PBL session, the problem-situation addressed the consequences of the introduction of invasive plants in costal ecosystems and the contributions of science to the understanding of this phenomenon and its resolution. In the second session, a problem-situation that introduces preservice teachers to the MacArthur-Wilson’s insular biogeography model.

Preservice teachers, working in small-groups (three or four elements), started by reading the problem-situation, identifying the themes they already knew, discussing (comparing and contrasting) individual prior ideas, thinking about questions and identifying what they needed to research and performed the investigation, and finally presenting a possible solution to the problem-situation. Additionally, in each session preservice teachers were presented to some problematic questions, such as identification of the questions about NOS and Biology raised by the problem-situation and which NOS aspects were included in the problem-situation. At the end of each session, each group communicated their solution to the problem-situation and to each problematic-question to the all class, and the teacher/investigator discussed all the solutions.

Additionally, at the end of the first PBL session, preservice teachers were also asked to identify the controversial issue addressed in the problem and if they classify it as a SSI.

Each session ended with a short PowerPoint presentation by the teacher/investigator to promote discussion of all NOS aspects present, potential curricular contextualization for K-12 education and suggestions on how to adapt the resources to middle and high school students, problematic-questions raised by the problem-situation, main learning objectives and suggested related problem to be pursued in another PBL cycle.

At the end of the unit a conceptual map (Garabet & Miron, 2010) was also presented to the preservice teachers to clarify the concept of conceptual map and then they were asked to construct a map about the concept of science (description in detail in the following section Data collection and analysis).

Data collection and analysis

In this concurrent mixed-methods study we integrated both qualitative and quantitative methods with the main purpose of triangulation of data to enable a more complete and accurate description of the phenomena (O'Hanlon, 2018).

Preservice teachers' perceptions about PBL environment were assessed by using an anonymous questionnaire of evaluation of the learning process, upon authorization by the authors about their use, adapted from Senocak (2009) and Garcia et. al. (2017), with a Likert scale, 1 (never) to 5 (always), that preservice science teachers completed after each PBL session (Appendix 5).

Due to time restrictions, a brief pre-posttest questionnaire Understanding about NOS, SSI and controversial issues (Appendix 6) was designed based on the literature on the subject (Borgerding & Dagistan 2018; Lederman et al. 2014; Liang et al. 2009; Liu & Tsai 2008; Tsai & Liu 2005) and the learning outcomes intended for the unit. Content validity of the open items were checked by two experts. Preservice teachers completed it before (pretest questionnaire) and after (posttest questionnaire) the PBL unit, for 30 minutes, a week before the first session and a week after the second session. Qualitative and quantitative datasets were compared and integrated, as the analysis for all content was performed and the total score (for the section containing questions about NOS) was analysed, using a non-parametric test Wilcoxon Signed Ranks Test, using data-analysis software SPSS version 25 for Mac.

A pre-posttest conceptual map activity "What is Science?" was proposed consisting in providing to the preservice teachers 24 concepts (Appendix 7), and asking them to, individually, elaborate a conceptual map, with the provided concepts and, if needed, adding additional ones, before (pretest map) and after (posttest map) the PBL unit, during 15 minutes a week before the first session and a week after the second session. The constructed maps consisted in data obtained from this learning activity that were analysed using both a qualitative and a quantitative approach according to Wheeldon (2010).

## 3.6. Methodology of studies on K-12 education (studies with 8th grade students)

### 3.6.1. Changes of middle school students' Nature of Science and ecological conceptions upon a PBL intervention using a socioscientific issue

Participants

The participants were Portuguese 8th grade students (N = 34), 13 to 16 years old (Mean = 13.26 and SD = 0.79), 18 females and 16 males, distributed in two Natural Sciences classes (referred as A and B), in a State-funded school located outside one of the largest Portuguese cities, in a rural area, with a high percentage of economically disadvantaged students, with some government funding to support their attendance to school. The students willing to participate in the study were asked to present an informed consent signed by the parent/person responsible for education.

The Natural Sciences teachers of each class (designated Teacher A and Teacher B, of the class A and B, respectively), in the participating school, observed all the PBL sessions.

The first author conducted the intervention about invasive species that is part of the Natural Sciences curriculum, as essential learning "Explain how pollution, deforestation, fires and biological invasions can affect ecosystems" (DGE, 2018a), that consisted in 3 PBL sessions (total duration of 120 min), during one week of the academic year of 2017/2018.

Brief description of the PBL intervention

The PBL intervention consisted in 3 session, in a total duration of 120 minutes (Figure 3.3).

**PBL session 1**

The problem was presented to the students, in an electronic presentation, by the author, and a small introduction to it, images from the websites (bioclimatic explorer; website about invasive plant species) and software (Google Earth, with native and invasive species geographic distribution) they should use. Students suggest preliminary solutions to the problem.

The groups start reading the problem-situation (Appendix 2).

**PBL session 2**
The small-group work starts using a hard learning scaffold (Appendix 8), that they complete with facts, questions and learning objectives, upon using data from different sources.

**PBL session 3**
To reinforce some aspects were students had more difficulties the teacher participated in the group work by asking questions to promote learning, in each group, about ecosystems services, and the role of society in financing, and stating that the results obtained by scientists are medians (this constitutes a soft scaffold provided).
Students discussed and presented to the class their proposed solution to the problem.

**Figure 3.3.** Schematic representation of the learning environment and description of each PBL session.

Data collection and analysis

The impact of the intervention was assessed using a pre-/post-questionnaire including several statements about NOS (in a Likert scale) and open and multiple-choice questions about NOS and ecological concepts (Appendix 9, p3) and pre-/post-questionnaire (Appendix 10) with items about NOS adapted from other authors (Liang et al., 2006; Tsai & Liu, 2005) that were previously contacted and authorized their use and by using literature about the theme (Abd-El-Khalick, 2012; Harwood, 2004; Lederman et al., 2014). The content validity of the questionnaire was validated by a panel of 5 experts (educational scientists, faculty professors and a middle school teacher).

Descriptive statistics and Wilcoxon Signed Ranks Test (Z and p are presented) are performed for data analysis, of the items using a Likert scale, using the Statistical Package for Social Science for Mac (SPSS 25). The effect size (r) is calculated according to Field (2009): $r = Z/\sqrt{N}$, with N as number of observations.

The contents of the students' answers in open and multiple-choice questions are also analyzed (Appendix 9, p3).

We also designed instruments for observation of the PBL process, with a 1 (never) to 5 (always) Likert scale, with some items of our own authorship and based on instruments designed by other authors (Senocak, 2009; Garcia et al., 2017), that were contacted and authorized their use. One instrument was applied for participatory observation (first author) and another was applied to the teachers of the class that observed the PBL sessions performed by the investigator.

Both observing teachers were interviewed (Appendix 11) and the contents of their answers were analyzed.

The contents of the scaffolds, that each group of students completed (with facts, questions and learning objectives), were analyzed.

### 3.6.2. Changes in students' Nature of Science conceptions upon a HOS and NOS-enriched PBL intervention

Outline of the intervention

The intervention consisted of 3 PBL sessions (50 min each). Students were provided with a problem-situation (Appendix 12) and a learning scaffold (Appendix 13) related to several theories about the origin of life enriched with an historical perspective, and with NOS aspects. This subject is included in curricular documents for compulsory education of 8$^{th}$ grade "Argue about some theories of the origin of life on Earth" (Bonito et al., 2013, p.18). Considering that students have access to considerable amounts of information and the short length of time available for the PBL unit, selected information about each theory was provided. This intervention occurred during the academic year 2017/2018 and was previously authorized by the National General Direction of Education.

Participants and settings

Participants in this study (N=34) were 8$^{th}$ grade students in two different classes of a Portuguese state-funded school (Oporto region, Portugal). Ages 13 to 16 years old (Mean = 13.26 and SD = 0.79), 18 females and 16 males willing to participate in the study after the corresponding informed consent signed by the parent/person responsible for education. The first author was responsible for the intervention and taught the intervention unit to all the students. The Natural Science teachers of the two classes, as voluntary participants, observed all the lessons.

Data Collection and Analysis

The impact of the intervention was assessed using a mixed-methods approach using a pre-/post-questionnaire (with items in a Likert scale) and qualitative analysis about the observation of the classes.

The NOS conceptions questionnaire is under development, in which some items were adapted from other authors (Park et al., 2014; Liang et al., 2006; Tsai & Liu, 2005) that were contacted and authorized their use while others were constructed based on literature about the theme (e. g. Moore, 1984). Previously, a panel of 5 experts (educational scientists, faculty professors and a middle school teacher) validated the content of the questionnaire. The adequate time for students to complete it was assessed and provided, and an adjustment to the vocabulary was performed. The quantitative responses were analyzed, using the software Statistical Package for the Social Sciences (SPSS, version 25), the Wilcoxon Signed Ranks Test (Z and p are presented in Table 1), and the effect size (r) was calculated according to Field (2009).

We also designed an observation instrument regarding PBL facilitation, with a 1 (never) to 5 (always) Likert scale. Some items were of our own authorship and some were based on instruments designed by other authors Garcia et al. (2017) and Senocak (2009) that were contacted and authorized their use; one instrument was applied for participatory observation (including observation of each group of students) and another one was applied to the teachers who observed the classes.

## 3.6.3. Development of an instrument for assessment of middle school students' epistemological conceptions of science

### 3.6.3.1. Development of a multidimensional instrument for assessment of middle school students' epistemological conceptions of science

Participants in this study (N = 431) are eight-grade middle school students (220 males and 211 females, mean age = 13.6 years) at five Portuguese state-funded schools that willing to participate in the study had the corresponding informed consent signed by the parent/person responsible for education. The questionnaire was administered in 2017/2018 (in four schools) and 2018/2019 (in one school).

The design of the instrument (Appendix 10) started by revision of the literature and some items were selected from studies from other authors (Liang et al., 2009; Liu & Tsai, 2008), while others were constructed based in the literature about the theme (Abd-El-Khalick, 2012; Harwood, 2004; Lederman et al., 2014). During the next phase of development of the instrument its content validity was assessed by 4 science education experts currently engaged in research and/or teaching of NOS and a middle school teacher. All the items are presented on a 1 (strongly disagree) to 5 (strongly agree) Likert scale and a high score indicates that the NOS informed view is accepted by the student.

An exploratory factor analysis, using principal component analysis (PCA), to identify the underlying dimensions was performed on the initial 37 items, KMO was 0.695 and Bartlett's test of sphericity was significant indicating that correlations between categories were sufficiently large for PCA. Items with similar correlation coefficient Spearman's rho with more than 5 items, communalities < 0.36 and/or with factor loading less than 0.40 were omitted.

For follow-up interviews we selected students (N=17) according to Tsai & Liu (2005) from three groups based on their sum scores on the questionnaire (a group of students who scored top 15% of the SEV instrument, a second group was an "average" group, which scored close to the mean of all students and a third group that had the bottom 15% scores) and used semi-structured interviews (Appendix 14).

SPSS Statistics version 25 for Mac was the software used.

#### 3.6.3.2. Characterization of Portuguese middle school students' epistemological conceptions of science and development of an instrument for assessment

The participants in this study (N = 362) are eight-grade middle school students (185 males and 177 females, mean age = 13.57 years, SD = 0.796) at four Portuguese state-funded schools that willing to participate in the study had the corresponding informed consent signed by the parent/person responsible for education.

Methodology

The design of the instrument (Appendix 10) started by revision of the literature and some items were selected from studies from other authors (Liang et al., 2009; Liu &

Tsai, 2008), while others were constructed based in the literature about the theme (Abd-El-Khalick, 2012; Harwood, 2004; Lederman et al., 2014). During the next phase of development of the instrument its content validity was assessed by 4 science education experts currently engaged in research and/or teaching of NOS.

Since the exploratory factor analysis we conducted was able to produce a questionnaire with only 16 items and the confirmatory factor analysis did not find any solution we decided that the characterization of students' epistemological conceptions of science (SECS) would be performed using an instrument not considering different factors, using the sum of several items. For this objective we used a portion of the sample in 3.6.3.1. corresponding to four schools in which the questionnaire was administered on the same academic year.

Calculation of reliability of the instrument was performed and some items were omitted to obtain a questionnaire with an acceptable value of alpha Cronbach.

All the items are presented on a 1 (strongly disagree) to 5 (strongly agree) Likert scale and the options of 'strongly agree', 'agree', 'not sure', 'disagree', and 'strongly disagree' were coded as 5, 4, 3, 2, and 1, respectively. For the negative items, the codes of '5', '4', '2', and '1' were re-coded as '1', '2', '4', and '5', respectively. In order to calculate the total score for each participant based on the responses to the entire questionnaire, it is important to reverse-score the negative items so that they are all coded in the same direction.

SPSS Statistics version 25 for Mac was the software used.

### 3.6.4. Changes of students' epistemological conceptions of science upon Problem-Based Learning through History of Science about the origin of life

In this study we used a two-group pretest-posttest quasi-experimental research design with students not randomly allocated to the two groups of PBL and non-PBL, a pre-test-post-test non-equivalent group design according to Cohen et al. (2007).

Participants

The students participating in this study (N=36 in the PBL group and N=33 in the non-PBL group) were students at a Portuguese State-funded school, of four different classes of the same school, of the Middle School (8$^{th}$ grade), between 12 and 16 years old (for the PBL group Mean=13.44 and SD=0.81 and for the non-PBL group Mean=13.55 and SD=1.18), and were 20 females and 16 males for the PBL group and

14 females and 19 males for the non-PBL group that willing to participate in the study had the corresponding informed consent signed by the parent/person responsible for education.

The author was responsible for the intervention by teaching the curricular unit to all the students and the teachers of each class observed all the lessons and were interviewed.

Outline of the intervention unit

The PBL activity proposed (Appendix 1) is an ill-structured problem-situation (that has several possible solutions), enriched with HOS and NOS aspects, about the characterization of a universal common ancestor (UCA) designed according to Dolmans et al. (1997) and as previously suggested (Sousa, 2016d). This subject is included in curricular documents for compulsory education of 8$^{th}$ grade “Argue about some theories of the origin of life on Earth” (Bonito et al., 2013, p.18).

At the end of the unit, each team of students presents a written description and a drawing of their proposed UCA. In doing this, students will activate their prior knowledge as they need to think about UCA’s characteristics: unicellular or pluricellular, prokaryotic or eukaryotic, heterotrophic or autotrophic, photosynthetic or chemoautotrophic, aerobic or anaerobic, living in land, or in a fresh or in a salt water environment. The problem-situation encourages students to search for more information about the theories mentioned and, eventually, other aspects they may consider relevant to be able to propose a solution.

The proposed PBL activity has a total of 7 sessions (each session with 50 minutes) described in the sections bellow.

Sessions 1 to 4

The first step in the PBL process started with the all class as a group and the beginning of conceptual change (by the teacher as the tutor identifying misconceptions) by promoting the construction of a conceptual map about life. Some of the concepts were: what sciences study the subject (e. g. Biology and Paleontology), characteristics of living beings (multiplication, heredity, variability) and the fact they share a common ancestor. Then answering the problem only with the previous knowledge, identifying misconceptions, and then started to read and analysis of the problem-situation.

Then, in small-groups of students they read the problem-situation (Appendix 1), identified previous knowledge and unknown concepts included in the problem situation. Upon discussing, each group was asked to complete a hard-scaffold (Appendix 15), starting with the column Facts of the hard scaffold, identifying concepts they know and the ones they don't know and questions about these (column Questions of the scaffold in Appendix 15).

The teacher/author frequently visited each group providing soft scaffolding with the purpose to promote higher order thinking, in accordance with other authors (Oguz-Unver & Arabacioglu, 2014), by asking questions such as how do you explain that?, what do you mean?, how do you know that's like that?.

Students then started searching several sources of information, such as a biographic documentary with animations and computer simulations, a TED talk, newspapers and interviews. Some resources were given to the students (Appendix 16) and students may search out their own information to answer their questions and the problem-questions included in the problem-situation. They did this as a group or defining different tasks for each group member. To guide this search, students completed the column 'What we need to know?' enabling them to identify their own learning objectives.

In the comparison group, students were provided with all the sources of information of the PBL group as a Power Point presentation (Appendix 16) by the teacher/author and performed some problem-solving questions about each subject, individually or as pairs and a text (Appendix 17).

Sessions 5 to 7

After completing the hard-scaffold, each group of students discussed, negotiated and decided the group's common response to the questions included in the problem-situation What is the theory/hypothesis of the origin of life that you consider the most explanatory? Why? And was it or can it be proven? – these constitute conceptual change questions according to Yip (2004). The teacher/author asked each group of students to present, to the class, their answer including adequate supporting argumentation – this was the moment to promote a reflective and explicit strategy about NOS. Students are then asked After all what is a theory? (in the problem-situation, Appendix 1) that promoted students to discuss and summarize their knowledge about NOS by constructing a conceptual map - What is Science? - as a pencil and paper activity (with a given list of 24 concepts).

Students proposed a solution to the problem How do you characterize the common ancestor of all living beings? by thinking about the last universal common ancestor (LUCA) or about a previous organism or entity (e.g. early organisms would be unicellular anaerobic and heterotrophic existing in a primitive soup, according to Oparin's theory). The teacher/author asked each group to present their solution to the class, each group presented and defended their classification with argumentation, and the teacher promoted a discussion, highlighting the fact that students usually use the theory they considered most explanatory to characterize the universal common ancestor, such as scientists (this constitutes a NOS aspect of theory-laden NOS).

In the last session before responding the questionnaires the teacher shows in a Power Point presentation a more adequate conceptual map about science and theories and highlights the unfinished NOS, the notion that one can never prove a theory, but it can be disproved, and the specific characteristics of the subject origin of life, facilitating the conceptual change using a most adequate conceptual map (for PBL and non-PBL groups).

The teacher then proposes to the students to think about a new problem related with the one presented, as a novel full PBL cycle, that they propose to the all class, such as the problem of how to organize a mission for searching for life in other planets.

In the comparison group, the teacher/author presented a Power Point presentation and the students performed some problem-solving questions about each subject (e.g. What was meant to simulate Miller in each of the glass balloons?), individually or as pairs. At the end of the unit the students completed individually the conceptual map about what is a theory and what is science.

Data Collection and Analysis

The impact of the intervention was assessed using two pre-/post-questionnaires including Students' Epistemological Conceptions Questionnaire (an instrument with items in a Likert scale, Appendix 9). Some items of the Students' Epistemological Conceptions Questionnaire were adapted from other authors (Liang et al., 2006; Liu & Tsai, 2008; Tsai & Liu, 2005) that were contacted and authorized their use and by using literature about the theme (Abd-El-Khalick, 2012; Harwood, 2004; Lederman et al., 2014; Moore, 1984). For content validity the questionnaire was validated by a panel of 5 experts (educational scientists, faculty professors and a middle school teacher). To calculate reliability the questionnaire and to characterize 8$^{th}$ grade Portuguese students' epistemological conceptions of science the questionnaire was administered to 362 students of four Portuguese State funded schools. The Cronbach alpha was calculated as 0.7.

To avoid the limitations related with the use of the force choice instrument for evaluating students' epistemological conceptions, since due to time restrictions of the participants our study could not include interviews, we used some open-items (Appendix

18) to allow students to more fully and accurately describe their understandings: Are all scientific investigations carried out in the same way following the same steps as the scientific method? justify (if you agree, explain why there is only one way to do a scientific research and describe it; if you do not agree, describe two investigations that follow different methods and explain how the methods differ and how both investigations can be considered scientific) – an item adapted from VASI questionnaire (Lederman et al., 2014). The other item was “Do you agree with the statement: Are scientific theories explanations, built by scientists, about a wide variety of related phenomena that have already been tested? Justify (explaining the difference between theory and hypothesis).

We also used some open-item about the biology subject of the intervention such as “Do you agree with the statement: are all living things on Earth related to each other because they share a common ancestor that existed millions of years ago? Justify.” and “Indicate the name of one of Darwin’s theories”. We also asked, as a multiple-choice question, “Indicate the age of the oldest life evidence you know”.

A learning scaffold was presented to the students, of the PBL group, that they completed with facts (from the problem-situation), questions and learning objectives (in the section what they need to know), then the contents of this scaffold were analyzed. All the documents necessary to find information for this scaffold were provided to both groups.

Both groups were asked to construct, individually (comparison group) or in group (PBL group), a conceptual map What is science? What is a theory? and 24 total concepts were provided, and the maps were analyzed.

The quantitative responses were analyzed using the Wilcoxon Signed Ranks test (Z and p are presented) and Independent Samples Mann Whitney test (for PBL an control compararison).

## 3.7. Review of Portuguese textbooks

### 3.7.1. Teaching Nature and History of Science in context with ecological niche: review of Portuguese textbooks and curricular documents

All over the world there is some guidance for teachers about the contents to include in K-12 Science classes that is provided by curricular documents, that in some countries constitute only guidelines and in others are mandatory by law (e. g. Portugal). Therefore, we decided to analyse the contents of the current curriculum reference documents for Middle School (7$^{th}$ to 9$^{th}$ grades) of the discipline Natural Sciences, since these corresponds to the common curriculum to all students (in High School only a portion of students have the Biology discipline, in Portugal). So, the following guidance documents were analysed:

1) Essential Learning (DGE, 2018a) indicates the indispensable learning for the meaningful construction of knowledge, as well as the development of cognitive processes and attitudes particularly associated with science,

2) Curriculum Goals (Bonito et al, 2013) that describes the set of the curriculum goals of the Natural Sciences subject that students must achieve during the Basic Education,

3) Curriculum Guidelines (Galvão et al, 2001) that assumes curricular flexibility that the formal curriculum can give place to curriculum decisions that imply different teaching and learning practices.

Since textbooks have been described as the main element that determines the content and discourse of middle and high school science classes (Abd-El-Khalick et al. 2017) we also analysed all (nine) the textbooks for 8th grade Natural Sciences presently certified by the Ministry of Education, commercially available and in use in Portuguese schools.

The curriculum documents and textbooks were reviewed and statements about NOS were identified according to McComas & Nouri (2016) and Abd-El-Khalick et al., (2017). These identified statements were classified based on the location in the curriculum document in which it appeared according to Olson (2018).

Content analysis was performed for HOS using appropriate extant checklist in specialized literature (Leite, 2002).

Additionally, we systematically reviewed the Web for the concept “ecological niche” and “niche” using Google Scholar, compared with related concepts, and annotated the number of hits obtained (search performed on April 24th 2019).

### 3.7.2. Origin of life in Portuguese textbooks

Since textbooks have been described as the main element that determines the content and discourse of middle and high school science classes (Abd-El-Khalick et al. 2017) we analysed all (nine) the textbooks for 8th grade Natural Sciences presently certified by the Ministry of Education, commercially available and in use in Portuguese schools.

A comparative analysis of HOS content, adapted from Leite (2002), was performed regarding the type of historical information (e.g. scientist name mentioned, date of birth and death of scientist responsible), type of materials used (e.g. text and image/illustration) and if contained in a learning activity (e.g. a question).

# Chapter 4
# Results and discussion

# Chapter 4

# Results and discussion

Parts of this chapter were already presented at international conferences and/or published, submitted to publication or are in preparation for publication:

- Sousa, C. & Chagas, I. (2018). Using Nature of Science enriched-PBL in pre-service science teacher education. In Conference proceedings "New perspectives in science education" (p592-595). Itália: Libreriauniversitaria edizione. ISBN: 978-88-6292-976-9. Online in: http://bit.ly/35fqUuo. [Section 4.1.1.]
- Sousa, C. & Chagas, I. (2019) Teaching the nature of science using problem-based learning in pre-service biology and geology teacher education presented orally at Winter Conference of Association for Teacher Education in Europe - Science and Mathematics Education in the 21st century (16/04/2019) [Section 4.1.2.]
- Sousa, C. (2019) Fostering Pre-Service Science Teachers' Learning About Nature of Science Using a Problem-Based Learning Activity on Biogeography presented orally at International History, Philosophy and Science Teaching Conference: Re-introducing science - Sculpting the image of science for education and media in its historical and philosophical background (17/07/2019) [Section 4.1.2.]
- Sousa, C. (Science & Education, submitted) NOS-enriched Problem-Based Learning using History of Science combined with a Socioscientific Issue in preservice science teacher education [Section 4.1.2.]
- Sousa, C. (IJPBL, submitted) Change of middle school students' Nature of Science and ecological conceptions upon a PBL intervention using a socioscientific issue [section 4.2.1]
- Sousa, C. (2019) Nature of Science-enriched Problem-Based Learning about the ecological niche concept using a socioscientific issue, presented orally at International Conference of European Ecological Federation & SPECO - Ecology across Borders (30/07/2019) [sections 4.2.1. and 4.3.1.]
- Sousa, C. & Chagas, I. (2019). Changes in Students' Nature of Science Conceptions upon a HOS and NOS-Enriched PBL Intervention. In New Perspectives in Science Education Conference Proceedings (p537-543). Italy: Filodiritto Editore. [section 4.2.2]
- Sousa, C. (2019) Characterization of students' scientific epistemological conceptions and development of a multi-dimensional instrument for the assessment presented orally at ESERA Conference "The beauty and pleasure of understanding: engaging with contemporary challenges through science education" (26/08/2019) [section 4.2.3.1.]
- Sousa, C. (in preparation) Changes of students' epistemological conceptions of science upon Problem-Based Learning through History of Science about the origin of life" [sections 4.2.3.2. and 4.2.4.]
- Sousa, C. (in preparation) Teaching Nature and History of Science in context with ecological niche: philosophical considerations and a review of Portuguese textbooks and curricular documents [section 4.3.1.]
- Sousa, C. (2019) History and Nature of Science about the Origin of Life: Analysing Textbooks and Guidelines for a Novel Teaching Approach presented orally at International History, Philosophy and Science Teaching Conference: Re-introducing science - Sculpting the image of science for education and media in its historical and philosophical background (18/07/2019) [section 4.3.2.]
- Sousa, C. (in preparation) Origin of Life as Context for Nature and History of Science teaching: A systematic analysis of textbooks, teaching guidance documents and a novel teaching proposal. [section 4.3.2.]

# Chapter 4. Results and discussion

## 4.1. Studies with preservice science teachers

### 4.1.1. Using Nature of Science enriched-PBL in pre-service science teacher education

In general, preservice teachers considered the learning process positive (Table 4.1) with some disparities regarding the items about teacher support as shown by their responses to the items of the questionnaire, with a Likert scale, 1 (never) to 5 (always),

**Table 4.1.** Frequency of preservice teacher responses about teacher support

| Items | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| The teacher directed us with pertinent questions. (Senocak, 2009) | 0 | 0 | 0 | 5 | 3 |
| The teacher stimulated us to exploit prior knowledge. (Garcia et al., 2017) | 0 | 0 | 1 | 2 | 5 |
| The teacher gave us clues instead of the correct answer, when asked a question. (Senocak, 2009) | 0 | 0 | 0 | 2 | 6 |
| The teacher promoted questioning by all the students in each group. (Garcia et al., 2017) | 0 | 0 | 0 | 4 | 4 |
| The teacher encouraged us to express our ideas clearly. (Senocak, 2009) | 0 | 0 | 2 | 4 | 2 |
| The teacher asked us how we came to the solution and what reasoning we followed. (Senocak, 2009) | 1 | 0 | 1 | 2 | 4 |

Note: n = 8 students.

It is interesting to note that all students considered that the teacher/author promoted questioning by all the students in each group and also directed them with pertinent questions, what shows a constructive interaction established.

In general students considered the learning process positive about the quality of the problem and resources as shown by their responses to the items of the questionnaire (Table 4.2), with a Likert scale, 1 (never) to 5 (always).

**Table 4.2.** Frequency of preservice teacher responses about quality of the problem and resources

| Items | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| The problem presented has several solutions. (Senocak, 2009) | 0 | 0 | 3 | 0 | 5 |
| The problem was written in a comprehensible language. (Senocak, 2009) | 0 | 0 | 3 | 3 | 2 |
| The problem provided was interesting and stimulated motivation towards learning. | 0 | 0 | 3 | 2 | 3 |
| The resources made available for the research were adequate. (Garcia et al., 2017) | 0 | 1 | 1 | 3 | 3 |
| The scaffold provided promoted a structured learning. | 0 | 0 | 1 | 5 | 2 |

Note: n = 8 students.

The disparity obtained regarding the resources made for middle school students was explained since they commented that they considered too dense, too demanding and too long and we further simplified these resources before being given to 8$^{th}$ graders.

In general students considered the learning process positive about students' role and interaction (Table 4.3) as shown by their responses to the items of the questionnaire (Table 4.3), with a Likert scale, 1 (never) to 5 (always).

**Table 4.3.** Frequency of preservice teacher responses about students' role and interaction

| Items | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| I participated in the group work. (Senocak, 2009) | 0 | 0 | 0 | 0 | 8 |
| When I came across something I didn't understand, first I consulted with a fellow student then consulted the teacher. (Senocak, 2009) | 0 | 0 | 0 | 1 | 7 |
| I collected and selected relevant information for the group work. (Senocak, 2009) | 0 | 0 | 1 | 4 | 3 |
| I raised pertinent questions. | 0 | 1 | 3 | 3 | 1 |
| I responded the pertinent questions I have raised. | 0 | 0 | 2 | 5 | 1 |
| I discussed with colleagues in the group with respect for different ideas. (Senocak, 2009) | 0 | 0 | 1 | 1 | 6 |
| I performed an important role in my own learning process. (Senocak, 2009) | 0 | 0 | 1 | 5 | 2 |
| I justified my opinions using scientific arguments. | 0 | 0 | 2 | 5 | 1 |
| I was able to propose a solution to the problem. | 0 | 2 | 1 | 4 | 1 |

Note: n = 8 students.

It is interesting to note that some students considered they didn't propose a solution although all the groups were able to do it.

Each group presented a different solution to the class and all the solutions were discussed: neutralize the pH of the soil, introduce a plant-specific virus that affects the invasive plant, and manual removal of all the parts of the invasive plant.

All the students were actively engaged in the process of solving the problem-situation and were able to identify the NOS items included, such as the scientific methods, interaction between scientists, and the importance of publishing.

Giving the positive way students reacted to the NOS enriched-PBL task it is pertinent to conclude that Life Science's problems about timely themes included in the national curriculum of Life and Earth Sciences at the middle and high school level (grades 8 and 10 of K-12), integrated with NOS aspects and several curriculum objectives, may constitute an applied learning method for pre-service science teacher education. This proposal is according to authors that have suggested critical and reflexive reading of cases for NOS teaching (Acevedo-Díaz et al., 2017) and that highly contextualized NOS instruction may induce students' connection to science knowledge (Bell et al., 2016).

### 4.1.2. NOS-enriched Problem-Based Learning using History of Science combined with a Socioscientific Issue in preservice science teacher education

***Session 1 – SSI approach***

All preservice teachers were actively engaged in the PBL process and were able to propose NOS questions that were promoted by the problem-situation (e.g. "what is the importance of publishing in scientific journals?") and identify NOS aspects in the problem-situation, such as: the methods used by scientists, the interactions between scientists and the importance of publishing. Preservice teachers also commented that the "all the session is NOS learning because we used one scientific method, as we worked as a team and we used a theory as support to solve a problem". If any misconceptions (e.g. myth of a single method) were discussed, they were discussed at the end of the lesson to avoid reinforcement of any myths and promote the conception that there are frequent activities developed by scientists, such as working in teams.

Each group presented a different solution to the class and all the solutions were adequate and were discussed:

1) manual removal of all the parts of the invasive plant and to plant the native species, sensitize local people about the importance of maintaining native plants, monitoring and punishing to comply with legislation,

2) eliminate/control wild rabbits that propagate seeds or eliminate fruits or change soil pH (two alternative solutions proposed, since the group failed to reach final consensus), and

3) to study the characteristics of the geographic areas where the invasive species does not occur, based on the geographic distribution map of the species.

Results from the questionnaire on preservice teachers' perceptions about PBL environment (Likert scale 1 to 5) are consistent with the other results since they showed that all preservice teachers considered as positive the teacher support (Table 4.4 ), all considered positive the quality of the problem and resources provided (Table 4.5) and 8 out of 10 preservice teachers considered all the items positive about the their own role and interaction (Table 4.6 ).

**Table 4.4.** Frequency of preservice teacher responses about teacher support.

| Items | PBL session 1 | | | | | PBL session 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** |
| The teacher directed us with pertinent questions. (Senocak 2009) | 0 | 0 | 0 | 4 | 6 | 0 | 0 | 2 | 5 | 3 |
| The teacher stimulated us to exploit prior knowledge. (Garcia et al. 2017) | 0 | 0 | 2 | 3 | 5 | 0 | 0 | 1 | 8 | 1 |
| The teacher gave us clues instead of the correct answer, when asked a question. (Senocak 2009) | 0 | 0 | 1 | 3 | 6 | 0 | 0 | 0 | 6 | 4 |
| The teacher promoted questioning by all the students in each group. (Garcia et al. 2017) | 0 | 0 | 1 | 1 | 8 | 0 | 0 | 0 | 5 | 5 |
| The teacher encouraged us to express our ideas clearly. (Senocak 2009) | 0 | 0 | 1 | 4 | 5 | 0 | 0 | 2 | 4 | 4 |
| The teacher asked us how we came to the solution and what reasoning we followed. (Senocak 2009) | 0 | 0 | 0 | 5 | 5 | 0 | 0 | 4 | 2 | 4 |

Note: n = 10.

**Table 4.5.** Frequency of preservice teacher responses about quality of the problem and resources.

| Items | PBL session 1 | | | | | PBL session 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** |
| The problem presented has several solutions. (Senocak 2009) | 0 | 0 | 1 | 4 | 5 | 0 | 0 | 5 | 1 | 4 |
| The problem was written in a comprehensible language. (Senocak 2009) | 0 | 0 | 1 | 4 | 5 | 0 | 0 | 2 | 4 | 4 |
| The problem provided was interesting and stimulated motivation towards learning. | 0 | 0 | 1 | 3 | 6 | 0 | 1 | 0 | 4 | 5 |
| The resources made available for the research were adequate. (Garcia et al. 2017) | 0 | 0 | 0 | 3 | 7 | 0 | 0 | 1 | 6 | 3 |

Note: n = 10 students.

It is important to note the promotion of the collaboration, reported by others in PBL comparing with traditional teaching (Ding et al., 2014), as all students report that when came across something they didn't understand, they first consulted with a fellow student then consulted the teacher (Table 4.6) as well as all students report participating in the group work (Table 4.6).

**Table 4.6.** Frequency of preservice teacher responses about their own role and interactions.

| Items | PBL session 1 | | | | | PBL session 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** |
| I participated in the group work. (Senocak 2009) | 0 | 0 | 0 | 2 | 8 | 0 | 0 | 2 | 1 | 7 |
| When I came across something I didn't understand, first I consulted with a fellow student then consulted the teacher. (Senocak 2009) | 0 | 0 | 0 | 3 | 7 | 0 | 0 | 1 | 2 | 7 |
| I collected and selected relevant information for the group work. (Senocak 2009) | 0 | 0 | 1 | 3 | 6 | 0 | 0 | 1 | 6 | 3 |
| I raised pertinent questions. | 0 | 1 | 2 | 3 | 4 | 0 | 1 | 2 | 5 | 2 |
| I responded the pertinent questions I have raised. | 0 | 0 | 3 | 5 | 2 | 0 | 1 | 4 | 2 | 3 |
| I discussed with colleagues in the group with respect for different ideas. (Senocak 2009) | 0 | 0 | 1 | 1 | 8 | 0 | 0 | 1 | 2 | 7 |
| I performed an important role in my own learning process. (Senocak 2009) | 1 | 0 | 3 | 5 | 1 | 0 | 0 | 1 | 8 | 1 |
| I justified my opinions using scientific arguments. | 0 | 0 | 1 | 4 | 5 | 0 | 2 | 0 | 4 | 4 |
| I was able to propose a solution to the problem. | 0 | 0 | 2 | 4 | 4 | 0 | 0 | 1 | 7 | 2 |

Note: n = 10 students.

***Session 2 – HOS approach***

Upon reading, brainstorming, using the computer simulation and discussing, each group presented its solution to the class about what factors influence the colonization and biodiversity observed on an island by drawing a graph. However, only one (out of three) group drew a completely adequate one (Figure 4.1.) and all the solutions were discussed.

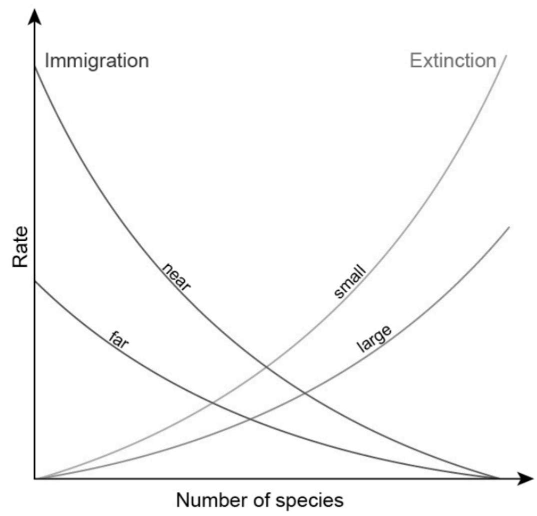


**Figure 4.1.** One possible solution to the problem presented using the MacArthur & Wilson's model of insular biogeography (Adapted from MacArthur & Wilson 1963).

Preservice teachers were also asked to identify NOS items present in the problem and their ideas were discussed. All preservice teachers were actively engaged in the PBL process and were able to propose NOS questions that were promoted by the problem-situation and identified NOS aspects included, such as: the use of several methods by scientists, the importance of publishing, the process of peer-review, beginning of any investigation with one question, need of imagination and creativity in scientists, and the role of society influencing science. One group mentioned that the methods used by scientists are influenced by the society, for example due to bioethical concerns and mentioned the example, presented in the problem-situation, of fumigation of natural areas in the 1960s and the teacher facilitated the discussion describing also the availability of new imaging technologies that allowed the identification of volcanic islands being formed that are potential areas for these studies. And there was also the promotion of more informed conceptions about some NOS aspects, such as: theories can be tested but not proven and that scientific models are included within theories.

The learning process was also assessed, using an anonymous questionnaire (using a Likert scale 1 to 5), in which all preservice teachers considered as positive all the teacher support (Table 4.4), 9 out of 10 preservice teachers considered all the items positive about the quality of the problem and resources provided (Table 4.5) and 6 out of 10 preservice teachers considered all the items positive about their own role and interaction (Table 4.6).

***Impact of the PBL unit***

The results obtained using the questionnaire Understanding about NOS, SSI and controversial issues show there was a significant change between pre- and post-NOS conceptions of preservice teachers (Z = -2,805, p = 0.005) suggesting that the PBL intervention had made a significant impact on preservice teachers' NOS conceptions, corresponding to a high effect size (r = 0,627), according to Field (2009).

The qualitative approach allows to suggest that, in general, preservice teachers showed some improvement in their NOS conceptions and argumentation ability. Some examples of adequate open-ended responses, in the posttest, by preservice teachers for each NOS aspect are presented below:

- Scientific theory concept - "Scientific theories are explanations of phenomena that have not necessarily been tested" (question 1, student 2, pretest) and "The scientific theories try to explain natural phenomena and are subject to constant tests" (question 1, student 2, posttest); "Scientific theories if not tested would be hypotheses" (question 1, student 10, pre and posttest);
- tentative nature of scientific knowledge – "Science is always constantly evolving, new tests and discoveries must be applied" (question 3, student 1, pretest) and "Science is not static, it is under constant construction. Nothing is an absolute truth, otherwise it would be dogma" (question 3, student 1, posttest); "I do not agree that theories can be tested but cannot be proved because the test results support and prove the theories, but it is always possible that another theory will provide evidence to the contrary and that the first was incorrect or incomplete" (question 8, student 5, pretest) and "I agree that theories can be tested but cannot be proved because scientists seek positive results for their tests, but they do not fully prove a theory" (question 8, student 5, posttest);
- scientific methods – "Scientific research begins with the formulation of questions or hypothesis, since it can be based on hypothesis, but can also have other purposes" (question 2, student 3, pretest) and "Scientific research begins with the formulation of questions and additionally hypotheses can be elaborated; however not all research work is based on hypotheses, for

example human genome project" (question 2, student 3, posttest); "Science only makes sense if knowledge is built on experimental evidence." (question 6, student 4, pretest) and "Evidences can be experimental, observations and even demonstrations." (question 6, student 4, posttest)

- subjectivity and influence of society and culture - "false, biology is universal, but the interpretation of observed phenomena varies from country to country and that will influence scientific inquiry" (question 4, student 2, pretest) and "false, different cultures and societies pose different questions to scientists. In addition, the culture of one country can restrict the action of scientists and in another country it does not" (question 4, student 2, posttest); "Studies are never impartial, scientists are humans and everything always has a final goal" (question 5, student 1, pretest) and "It is never impartial, science developments has socioeconomically dependence, for example the investigations depend on the ideology of whom is in government" (question 5, student 1, posttest).

However, we found some uninformed NOS conceptions shown to be difficult to change, such as the conceptions about how the scientific research is conducted: "[scientific research starts] posing a question, then a hypothesis is formulated that will be tested" (question 2, student 3 pre and posttest), and "(…) when experiments respect a series of scientific rules and present consistent results, with low standard deviation can be considered their results as true and accurate" (question 9, student 4, pretest) and "(…) if there is low standard deviation and are performed in triplicate, among others, the probability of being true and accurate is greater" (question 9, student 4, posttest). Another NOS conceptions shown to be difficult to change was about the distinction between theory and law: "One scientific theory may be proved, but then it becomes, for example, a law" (question 8, student 3, pre/posttest), as previously described by other authors (Mesci & Schwartz, 2017), however our short intervention is focused on the concept of theory and model and did not address this distinction between theory and law.

In the conceptual map "What is Science?" activity we observed an improvement promoted by the unit since several (eight) preservice teachers, after the sessions, unite "communication between scientists" either to "accepted theories" (1 preservice teacher) or to "theories" (5 preservice teachers) or to "body of knowledge" (2 preservice teachers), while before the unit this was only present in two maps. In general, the number of concepts and of links between these increase upon the unit with an example in Figure 4.2.

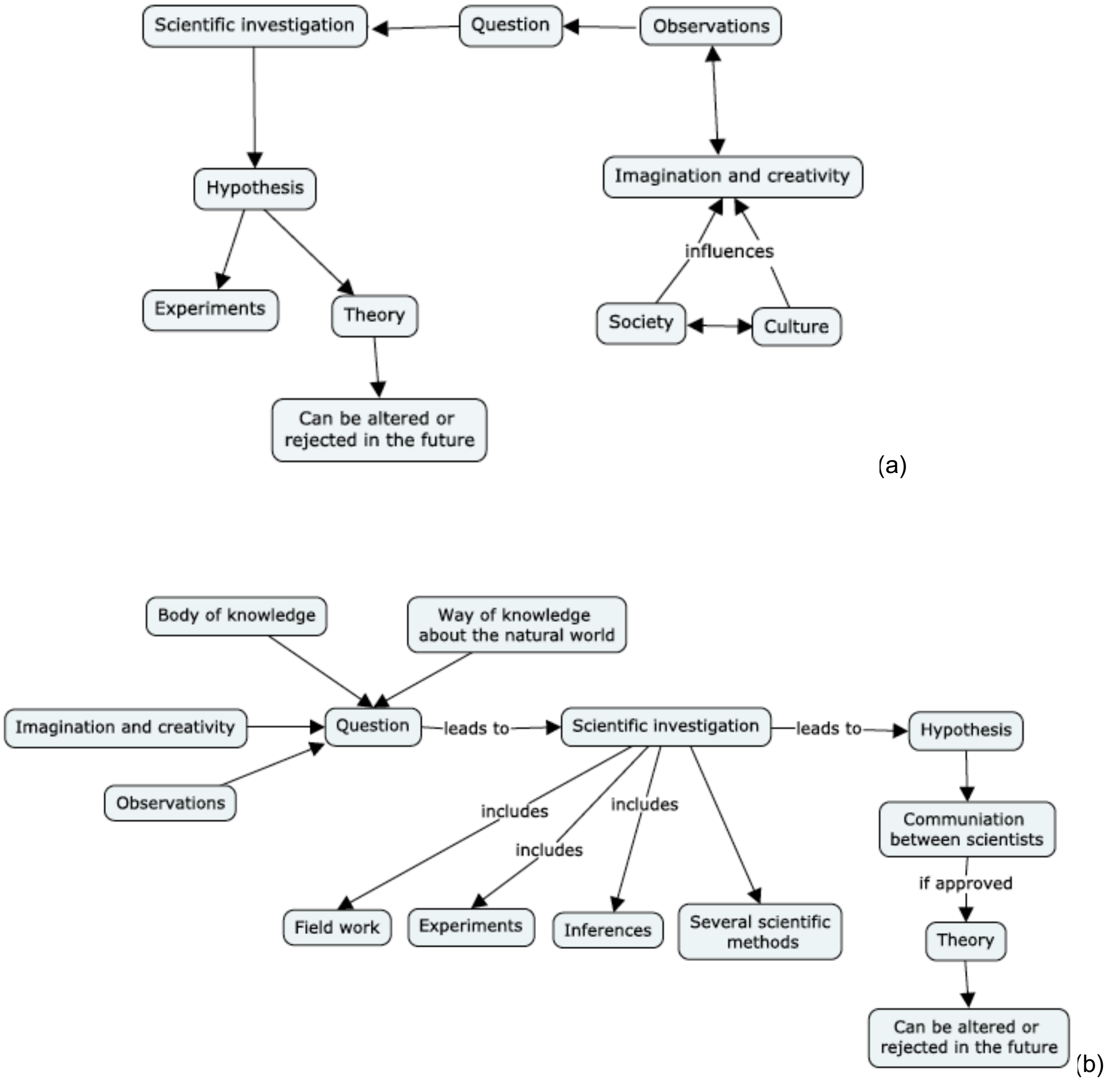


**Figure 4.2.** Conceptual map of one preservice science teacher: (a) pre-PBL unit and (b) post-PBL unit.

However, we also observed some misconceptions, such as the one evidenced in one preservice teacher that unite “theories” to “laws” with the ligation terms “not changeable” (pretest) or “if absolute” (posttest). There are also misconceptions about the role of imagination and creativity as being related only to part of scientists’ activity in 4 and 3 preservice teachers, pre and post-PBL unit respectively (e.g. observations, question and hypothesis). The common misconception of a question leading to a hypothesis that is then tested is found in 5 preservice teachers, without change after the intervention. The conception that a question in generated by observation is only present in 4 preservice teachers, without change in number with the PBL unit.

Before the PBL unit, preservice teachers identified as controversial issues (in parenthesis we present the frequency of responses by preservice teachers) as:

1) the ones that society denies science – evolution (7), stem cells (1), origin of life (1), vaccination (5), alternative medicines (2), reproductive biology/areas of species reproduction (1), climate change (2), Earth structure (1), religious beliefs (1), creationism (1), astronomical issues (1);
2) the ones that are controversial within the scientific community - hereditary of acquired characteristics (2), climatic changes (1) and human role in climatic changes (1), use of animal models in research (2), back matter (1), cloning (1), studies using stem cells (1), human genetic engineering (1), vaccination (2) and none identified (1);
3) SSI - bioethics (2), genetic therapy (1), euthanasia (1), use of some scientific findings (1), environmental education (1), racial and equity issues (1), creationism as part of Biology classes (1), health (1), nutrition (1), abortion (1), extraterrestrial life (1) and none identified (2).

As introduction to the PBL session, preservice teachers were presented with the classification of controversial issues and SSI by Borgerding & Dagistan (2018), and then after the unit were asked again to identify SSI (in parenthesis we present the number of preservice teachers' responses): euthanasia (2), abortion (2), research funding (1), any progressive issue (1), vaccination (1), invasive species control (3), global warming due to human action (3), hunting (1), sexuality (1), existence of races (1), gender issues (1), discussion between evolution and creationism (2) and none identified (2).

We highlight the effectivity of the unit, since after the unit, preservice teachers were able to identify some issues that were not mentioned before the unit as SSI, such as: the research funding decisions, the control of invasive species, vaccination and the human action in global warming.

However, we consider that this short length unit was not effective in changing some uninformed opinions, since some preservice teachers still identify vaccination (2 preservice teachers) and climatic change (1 preservice teacher) as controversial issues within the scientific community.

Preservice science teachers when asked, in the questionnaire, which scientific controversial issues should be included in middle and high school, considered after the PBL unit (in parenthesis we present the frequency of responses by preservice teachers): SSI and the ones that society denies science (1), SSI (3), the ones that are controversial within the scientific community (1), the ones that society denies science (1), the ones that society denies science and the ones that are controversial within the scientific community (1) and all (2).

After the PBL unit preservice teachers were able to identify the advantages of the inclusion of SSI. Some examples of responses include: "Will enable students to become more knowledgeable about these issues, to be more critical and to make informed decisions in society if necessary" (preservice teacher 1) and "Train students and citizens (well) informed so they can critically analyze information" (preservice teacher 2). While before the unit the advantage commonly referred was "To increase students' curiosity about the themes".

Preservice teachers showed informed opinions about the role of students' beliefs in the teaching-learning process and were able to reflect and anticipate the subjects they think will be more difficult to teach in their future. The subject most frequently identified, before and after the unit, was evolution (4 out of 10 preservice teachers), and one example of reasons mentioned is "evolution is a subject that clashes with many religious beliefs". Other subjects were (in parenthesis we present the frequency of responses by preservice teachers): bioethics (1), gender issues (1), vaccination (1), abortion (1), religion-related issues (2).

The assessment of learning process, using an anonymous 5-point Likert scale questionnaire, are consistent with these results above about the impact of the PBL unit with results overall positive in both sessions about the teacher support (Table 4.4), the quality of the problem and resources provided (Table 4.5) and the students' role and interaction (Table 4.6).

Our teaching proposal is according to authors who have suggested critical and reflexive reading of historical examples for NOS teaching may induce students' connections to science knowledge (Conant 1947) and that short length (< 8h) interventions have positive effects on NOS views of preservice elementary teachers in a Biology introductory course (Williams and Rudge 2016). The use of PBL is also in accordance with others that showed change efficacy of NOS conceptions in preservice science and mathematics teachers during an undergraduate elementary science methods course (Akerson et al. 2014) and in elementary teachers, in an intervention similar to PBL, using what we consider to be Project-Based Learning (Maeng et al., 2018). Our results are in a framework considering aspects of nature of scientific knowledge and nature of scientific inquiry, NOS and NOSI, respectively, (McComas, 2017; Schwartz et al. 2012) as a result of a learning sequence that includes epistemic aspects of NOS and NOSI and expands to more complex aspects as suggested by Kampourakis (2016b), and consistent but a simplified version, with sampling of some social-institutional (e. g. relevance of peer review) and epistemic-cognitive aspects (e.g. a question as the beginning of any investigation) of Erduran and Dagher (2014).

Our results are consistent with Kaya et al. (2019) that showed the efficacy of an intervention (pedagogy used not mentioned) using the reconceptualized family resemblance approach to NOS in changing NOS conceptions of preservice science teachers. For future interventions, we intend to use this conceptual map activity as a diagnostic tool for the preconceptions of preservice teachers and, additionally the specific one presented (Figure 4.3) as a visual learning tool, in class, to improve learning.

To avoid the limitations related with the use of a force choice instrument for evaluating preservice teachers' NOS conceptions, since due to time restrictions of the participants our study could not include interviews, we used an open-items questionnaire to allow preservice teachers to more fully and accurately describe their understandings.

Although the sample size of 10 preservice teachers can be considered small for a quantitative methodology as used in this study, other authors defend the use of a t-test with very small sample size, such as ≤ 5 (De Winter, 2013) and with small samples of 15 (Kaya et al., 2019). Therefore, we used a non-parametric test, which is more appropriate for these small samples (Field, 2009), that suggested a significant impact of the intervention in changing NOS conceptions. Our quantitative approach suggested a positive effect of our intervention and we complemented this data with a qualitative approach to gain better understanding about the specific responses by each preservice teacher and we were able to obtain corroboration.

This proposal is supported by evidences obtained in a previous exploratory study conducted in 2017 (n = 8), including only one PBL session about invasive plants introduction, that showed us promising results, such a positive reaction of preservice teachers to future similar lessons, ability to identify NOS aspects, finding the problem stimulating, and proposing a solution to it (Sousa and Chagas 2018).

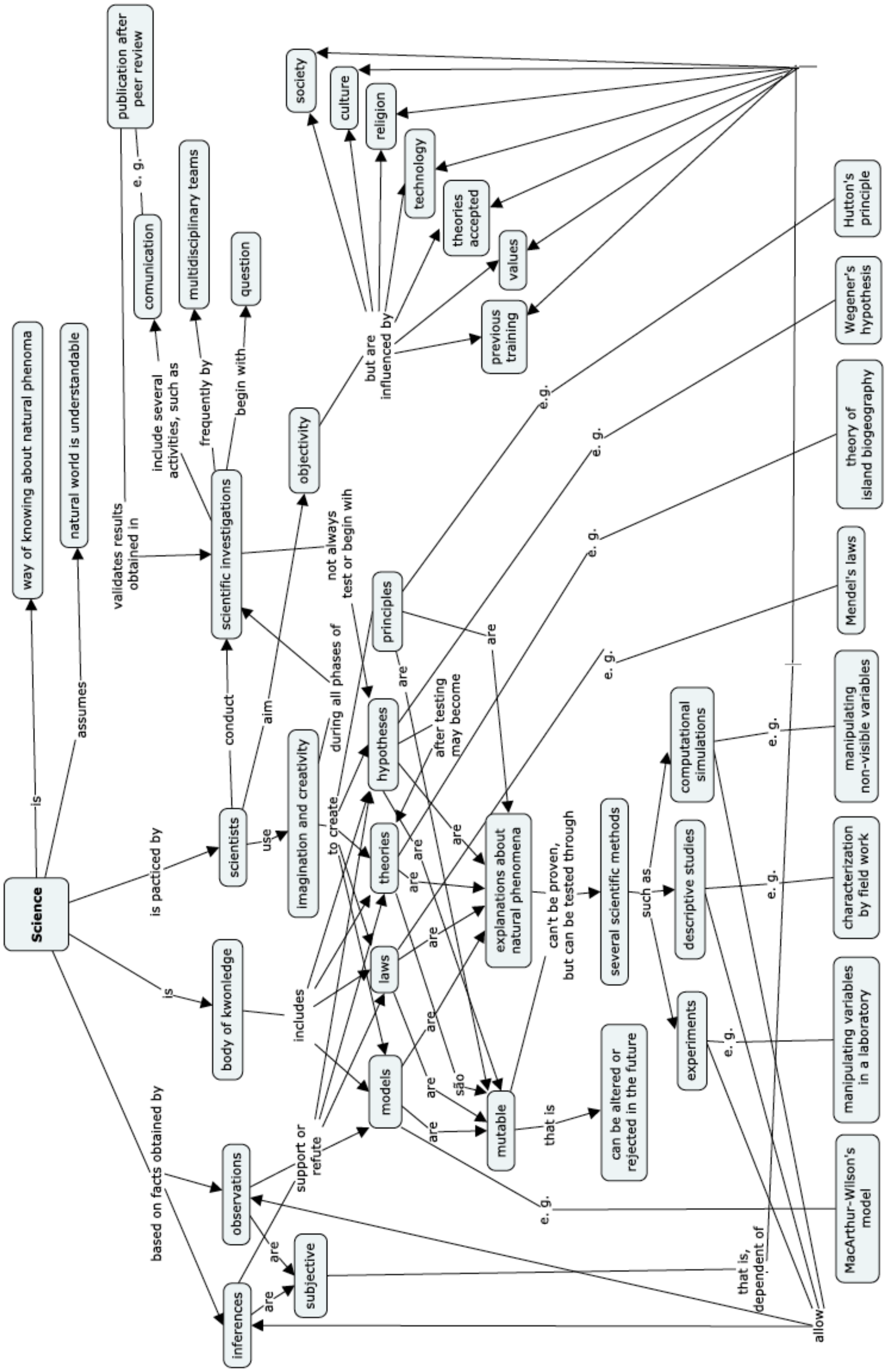


**Figure 4.3.** Conceptual map about NOS in Natural Sciences.

Preservice teachers were asked to construct a conceptual map, as a research instrument, however, in fact, it constitutes the first learning activity performed individually that can be considered as part of step one of our first PBL session. The choice of this type of visual representation is in accordance with our theoretical framework of conceptual change since according to Novak (2002) concept mapping promotes meaningful learning in modifying students' knowledge structures or maps. Additionally, it is in accordance with others that showed a positive effect of a visual tool about NOS according to the family resemblance approach in NOS understanding (Kaya et al., 2019). We found that students were not used to constructing conceptual maps, not representing hierarchy, connectors or cross links, so a total score was not calculated. We only used a qualitative approach that allowed us to identify some misconceptions such as the role of imagination and creativity as being related only to a part of scientists' activity and to observe positive effect on NOS conceptions relating the communication between scientists to the acceptance and construction of theories.

Three of the preservice science teachers have experience of research leading to a master or a PhD thesis and in general, they have adequate NOS conceptions. However, we found some misconceptions, and observed that their conceptions became more informed upon our PBL unit. Therefore, our study suggests the need for explicit NOS teaching in K-U and preservice science teachers' education and the efficacy of our strategy in changing some NOS conceptions.

This study has also implications for K-12 education, since we propose the use of simplified versions of these problem-situations to introduce middle and high school students to both biological concepts included in the curriculum and NOS aspects.

The fact that some preservice teachers considered vaccination and climatic change as controversial issues within the scientific community, suggests that in future studies and applications an extra session is required to include a longer final discussion in order to include a higher number of scientific controversial issues, focusing in the ones previously identified by the preservice teachers.

## 4.2. Studies on K-12 education (studies with 8th grade students)

### 4.2.1. Changes of middle school students' Nature of Science and ecological conceptions upon a PBL intervention using a socioscientific issue

We found significant results comparing students' pre/posttest responses to the performance questionnaire, which includes questions about NOS and ecological concepts, (Table 4.7) and we are able to classify the intervention as having a medium effect (r = 0.38).

**Table 4.7.** Student's performance questionnaire.

| | Mean | SD | Median | Min | Max | Z | p | r |
|---|---|---|---|---|---|---|---|---|
| Pre-test | 23.94 | 12.91 | 26.00 | 0 | 50 | -4.350 | 0.000 | 0.38 |
| Post-test | 42.46 | 17.91 | 41.00 | 0 | 88 | | | |

When analyzing specific Likert items about NOS aspects addressed in the intervention (Table 4.8) we found a statistically significant improvement on the items 'scientific investigations all begin with a question' (in Lederman et al, 2014) and 'new scientific knowledge acquires its credibility through the recognition by many scientists in the field' (in Tsai & Liu, 2005).

**Table 4.8.** Students' understandings of NOS (Likert scale items).

| | | Median | Min | Max | Z | p | R |
|---|---|---|---|---|---|---|---|
| Scientific investigations all begin with a question | Pre-test | 4 | 2 | 5 | -2.162 | 0.031 | 0.26 |
| | Post-test | 5 | 3 | 5 | | | |
| New scientific knowledge acquires its credibility through the recognition by many scientists in the field | Pre-test | 4 | 2 | 5 | -2.180 | 0.029 | 0.26 |
| | Post-test | 4 | 2 | 5 | | | |

The items related with the learning objectives (Table 4.8) promoted by the designed problematic-situation, show significant results suggesting that the intervention changed the students' epistemological conceptions.

Using an open-ended question 'When scientists use the scientific method correctly, their results are true and accurate? Justify.', we found that some students improved their views, for example, one student after the intervention said: 'They may even use the most correct scientific method that their results will never be accurate, they may be true but when scientific studies are being performed the average is calculated, so it will never be accurate' (student 1), and before the intervention said: 'They may even use the truest, most studied and proven scientific methods that results may be false and inaccurate, science is not precise (student 1). Another example is a student that in the pre-test agreed with the affirmation and said: 'Because the scientific methods are also true and accurate' (student 2), and in the posttest didn't agree with the item and justified: 'Because the results also vary with other factors.' (student 2).

About the item 'Comment the following affirmation: scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.' we found an improvement of students' NOS conceptions, for example, one student after the intervention in the said that: 'Scientific research is influenced by society, as scientists even ask society for inquiries and look for facts in culture.' (student 3), and the same student before the intervention said that: 'I don't know, I'm sorry' (student 3).

About the promotion of an adequate PBL environment we analyzed the results obtained with instrument for observation of PBL facilitation, that was positive with responses 3 to 5 (in the instrument of observation by other teacher) about teacher support including encouraging students to apply prior knowledge (Table 4.9), quality of problem and of resources provided (Table 4.10) and about students' role and interaction, including promoting self-directed learning (Table 4.11).

**Table 4.9.** Instrument for observation of PBL facilitation – answers about teacher support.

| **Items** | **Teacher A** (1 to 5 response) | **Teacher B** (1 to 5 response) |
|---|---|---|
| The teacher placed pertinent questions. | 5 | 5 |
| The teacher stimulated the students to exploit prior knowledge. | 5 | 5 |
| The teacher gave clues instead of the correct answer, when asked a question. | 5 | 5 |
| The teacher promoted questioning by all the students in each group. | 5 | 4 |
| The teacher encouraged the students to express our ideas clearly. | 5 | 5 |
| The teacher asked the students how they came to the solution and what reasoning they followed. | 5 | 5 |

**Table 4.10.** Instrument for observation of PBL facilitation – answers about quality of the problem and resources.

| Items | Teacher A (1 to 5 response) | Teacher B (1 to 5 response) |
|---|---|---|
| The problem presented has several solutions. | 5 | 5 |
| The problem was written in a comprehensible language. | 4 | 4 |
| The problem provided was adequate to the learning objectives defined for 8th grade students. | 5 | 5 |
| The resources made available for the research were adequate. | 5 | 5 |
| The scaffold helped the students to structure the knowledge to solve the problem situation. | 5 | 5 |

**Table 4.11.** Instrument for observation of PBL facilitation – answers about students' role and interaction.

| Items | Teacher A (1 to 5 response) | Teacher B (1 to 5 response) |
|---|---|---|
| The students participated in the group work. | 5 | 5 |
| The students when came across something they didn't understand, first consulted with a fellow student then consulted the teacher. | 5 | 4 |
| The students collected and selected relevant information for the group work. | 4 | 4 |
| The students raised pertinent questions. | 3 | 5 |
| The students responded the pertinent questions they have raised. | 3 | 4 |
| The students discussed with colleagues in the group with respect for different ideas. | 5 | 5 |
| The students defined their own learning objectives. | 3 | 4 |
| The students justified their opinions using scientific arguments. | 3 | 4 |
| The students were able to propose a solution to the problem. | 4 | 5 |

With the interview with the observing teachers of each class we were able to assess that neither have used PBL with these classes, and we to get an opinion about the resources used in the unit:

> "Good. It allowed to get in touch with what is the work of a scientist, it allowed more time to reflect, were enough to get there, with some students faster, others less, suitable language for this class, allowed group work that is very important, and there is little time for this generally." (Teacher A)

The opinion of Teacher B was: "Very good, but scaffold has very dense structure, the problem-situation has a reasonable size, however shorter phrases would facilitate learning for these students."

An efficient PBL environment was obtained since the aspects that the teacher of the class considered more positive were: 'Group work, get in touch with other areas of science and team research and discussion, collaborative training and consensus.' (Teacher A) and 'contact with different people, possibility of contact with other forms of structuring materials, bringing more value in the acquisition of students' knowledge' (Teacher B).

About the involvement of the students in these PBL classes the observing teacher said: 'They got involved well, showed interest, commitment to reach goal, harmonious work, they were able to share tasks.' (Teacher A). This was also observed by the Teacher B: 'they got involved despite the conversation, they are immature and very talkative. Some are slower other ones are faster. They got involved as if they normally do'.

The scaffold contents were analyzed at the end of each class and since the intervention in one of the classes (B) occurred the day after the first class (A), some improvements were made, mainly by increasing the soft scaffolds by the teacher/researcher, participating in the group work by asking questions to promote learning, mainly about ecosystems services, and the role of society in financing, and stating that the results obtained by scientists are medians, however none of these items were statistically significant, larger samples and higher length of the unit would be interesting to pursue.

We observed that 2 of 6 groups (class B) and 1 of 6 groups (class A) showed some difficulties in selecting relevant information. We observed that 3 of 6 groups (class A) and 2 of 6 groups (class B) showed more difficulty formulating questions, requiring more support from the teacher.

By analyzing the contents of the scaffold, we observed that students of 4 out of 6 groups (of class A) and 6 of 6 groups (of class A) were able to complete with "question" the affirmation "any research in Biology starts with a _____".

Generally, the students were able to select relevant information and complete adequately the scaffold provided, and by analyzing the pieces of information obtained in websites and species geographic distribution using Google Earth, students of 11 of 12 groups were able to conclude that the native and the invasive species have similar ecological niche.

Each group of students was able to propose a solution to the problem presented in the problem-situation of how to avoid the extinction of native species (groups 1 to 6 of class A and 7 to 13 of class B), presented bellow grouped in categories (soil chemistry-based solutions; ecology-based solutions, science communication-based solution and herbicide-based solutions):

- Soil chemistry-based solutions: 'We can increase the pH, decrease salinity and organic matter (of the soil) to avoid that the invasive plant continues to invade the dunes, to increase the pH we would add bases to the invaded areas' (group 1); 'We can increase the pH adding alkaline solutions to the invaded areas' (group 5); 'Protect the threatened plants, increase the pH of sand dunes by adding alkaline products, we justify through scientific knowledge' (group 4); 'Increase the pH of the soil with the invasive plants hoping that the [results of] research study would happen' (group 10); 'We would have to do the research about the pH level that the native species needs to survive and based on this, we would change the pH of the soil' (group 11).

- Ecology-based solutions: 'Create greenhouses to divide species so that both species can evolve without competition' (group 2); 'If using a predator of the invasive plant we would diminish the population of this species, increasing the space and resources necessary for the existence of the native species, first it would be necessary to study a possible predator; we used the example of the starfish that when eating the mussel releases space and resources for other species allowing the continuity of the existence of these' (group 6); 'Tear the roots of the Hotentog fig such as when we tear out weeds and plant more native species' (group 7); 'Remove part of the Hotentog fig and germinate more native species' (group 8); ''Tear the roots of the Hotentog fig and plant native species' (group 9).
- Science communication-based solution: 'Publication of articles to alert the world population about invasive species through newspapers, multimedia, posters and leaflets (group 3).
- Herbicide-based solution: 'the application of specific herbicides for invasive species (to apply the herbicide we should do first do a previous study) and to remove the roots of the invasive plants' (group 3); 'Plant native species and add herbicides in the roots and leaves of the Hotentog Fig, to increase number of native and reduce number of invasive' (group 12).

The current study provides support for the ability of short PBL interventions to influence students' NOS and Biology understanding and suggest that the teacher support during team work and teacher's role in promoting a final class discussion is relevant to allow a more inclusive education.

We didn't find statistical significance for some items, such as "Society and culture determine *how* science is conducted" and accepted it would be interesting to pursue this with a larger sample in future work and longer intervention.

The item the students found more difficult was that 'scientific theories exist in the natural world and are uncovered through scientific investigations' (Liang et al., 2009) and this intervention had no statistical significance change in the item. This is in accordance to others (Williams & Rudge, 2016).

We considered general accepted features of science although some philosophers of science and scientists recognize distinctions in the nature of science disciplines (Schwartz & Lederman, 2007). Our study is in accordance to some international recommendations, for example NGSS recommendations, about the aspects of NOS that should be included in K-12 science which are presented in a generalized, discipline-independent manner.

A potential limitation of the study is the short length of the intervention itself, however, previous studies have shown that shorter interventions have positive effects on NOS views (Williams & Rudge, 2016).

Although conclusions are limited by the small sample size and some environmental factors, such as a Portuguese background with underprivileged students and low to medium achievers, this exploratory study contributes to our understanding of the role of PBL in improving students' views about NOS using a socioscientific issue contextualized in Life Sciences curriculum and allow us to determine the best strategy to implement an explicit NOS teaching approach.

This study has several limitations that are often encountered when carrying out research in school classroom setting, such as non-random distribution of students into classes.

Our claim is that the intervention was useful for improving certain aspects of students' NOS understandings. However, this study has certain limitations, such as the choice of an instrument with a Likert scale for evaluating students' NOS understanding may not have allowed students to fully describe their understandings, this limitation is somewhat mitigated by the use of an open-ended questions in the Students' performance questionnaire that demanded students to explain two of their responses about NOS. Another limitation is the small size of the sample that was a sample of convenience and there was no control group.

The students in this study presented gains in the understanding of NOS and Biology concepts, however the intervention may not be effective for all types of students.

This study constitutes an exploratory and the difference between pretest and posttest observed can be seen as an indication that with a larger sample we would find higher effect/differences (Gardner & Belland, 2017).

### 4.2.2. Changes in students' Nature of Science conceptions upon a HOS and NOS-enriched PBL intervention

A comparison of students' responses from the pre- and post-test showed improvement of student's NOS understandings regarding some NOS aspects.
Students showed the most change (r = 0.41) in the item 2 - Scientists do not use their imagination and creativity because this is contrary to their logical reasoning (Table 4.12).

**Table 4.12.** Changes in students' epistemological conceptions of each NOS item, using the Wilcoxon signed ranks statistical test results (Z) and effect size (r) for items with statistical significance.

| Items | Z | R |
|---|---|---|
| 1 - Scientists do not use their imagination and creativity because they can interfere with objectivity (Liang et al., 2006). | -3.178** | 0.39 |
| 2 - Scientists do not use their imagination and creativity because this is contrary to their logical reasoning (Liang et al., 2006). | -3.340** | 0.41 |
| 3 - Scientists use their imagination and creativity to collect data (Liang et al., 2006). | -3.229** | 0.39 |
| 4 - Scientists use their imagination and creativity to analyze and interpret data (Liang et al., 2006). | -2.110* | 0.26 |
| 5 - Unlike theories, scientific laws do not change (Liang et al., 2006). | -2.003* | 0.24 |
| 6 - Current scientific knowledge can be changed or totally rejected in the future (Tsai & Liu, 2005). | -2.302* | 0.28 |
| 7 - Scientists, at different times, can use different theories and methods to interpret the same natural phenomenon (Liu & Tsai, 2008). | -0.559 | - |
| 8 - Science is a form of knowledge that provides evidence-based explanations. | -0.384 | - |
| 9 - Science is a way of looking for answers to questions about natural phenomena (adapted Moore,1984). | -0.500 | - |
| 10 - Scientists use different methods to conduct scientific investigations (Liang et al., 2006). | -0.465 | - |
| 11 – Scientific research around the world is carried out in the same way, because science is universal and independent of society and culture (Liang et al., 2006).. | -0.179 | - |

Note: *Statistical significance at $p \le 0.05$; **Statistical significance at $p \le 0.001$

The difference between pretest and posttest was significant for several items (items 1, 2, 3, 4, 5 and 6, in Table 4.12) and in the overall mean classification of the total questionnaire, including some NOS aspects not explicit addressed in this unit, (Z = -2.099, p = 0.036 and r = 0.25); hence, the null hypothesis is statistically rejected. However, no statistical significance was found in other items that we would expect to find (e. g. item 7).

Positive results were shown from the observation instrument for PBL facilitation. Responses 4 (frequently) or 5 (always) for the majority of groups of students and 2 (rarely) or 3 (sometimes) for 2 out of 13 groups (in the participatory observation instrument) and responses 3 to 5 (in the instrument observation instrument filled by the other two teachers) about teacher support including encouraging students to apply prior knowledge, student responsibility, student interaction and collaboration, quality of problem and of resources provided and promoting self-directed learning (such as formulating and answering their own questions). Therefore, this Origin of Life unit was an effective PBL unit.

The NOS aspect that students struggled the most are the distinction between scientific laws and theories, in accordance with others (Williams & Rudge, 2016), and in our study showed an improvement on the post-test after the intervention. The NOS aspect about the role of imagination and creativity in science, in which students showed a naive view, had a significant change after our intervention.

Our claim is that the intervention was useful for improving certain aspects of students' NOS understandings, however this intervention may not be effective for all types of students. This study has certain limitations, such as the small size of the sample that was a sample of convenience, and the choice of the school was based on its proximity and collaboration to the university. And also, due to the timing of the authorization of the study and the school schedule, the fact that the teachers of the classes of this study provided a previous non-PBL unit (3 sessions), about part of the contents of this intervention, and a previous NOS-enriched PBL unit (3 sessions), which may explain not finding statistical significance in items we would expect to find (e. g. item 7) and in the overall questionnaire.

Another potential limitation of the study is the short length of this intervention; however, previous studies have shown that shorter interventions have positive effects on NOS views (Williams & Rudge, 2016; Gardner & Belland, 2017). The short length of time of the intervention can be seen as strength, as it is a cost-effective method for increasing student achievement (Gardner & Belland, 2017).

NOS aspects are not found in the curricular objectives of the Portuguese curriculum for middle school students, so our PBL unit was intentionally designed to align with current content standards defined for 8$^{th}$ grade students - learning goal "to argue about some theories of the origin of life on Earth" (Bonito et al., 2013, p.18) - that was achieved by using an ill-structured problem, which leads students to the contents required in the curriculum.

### 4.2.3. Development of an instrument for assessment of middle school students' epistemological conceptions of science

#### 4.2.3.1. Development of a multidimensional instrument for assessment of middle school students' epistemological conceptions of science

We extracted a 6-factor structure (Table 4.13) by performing Principal Component Analysis with orthogonal (varimax) rotation.

**Table 4.13.** Instrument's dimensions (factor loadings and Cronbach's alpha).

| Factor/dimension | Items (reference) | Factor loading | Cronbach alpha |
|---|---|---|---|
| Imagination and creativity | 9 (Liang et al., 2009) | 0.724 | 0.665 |
| | 12 (Liang et al., 2009) | 0.723 | |
| | 16 (Liang et al., 2009) | 0.686 | |
| | 36 (Liang et al., 2009) | 0.673 | |
| Influence of Society and Culture in Science | 13 (Liang et al., 2009) | 0.821 | 0.655 |
| | 22 (Liang et al., 2009) | 0.820 | |
| Tentative feature of scientific knowledge | 21 (Liu and Tsai, 2008) | 0.417 | 0.422 |
| | 23 (Liu and Tsai, 2008) | 0.755 | |
| | 33 (Liu and Tsai, 2008) | 0.733 | |
| Role of Social Negotiation (including peer review) | 6 (adapt. Abd-El-Khalick, 2012) | 0.499 | 0.313 |
| | 10 (adapt. Harwood, 2004) | 0.662 | |
| | 18 (Liu and Tsai, 2008) | 0.643 | |
| Concepts of theory and law | 25 (Liang et al., 2009) | -0.746 | 0.265 |
| | 37 | 0.616 | |
| Methodology of scientific investigation | 8 (adapt. Lederman et al., 2014) | -0.751 | 0.279 |
| | 29 (adapt. Lederman et al. 2014) | 0.730 | |

The Cronbach alpha coefficient for the entire instrument is 0.524, KMO is 0.634, the Barlett test was significant and all the factors had eigenvalues range from 1.064 to 2.34 accounting for 57.10% of the variance.

The interviews were aligned with the responses in the questionnaire, for example student A (bottom 15% of score of questionnaire) that answered agree in the questionnaire to the item 12 (Scientists don't use their imagination and creativity because it goes against their logical reasoning) says "scientists use real facts and evidences I think they don't use creativity", while student B (top 15% of score of questionnaire) that answered totally disagree in the questionnaire to the item 12 says "creativity helps scientists and they must go against logical reasoning if they think it is correct" and student C (average 15% of score of questionnaire) disagree with item 12 and said "scientists have to be creative, because some concepts are not well defined because we cannot see them, but in other cases logical reasoning is necessary". So, a response in the questionnaire with score 4 is aligned with a level of understanding a little higher than naïve, but not completely informed. The response 3 (not sure) corresponds to answers such as from student C about item 4 (Scientific research is not influenced by society or culture because scientists are trained to carry out unbiased studies) that said "society and culture can influence, but I don't know if it influences" and student D (top 15% of score of questionnaire) answered "not sure" to the item 6 (Scientific knowledge is published in scientific journals after being reviewed and accepted by other scientists) and said "I don't know how publishing works, but I believe that someone reviews (other scientists or someone with more influence)".

The preliminary instrument obtained has a non-adequate level of internal consistency, however we conducted the confirmatory factor analysis, with the same sample, to examine the construct validity of the questionnaire and we could not reach any solution even though different estimators were tested (Maximum Likelihood Robust, Weighted Least Square, Diagonally Weighted Least Square). Therefore, further development of the instrument needs to be performed to construct novel items that fit each dimension, mainly for the dimensions with less than 3 items.

#### 4.2.3.2. Characterization of Portuguese 8th grade students' epistemological conceptions of science and development of an instrument for assessment

Calculation of reliability of the questionnaire with 30 items (Table 4.14) was alpha Cronbach = 0.661 which is considered acceptable (Nunnally & Bernstein, 1994).

**Table 4.14.** Students' epistemological conceptions 30-items questionnaire.

| **Items (reference)** |
|---|
| 2. All scientists follow the same step-by-step scientific method (Liang et al., 2009). |
| 3. Science is a way of seeking answers to questions about natural phenomena (adapt. Moore, 1984). |
| 4. Scientific research is not influenced by society or culture because scientists are trained to carry out unbiased studies (Liang et al., 2009). |
| 5. Observations of the same phenomenon by different scientists may be different, because what scientists already know may influence their observations (Liang et al., 2009). |
| 6. Scientific knowledge is published in scientific journals after being reviewed and accepted by other scientists (adapt. Abd-El-Khalick, 2012). |
| 8. All scientific research begins with a question (adapt. Lederman et al., 2014). |
| 9. Scientists do not use their imagination and creativity because they can interfere with the objectivity of their research (Liang et al., 2009). |
| 10. One of the activities of scientific research is communication with other scientists (adapt. Harwood, 2004). |
| 11. Scientific theories accepted by scientists do not interfere with the development of scientific knowledge (adapt. Liu & Tsai, 2008). |
| 12. Scientists don't use their imagination and creativity because it goes against their logical reasoning (Liang et al., 2009). |
| 13. Society and culture determine which science is realized and accepted (Liang et al., 2009). |
| 14. Observations of the same phenomenon by different scientists from different teams are always the same because scientists are not influenced. |
| 15. Scientific research around the world is carried out in the same way, because science is universal and independent of society and culture (Liang et al., 2009). |
| 16. Scientists use their imagination and creativity to collect data (Liang et al., 2009). |
| 18. Scientific knowledge becomes credible through recognition by other scientists in the field (Liu and Tsai, 2008). |
| 19. Scientists' research activities are influenced by their theories (Liu and Tsai, 2008). |
| 20. The development of scientific knowledge often involves changing concepts (Liu and Tsai, 2008). |
| 21. Current scientific knowledge provides provisional explanations for natural phenomena (Liu and Tsai, 2008). |

| |
|---|
| 22. Society and culture determine how science is realized and accepted (Liang et al., 2009). |
| 23. Scientists at different times may use different theories and methods to interpret the same natural phenomenon (Liu and Tsai, 2008). |
| 24. Scientists use different methods to conduct scientific research (adapt. Liang et al., 2009). |
| 26. When scientists use the scientific method correctly, their results are true and accurate (Liang et al., 2009). |
| 27. Scientific experiments are not the only resource for the development of scientific knowledge (Liang et al., 2009).. |
| 29. Scientific investigations do not necessarily test a hypothesis (adapt. Lederman et al. 2014). |
| 30. Science is a form of knowledge that provides evidence-based explanations. |
| 31. Religious beliefs are a form of knowledge that science cannot explain. |
| 33. Current scientific knowledge may be changed or totally rejected in the future (Liu and Tsai, 2008). |
| 34. Scientific argumentation uses scientific evidence. |
| 35. Observations of the same phenomenon by different scientists are always the same because observations are facts (Liang et al., 2009). |
| 36. Scientists use their imagination and creativity to analyze and interpret data (Liang et al., 2009). |

The questionnaire can be subdivided in seven theoretical categories (Table 4.15).

**Table 4.15.** Subdivision on theoretical categories of the 30-items questionnaire.

| Categories | Items |
|---|---|
| Scientific research methodology | 2, 8, 24, 26, 27 e 29 |
| Observations, objectivity and theory-laden exploration | 5, 11, 14, 19 e 35 |
| Social and cultural influence on science | 4, 13, 15 e 22 |
| Imagination and creativity in scientific research | 9, 12, 16 e 36 |
| Changeable and tentative feature of scientific knowledge | 20, 21, 23 e 33 |
| Social negotiation of science | 6, 10 e 18 |
| Science as a way of knowledge | 3, 30, 31 e 34 |

The characterization of Portuguese Middle School students' epistemological conceptions is presented for each category and as a sum of items. The Mean of the sum of items for males is 102.77 (N=185; SD=9.76) and 105.22 for females (N=177; SD=9.15). The mean obtained in the questionnaire is 3.45 for male (SD=0.311) and for female is 3.52 (SD=0.301).

Our results suggest a gender effect by an independent t-test (t = -2.4633, df = 360; p=0.014) with girls with higher scores than boys.

The results also suggest a correlation between the classification/performance score obtained at the discipline (evaluated by the teachers and according to several parameters such as exam score and participation in class) and the sum obtained in the questionnaire (Pearson correlation = 0.152, p=0.004).

Regarding the items of scientific research methodology (Table 4.16), the mean is 2.73 (item 26) to 4.18 (item 8), median 3 (item 26 and 29) and 4 (items 2, 8, 24, 27) and mode 2 (item 26), 4 (item 2, 24, 27, 29) and 5 (item 8). Therefore, we observe informed conceptions of the majority of students corresponding to the item 8 - All scientific research begins with a question.

**Table 4.16.** Descriptive statistics of items of scientific research methodology.

| Items (reference) | Mean | SD | Mode | Min. | Max. |
|---|---|---|---|---|---|
| 2. All scientists follow the same step-by-step scientific method (Liang et al., 2009). [inv] | F: 3.85<br>M: 3.76 | F: 0.930<br>M: 1.10 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 8. All scientific research begins with a question (adapt. Lederman et al., 2014). | F: 4.19<br>M: 4.17 | F: 0.808<br>M: 1.01 | F: 4<br>M: 5 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 24. Scientists use different methods to conduct scientific research (adapt. Liang et al., 2009). | F: 4.10<br>M: 4.00 | F: 0.726<br>M: 1.01 | F: 4<br>M: 4 | F: 2<br>M: 1 | F: 5<br>M: 5 |
| 26. When scientists use the scientific method correctly, their results are true and accurate (Liang et al., 2009). [inv] | F: 2.62<br>M: 2.83 | F: 1.04<br>M: 1.18 | F: 2<br>M: 2 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 27. Scientific experiments are not the only resource for the development of scientific knowledge (Liang et al., 2009). | F: 3.63<br>M: 3.45 | F: 0.908<br>M: 1.00 | F: 4<br>M:4 | F: 1<br>M:1 | F: 5<br>M:5 |
| 29. Scientific investigations do not necessarily test a hypothesis (adapt. Lederman et al. 2014). | F: 3.10<br>M: 3.13 | F: 1.086<br>M: 1.14 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |

About the items observations, objectivity and theory-laden exploration (Table 4.17), the mean is 3.32 (item 35) to 3.84 (item 5), median 3 (item 35) and 4 (items 5, 11, 14, 19) and mode 4 for all items.

**Table 4.17.** Descriptive statistics of items of items observations, objectivity and theory-laden exploration.

| Items (reference) | Mean | SD | Mode | Min. | Max. |
|---|---|---|---|---|---|
| 5. Observations of the same phenomenon by different scientists may be different, because what scientists already know may influence their observations (Liang et al., 2009). | F: 3.85<br>M: 3.81 | F:0.873<br>M:0.889 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 11. Scientific theories accepted by scientists do not interfere with the development of scientific knowledge (adapt. Liu & Tsai, 2008). [inv.] | F: 3.64<br>M: 3.39 | F: 1.073<br>M: 1.11 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 14. Observations of the same phenomenon by different scientists from different teams are always the same because scientists are not influenced. [inv.] | F: 3.81<br>M: 3.53 | F: 0.946<br>M: 1.15 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 19. Scientists' research activities are influenced by their theories (Liu and Tsai, 2008). | F: 3.77<br>M: 3.76 | F: 0.831<br>M:0.873 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 35. Observations of the same phenomenon by different scientists are always the same because observations are facts (Liang et al., 2009). [inv.] | F: 3.42<br>M: 3.23 | F: 1.085<br>M: 1.15 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |

Regarding the items social and cultural influence on science (Table 4.18), the mean is 2.8 (item 13) to 3.34 (item 15), median 3 (items 4, 13, 22) and 4 (item 15), and mode 3 (items 4, 13) and 4 (items 15, 22).

**Table 4.18.** Descriptive statistics of items of social and cultural influence on science.

| Items (reference) | Mean | SD | Mode | Min. | Max. |
|---|---|---|---|---|---|
| 4. Scientific research is not influenced by society or culture because scientists are trained to carry out unbiased studies (Liang et al., 2009). [inv.] | F: 3.21<br>M: 2.96 | F: 1.006<br>M: 1.016 | F: 3<br>M: 3 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 13. Society and culture determine which science is realized and accepted (Liang et al., 2009). | F: 2.85<br>M: 2.77 | F: 0.966<br>M: 1.089 | F: 3<br>M: 3 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 15. Scientific research around the world is carried out in the same way, because science is universal and independent of society and culture (Liang et al., 2009). [inv.] | F: 3.43<br>M: 3.26 | F: 1.106<br>M: 1.171 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 22. Society and culture determine how science is realized and accepted (Liang et al., 2009). | F: 3.11<br>M: 2.93 | F: 1.014<br>M: 1.139 | F: 3<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |

Regarding the items of imagination and creativity in scientific research (table 4.19), the mean is 2.79 (item 16) to 3.02 (item 12), median and mode 3 of all items.

**Table 4.19.** Descriptive statistics of items of imagination and creativity in scientific research.

| Items (reference) | Mean | SD | Mode | Min. | Max. |
|---|---|---|---|---|---|
| 9. Scientists do not use their imagination and creativity because they can interfere with the objectivity of their research (Liang et al., 2009). [inv.] | F: 2.89<br>M: 2.91 | F:1.107<br>M:1.217 | F: 3<br>M: 3 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 12. Scientists don't use their imagination and creativity because it goes against their logical reasoning (Liang et al., 2009). [inv.] | F: 3.03<br>M: 3.01 | F: 1.07<br>M: 1.149 | F: 3<br>M: 3 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 16. Scientists use their imagination and creativity to collect data (Liang et al., 2009). | F: 2.82<br>M: 2.75 | F:1.084<br>M: 1.14 | F: 3<br>M: 2 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 36. Scientists use their imagination and creativity to analyze and interpret data (Liang et al., 2009). | F: 2.95<br>M: 2.93 | F: 1.09<br>M: 1.11 | F: 3<br>M: 3 | F: 1<br>M: 1 | F: 5<br>M: 5 |

About the items of changing and tentative feature of scientific knowledge (Table 4.20) the mean is 3.67 (item 20) to 4.01 (item 23), median and mode 4 of all items.

**Table 4.20.** Descriptive statistics of items of changeable and tentative feature of scientific knowledge.

| Items (reference) | Mean | SD | Mode | Min. | Max. |
|---|---|---|---|---|---|
| 20. The development of scientific knowledge often involves changing concepts (Liu and Tsai, 2008). | F: 3.67<br>M: 3.66 | F: 0.766<br>M: 0.967 | F: 4<br>M: 4 | F: 2<br>M: 1 | F: 5<br>M: 5 |
| 21. Current scientific knowledge provides provisional explanations for natural phenomena (Liu and Tsai, 2008). | F: 3.69<br>M: 3.83 | F: 0.82<br>M: 0.966 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 23. Scientists at different times may use different theories and methods to interpret the same natural phenomenon (Liu and Tsai, 2008). | F: 4.17<br>M: 3.97 | F: 0.793<br>M: 0.93 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 33. Current scientific knowledge may be changed or totally rejected in the future (Liu and Tsai, 2008). | F: 3.99<br>M: 3.81 | F: 0.911<br>M: 1.13 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |

About the items of social negotiation of science (Table 4.21), the mean is 3.35 (item 6) to 3.76 (item 10), median 3 (item 6) and 4 (items 10, 18) and mode 3 (item 6) and 4 (items 10, 18).

**Table 4.21.** Descriptive statistics of items of social negotiation of science.

| Items (reference) | Mean | SD | Mode | Min. | Max. |
|---|---|---|---|---|---|
| 6. Scientific knowledge is published in scientific journals after being reviewed and accepted by other scientists (adapt. Abd-El-Khalick, 2012). | F: 3.32<br>M: 3.40 | F: 1.07<br>M: 0.996 | F: 3<br>M: 3 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 10. One of the activities of scientific research is communication with other scientists (adapt. Harwood, 2004). | F: 3.73<br>M: 3.79 | F: 0.901<br>M: 0.937 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 18. Scientific knowledge becomes credible through recognition by other scientists in the field (Liu and Tsai, 2008). | F: 3.55<br>M: 3.58 | F: 0.813<br>M: 0.925 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |

About the items of science as a way of knowledge (Table 4.22), the mean is 3.53 (item 31) to 4.15 (item 3) and median and mode 4 for all items.

**Table 4.22.** Descriptive statistics of items of science as a way of knowledge.

| Items (reference) | Mean | SD | Mode | Min. | Max. |
|---|---|---|---|---|---|
| 3. Science is a way of seeking answers to questions about natural phenomena (adapt. Moore, 1984). | F: 4.18<br>M: 4.12 | F: 0.710<br>M: 0.851 | F: 4<br>M: 4 | F: 2<br>M: 1 | F: 5<br>M: 5 |
| 30. Science is a form of knowledge that provides evidence-based explanations. | F: 3.72<br>M: 3.58 | F: 0.813<br>M: 1.01 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 31. Religious beliefs are a form of knowledge that science cannot explain. | F: 3.53<br>M: 3.53 | F: 1.079<br>M:1.183 | F: 4<br>M: 4 | F: 1<br>M: 1 | F: 5<br>M: 5 |
| 34. Scientific argumentation uses scientific evidence. | F: 3.76<br>M: 3.69 | F: 0.769<br>M: 0.839 | F: 4<br>M: 4 | F: 2<br>M: 1 | F: 5<br>M: 5 |

Our results suggest a gender effect with girls with higher scores than boys, however boys tend to have higher score than girls in some items with statistically results only for item 26 (When scientists use the scientific method correctly, their results are true and accurate) in the Mann-Whitney test (Z=-2.222; p=0.026). These results are in accordance to others obtained recently by other authors with a Likert scale questionnaire with 9th grade Israeli students that show gender differences in certain items, such as that boys tend to agree more with constructs about to coherence and objectivity and girls tended to agree more with aspects of science-for-girls (Emran et al., 2020).

The sample is constituted by four separate samples of convenience, rather than a random representative of the entire country that would not be humanly possible, the generalization of the results is limited. Since the maximum sum of the questionnaire is 150 corresponding to informed conceptions and we found values < 110 we would characterize the conceptions as transient. When analyzing each item, the mode is 2 (item 26) corresponding to naïve conceptions, 5 (item 8) corresponding to completely informed conceptions and is 3 corresponding to transient conceptions and 4 corresponding to informed conceptions of most students.

The gender effect we found needs to be further studied, with larger samples, and is in accordance to recent Programme for International Student Assessment (PISA) results in which girls significantly outperformed boys in reading in Portugal and across OECD countries (PISA, 2018).

In accordance to our results, a recent international study has showed that seven grade students in several countries (Portugal is not included) have an overall inadequate level of understanding of scientific inquiry, assessed by using the VASI instrument, although for some particular aspect of scientific inquiry they have better score than naïve (Lederman et al., 2019), these aspects correspond to our items on the category scientific research methodology.

#### 4.2.4. Changes of students' epistemological conceptions of science upon Problem-Based Learning through History of Science about the origin of life

Wilcoxon signed ranks test showed that the PBL unit (pretest vs posttest) was efficient for the sum of all (30) items of the questionnaire (Z=-3.658; p=0.000), with a mean of sum of 30 items of 103.2 (pretest, SD=7.16) and 110.0 (posttest, SD=9.26) and a mean of 3.45 (pretest, SD=0.241) and 3.67 (posttest, SD=0.305) so the PBL unit was efficient in promoting more informed epistemological conceptions of science.

Regarding the social negotiation of science, we observed that the PBL unit was efficient (pretest vs posttest) for items 6 (Z=-2.215; p=0.027) and 10 (Z=-2.270; p=0.023).

About imagination and creativity in scientific research we found the PBL unit to be efficient (pretest vs posttest) for three of four items – for item 9 (Z=-2.819; p=0.005), 12 (Z=-2.653; p=0.008) and 16 (Z=-2.582; p=0.010).

Regarding the category science as a way of knowledge we observed that the PBL unit was not efficient (pretest vs posttest).

In the category social and cultural influences on science we found the PBL unit to be efficient (pretest vs posttest) for one of the four items – item 4 (Z= -2.101; p=0.036).

The PBL unit was not efficient (pretest vs posttest) regarding the category observations, objectivity and theory-laden exploration.

About scientific research methodology we found the PBL unit to be efficient (pretest vs posttest) for two of six items – item 2 (Z=-2.645; p=0.008) and item 29 (Z=-2.228; p=0.026).

About the changeable and tentative characteristics of scientific knowledge we observed that the PBL unit (pretest vs posttest) was efficient for two of four items - for items 21 (Z=-2.034; p=0.042) and 23 (Z=-2.023; p=0.043).

Regarding the item 23 "Scientists at different times may use different theories and methods to interpret the same natural phenomenon" (Table 4.23) the Independent Samples Mann Whitney test showed no differences were found between the two groups before the intervention (Z=-0.210; p=0.833) and showed that the PBL unit was more efficient than the non-PBL comparison unit (Z=-2.534; p=0.011).

**Table 4.23.** Mean and SD of students of PBL and comparison group regarding answer item 23 (Scientists at different times may use different theories and methods to interpret the same natural phenomenon)

| | pretest | | posttest | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| PBL | 3.97 | 0.878 | 4.32 | 0.727 |
| Non-PBL | 4.03 | 0.809 | 3.94 | 0.618 |

The non-PBL was not efficient in promoting changing regarding the item 23, although was efficient for the sum of all (30) items of the questionnaire (Z=-4.442; p=0.000), with a mean of 101.97 (pretest, SD=7.17) and 108.81 (posttest, SD=10.08). Therefore, both interventions were overall effective in changing students' epistemological conceptions of science.

About the open item "Are all scientific investigations carried out in the same way following the same steps as the scientific method?" (Appendix 18) we found consistent responses with the Likert scale items of the questionnaire that was not able to detect statistically differences between PBL and non-PBL groups. We were able to observe that some students, were able to give examples as required, after the intervention: "because for example the theory of primitive soup that was made with an experiment and the theory of the origin of life in marine water used found fossils" (student 2007, PBL group) and "for example for primitive soup theory scientists have experimented and for common ancestor theory they have not experimented" (student 2016, PBL group).

Regarding the item "Do you agree with the statement that scientific theories are explanations, built by scientists, about a wide variety of related phenomena that have already been tested?" (Appendix 18) we observed adequate response in 54.5% pre-test and 72.7% posttest (PBL group) and 65.5% pre-test and 79.3% posttest (non-PBL group), so both the interventions were effective. Some students were able to justify adequately their response after the PBL unit, providing a more informed response after the unit: “a theory is something that is true that has already been proven and a hypothesis we are not sure” (pretest, student 2006, PBL group) and ”A theory is something that has been tested and a hypothesis is something that we are in doubt, something we are not sure about.” (posttest, student 2006, PBL group); “I don't agree, because theories are just thoughts and ideas that can't be tested, while hypotheses are just ideas that can be tested.” (pretest, student 2116, PBL group) and “I agree, theory is something you can only prove that you are not sure, but it is the way to explain something, whereas the hypothesis is just a vague thought” (posttest 2116, PBL group).

About the open item “Are all living things on Earth related to each other because they share a common ancestor that existed millions of years ago” (Appendix 18) we observed an increase in the correct answers in the PBL group (45.4% pretest and 69.7% posttest) and non-PBL group (50% pretest and 67.9% posttest). The quality of the justifications increased, some examples are: “I agree because if everyone has a common ancestor they will descend from the same living being” (student 2007, pretest, PBL group) and “I agree because according to the theory all living things have molecular and cellular similarities” (student 2007, posttest, PBL group) and “I agree, because all living things have one thing in common that is that regardless of whether they are animals or plants, they live on planet Earth that has existed for millions of years” (student 2110, pretest, PBL group) and “I agree because in my opinion there was a million years ago a cell that gave birth to the living beings” (student 2110, posttest, PBL group). Regarding indicating a Darwin’s theory both interventions were effective with increase in the percentage of students with correct response (11% pretest and 72% posttest in PBL group and 6.9% pretest and 65.5% posttest). Regarding the multiple question both interventions were effective with increase in the percentage of students with correct response (8.3% pretest and 22% posttest in PBL group and 13.8% pretest and 72% posttest in non PBL-group) suggesting that the PBL group is not as effective as non-PBL in questions that only require recall factual knowledge as previously suggested by Wilder (2014).

The hard scaffold provided to the students (PBL group) had some problem-questions that the majority of groups of students were able to answer adequately (e.g. is there one scientific method or several scientific methods?).

All the groups were able to construct a conceptual map about what science is with a minimum of 8 (PBL group) and 3 (non-PBL group) concepts (of 24 total).

All the groups were able to answer which is the most explanatory theory and provide a solution to the problem accordingly: 4 groups proposed as solution an autotrophic organism, while 4 groups proposed as solution a heterotrophic and anaerobic organism and one proposed a virus. The most frequent answers about what was the most explanatory theory were the primitive soup theory and the theory of common ancestror.

In the interview of one of the observing teachers said about the advantages of the PBL:

> "Possibility of exchanging ideas in a more informal environment because in a group (talking and sometimes playing) and contact with deeper materials (it is scientific culture), it is formal because it is class, but they are more comfortable in the group, and helped to have respect for the ideas of others." (teacher A)

Since the students had limited prior experience with lessons about NOS, they were not expected to develop sophisticated NOS understandings after a single unit, but we showed that there was a statistically significant increase in the score of the questionnaire in both groups with a mean of 103.2 (pretest) and 110.0 (posttest) for the PBL group.

The NOS related statements in the category science as a way of knowledge (e.g. item 31 - Religious beliefs are a form of knowledge that science cannot explain) are probably the ones most resistant to change since we did not observe any statistically significant change (pretest vs posttest) in both conditions (PBL and non PBL).

Since we found no changes after the intervention on the statements in the category observations, objectivity and theory-laden exploration (e.g. item 19 - Scientists' research activities are influenced by their theories), we consider that these are also resistance to change and the unit was too short length to improve all the categories.

About scientific research methodology we found the PBL unit to be efficient (pretest vs posttest) for two of six items, we are not able to say this is a PBL unique feature since we found the same in the comparison group.

Regarding imagination and creativity, we found statistically significant differences after the PBL unit except in the item about analyzing and interpreting data, so in the future we will explore more this subject, mainly using the historical episode of Pasteur.

Students were not randomly allocated to the groups, since it is practical to use the preformed classes, but because of the threats to internal validity we used classes form the same school, with the most similar experiences in and outside the Natural Sciences classes. Another threat to the validity of the study is the non-equivalent number of students and of females and males in both conditions.

The students were not used to work in group and never experienced PBL, so the difficulties were greater to implement an efficient PBL unit and another limitation was the low number of students in each class.

The non-PBL group experienced the construction of the conceptual map "What is Science?", individually, while the PBL group experienced it in groups, however as suggested by Pease & Kuhn (2011) the engagement with the problem and not the social interaction are the most important feature of PBL, so the similar results of the PBL group and non-PBL groups regarding the questionnaire of epistemological conceptions may be explained by this fact. The main problem of how to characterize the universal common ancestor was only present in the PBL group and our results suggest that this improved the learning of the changeable and tentative characteristics of the scientific knowledge since students to address this problem need to think of all the theories and methods used in the different studies presented in the problem-situation.

The PBL unit was overall effective in promoting NOS and biology learning.

## 4.3. Review of Portuguese textbooks

### 4.3.1. Teaching Nature and History of Science in context with ecological niche: review of Portuguese textbooks and curricular documents

The concept of (ecological) niche is important, but not as frequently used as habitat, for example, since we were able to, by performing a Google Scholar search, with no filters (anytime, anywhere in the article), identify 161,000 hits regarding the concept "ecological niche" and 1,590,000 hits regarding the concept niche and, in comparation, I found for "habitat" 3,430,000 hits and for a much broader concept "ecology" I found 3,190,000 hits.

The concept of niche is not mentioned in any of the Curriculum Guidelines for Natural Sciences, they state "Students should understand the concepts of ecosystem, species, community, population and habitat" (Galvão et al. 2001, p23). However, in the Curriculum Goals document, we consider that this concept can be included associated with several goals, corresponding to the 8th grade, such as (Bonito et al., 2013): "Understand the levels of biological organization in ecosystems", "Explore the dynamics of interaction between living beings." These goals are specified in the Essential Learning guidance document with the following objectives, for the 8th grade: "Explain how biotic relationships can lead to the evolution or extinction of species" and "Extrapolate how […] biological invasions affect the balance of ecosystems." (DGE, 2018a).

Since the Portuguese guidance documents in which the concept can be included correspond to the 8th grade, we only analysed the corresponding textbooks.

There are ten textbooks certified, by the Portuguese authority for certification, but only nine of these are being, currently, used at the Portuguese schools during the academic year of 2018/2019, according to DGE (personal communication), so I analysed (Table 4.24) those and coded the textbooks ordered by the number of students reported to use it (DGE, personal communication).

**Table 4.24.** Textbook content analysis about the concept of ecological niche.

| Textbook code | Students using (%) | Ecological niche concept | Integrated with NOS | Integrated with HOS |
|---|---|---|---|---|
| **A** | 29.0 | - | n. a. | n. a. |
| **B** | 22.8 | - | n. a. | n. a. |
| **C** | 11.8 | - | n. a. | n. a. |
| **D** | 9.91 | - | n. a. | n. a. |
| **E** | 8.09 | + | - | - |
| **F** | 6.33 | + | - | - |
| **G** | 5.38 | - | n. a. | n. a. |
| **H** | 4.27 | - | n. a. | n. a. |
| **I** | 2.42 | + | - | - |

Note: present (+), absent (-) and not applicable, since concept is absent (n. a).
Source (information of number of students): DGE (personal comunication).

In only three (E, F and I, on Table 4.24) of the nine textbooks the concept of ecological niche is present and these three define, adequately for 8th grade students, this concept (e.g. “The set of functions that each species plays in its environmental space, such as the type of feed, the form of capture of the food or the type of reproduction, characterize its ecological niche” in Textbook F, p60). In Textbooks E and F the concept of niche is introduced after the concept of habitat, but additionally in Textbook F one can find an application activity, of reading and interpreting a small text, about explaining the coexistence of species. In Textbook I, the concept is introduced in the beginning of the section ecosystems after the concept of biotope and several examples of different species, with different niches, are provided, and again this is found upon the concept of competition.

None of three textbooks, in which the concept of ecological niche is found, contextualizes it with any historical content, with text or pictures, we found no biographical data of responsible scientists (e.g. first proposing it) or date of proposal, so we conclude that HOS is not found (Table 4.24).

None statements related to NOS were identified in the textbooks upon the introduction of the concept of ecological niche (Table 4.24).

Regarding the guiding documents, we can only find one mention to NOS in the Essential Learning document, in the introduction:

The implementation of the [transversal essential learning] requires that the teacher considers: "[...] the *nature of science*, seeking, whenever possible, to adopt strategies that demonstrate the process of construction of scientific knowledge exploring the interrelations between science, technology, society and the environment." (DGE 2018a, p.2, my italics)

In the Curriculum Guidelines we found the concept of NOS in the introduction of the document: "each of the organizing themes is developed, through two sets of issues: one of a more general approach, which sometimes implies the nature of science and of scientific knowledge" (Galvão et al. 2001, p5) and "it is proposed the analysis and debate of reports of discoveries scientific evidence of successes and failures, persistence and different influences of society on Science" (Galvão et al. 2001, p6).

The top 3 textbooks, corresponding to the textbooks used by 63.8% of the students, do not include the concept of ecological niche, although it has been suggested as relevant, especially in the context of Ecology (Sousa 2016e).

The reference to NOS in the introductory part of a guidance document, in "front matter", has been also described in most of the standard documents in several countries, such as Australia, Canada, Colombia, Lebanon, Mexico, South Africa and United States (Olson 2018), and in Colombia and Lebanon is only found in the front/back mater (Olson, 2018), such as in Portugal, however in those countries it were described 9 and 6 distinct NOS statements, respectively, which is not the case for Portugal.

This type of reference to NOS, as found in Portuguese guidance documents, have been described as not valuing NOS learning and therefore not promoting its inclusion by teachers (Olson 2018) and, as we observed in our study, also by textbook authors.

### 4.3.2. Origin of life in Portuguese textbooks

#### 4.3.2.1. Origin of life integrated-HOS episodes in Portuguese textbooks

The theory of common ancestor is not mentioned in any of the Curriculum Guidelines for Natural Sciences, however, in the Curriculum Goals document, we consider that this concept can be included associated with some goals, corresponding to the 8th grade, such as (Bonito et al., 2013, p18): "Argue about some theories of the origin of life on Earth." So, all the textbooks certified, by the Ministry of Education, and currently used in Portuguese schools, for 8th grade Natural Sciences, were analysed (9 in total), and we concluded that all use the History of Science, with some diversity in the episodes chosen.

A comparative analysis of HOS content was performed (Table 4.25) regarding the type of historical information (e.g. scientist name mentioned, date of birth and death of scientist responsible), type of materials used (e.g. text and image/illustration) and if contained in a learning activity (e.g. a question).

**Table 4.25.** Comparative analysis of HOS content about origin of life in Portuguese textbooks.

| Theories<br>Textbooks | Creationism | Spontaneous generation | Biogenesis | Darwin's contributes | Primitive soup | Panspermia |
|---|---|---|---|---|---|---|
| **A** | - | - | - | - | + (T, I, Q, Ieq) | + (T, I) |
| **B** | + (T, I, Q) | + (T, Is, Q, S, Bd) | - | - | + (T, Is, S, Bd, Ieq) | + (T, I, Q) |
| **C** | - | + (T, Is, S, Bd) | + (T, Is, S, Bd, Q, Ieq) | + (T, Is, S, Bd) | + (T, S, Bd, Q, Is, Ieq) | + (T, Is, S, Bd, Q) |
| **D** | - | + (T, S) | + (T, S) | - | + (T, S, Bd, Is, Ieq, Q) | + (T, I, S, Bd, Is, Q) |
| **E** | - | + (T, I, S, Bd, Q) | + (T, Q) | - | + (T, I, S, Bd, Ieq, Q) | + (T, I) |
| **F** | - | + (T) | + (T, Is, S, Bd) | - | + (T, I, S) | - |
| **G** | - | + | - | - | + (T, I, S, Ieq, Q, Is) | + (T |
| **H** | + (T) | + (T) | + (T, S) | - | + (T, I) | + (T, I) |
| **I** | - | + (T) | + (T, S, Bd) | - | + (T, I, S, Bd, Q) | + (T, I, Q) |

+ = present; - = absent; T= text; I=image/illustration of present/past environment or phenomenon; Q=question; S=scientist name; Bd=date of birth and death; Ieq = illustration of equipment; Is = illustration of scientist

The theory of spontaneous generation is mentioned in eight (of the nine textbooks) and in only four the name of the proponent (Aristoteles) is mentioned and in only three one can find some biographical data about him (at least date of birth/death).

The biogenesis theory is mentioned in only six (of the nine) textbooks and in only five the name of the proponent (Pasteur) is mentioned and in only three one can find some biographical data about him (at least date of birth/death).

Only one textbook (C, corresponding to 11.8% of students) mentions one of Darwin's contributions to the origin of life research study, corresponding to his contribute, in 1871, in the following two sentences: "In 1871, Charles Darwin, an English scientist, defended that life should have arisen by chemical evolution. For Darwin, carbon-rich molecules appeared before the onset of any living organism". So, none of the textbooks mention that Darwin hypothesized about the origin of life occurring, a long time ago, at a warm little pond. None of the textbooks refers to Darwin's theory of common descendent or common ancestry.

#### 4.3.2.2. 20th century and contemporary evidences and theories of the origin of life in Portuguese textbooks

The most known novel evidences and theories are absent of all the textbooks (Table 4.26), although we considered adequate for middle school students, such as: origin in shallow marine water and origin in hot springs. This may be due to several factors such as the usual delay between science findings and the incorporation in the textbooks.

**Table 4.26.** Comparative analysis of contemporary episodes about origin of life in Portuguese textbooks.

| Theories / Textbooks | Bubbles | Hydrothermal | Mica sheets | Shallow marine | Hot springs | Total |
|---|---|---|---|---|---|---|
| **A** | - | + (T, I) | - | - | - | 1 |
| **B** | - | - | - | - | - | 0 |
| **C** | - | + (T, I, S, Is, Q) | - | - | - | 1 |
| **D** | + (T, I, S) | + (T, I, S, Q) | + (T, I, S) | - | - | 3 |
| **E** | - | + (T, I) | - | - | - | 1 |
| **F** | - | + (T, I) | - | - | - | 1 |
| **G** | - | + (T) | - | - | - | 1 |
| **H** | - | + (T, I) | - | - | - | 1 |
| **I** | - | - | - | - | - | 0 |

+ = present; - = absent; T= text; I=image/illustration of present/past environment or phenomenon; Q=question; S=scientist name; Bd=date of birth and death; Ieq=image of equipment; Is = image of scientist

Only one textbook (C) describes recent evidences supporting panspermia theory, obtained in 2008.

# Chapter 5

# Conclusions and future perspectives

# Chapter 5. Conclusions and future perspectives

The empirical studies included in this thesis suggest the efficacy of NOS-enriched problems for middle school Natural Sciences classes as well as for Didactics classes for preservice science teachers. The main aim of this thesis was to characterize the effects of NOS-enriched PBL in both epistemological conceptions of science and biology conceptions of 8th grade and preservice science teachers and this was achieved by a combination of both a quantitative and a qualitative approach. In the quantitative approach we used Likert questionnaires about the epistemological conceptions of science of 8th grade students and of evaluation of the PBL process by the teachers that observed the intervention unit with 8th grade students, as well as by the preservice science teachers about the intervention in which they participated. We concluded that 8th grade students had non-informed conceptions about items such as social and cultural influence on science and imagination and creativity in scientific research, and this was consistent with the interviews performed to the 8th grade students. The PBL interventions with 8th grade students were efficient since we were able to change the epistemological conceptions of the students to more informed ones and increased performance related with biology concepts; and the teachers that observed the intervention unit with 8th grade students reported that they raised and responded pertinent questions and participated in the group work and were able to propose a solution to the problem what supports the efficacy of the unit. And these results were corroborated with the qualitative approach including interviews with the observing teachers and content analysis of the scaffolds completed by the students. Regarding the preservice science teachers, in the quantitative approach, they responded in the Likert questionnaire that they all participated in the group work and that 90% of them raised and responded their own pertinent questions what supports the efficacy of the unit; this was corroborated with the qualitative approach that used an open-item questionnaire presented to the preservice teachers in which we show more informed epistemological conceptions of science and better performance about SSI after the unit and classroom observations that describe that all the students were actively engaged and that all of the groups were able to propose a solution to the problem. The quantitative approach comparing PBL with control group show us the higher efficacy of PBL in the item scientists at different times may use different theories and methods to interpret the same natural phenomenon.

The studies of textbook analysis included in this thesis suggest some guidelines for their improvement as the inclusion of structuring ideas such as the ecological niche concept and the theory of common ancestor.

We admit that, with some self-critical sense, we undertook a certain boldness in the number of studies and interventions carried out. Looking retrospectively, we recognize that such an attitude may have compromised the unity and integration of the studies. Somehow, if we went back, we would opted for a reduced number of studies and deeper analysis of each.

As end-products of this thesis we propose some research instruments, that can be used both by researchers and teachers, such as our Questionnaire of Students' Epistemological Conceptions of Science.

Our results with the resources produced for PBL (problem-situations about theories of origin of life, MacArthur-Wilson insular biogeography model and ecological concepts) suggest that PBL is effective in teaching about NOS. In the applied point of view, our findings have some implications, such as providing some guidelines and novel strategies and resources, such as three problem-situations NOS-enriched, for:

(1) K-U Biology education

(2) Biology and Geology preservice teachers' education, and

(3) Biology and Geology in-service K-12 teachers' training.

Given the lack of guidance documents with concrete proposals for NOS inclusion, our research is also relevant from the applied point of view since it includes the production of innovative educational resources and a course for teachers and science education researchers (please find workshop proposal approved for International Conference of Association of Problem-Based Learning and Active Learning Methodologies, PAN-PBL 2019 in Appendix 19) to facilitate the integration of aspects of NOS in the curriculum, through PBL.

Our results suggest that the PBL units were overall effective in promoting NOS and biology learning, however the samples used are of convenience and we would like to use random samples to be able to further generalize future findings.

To the best of our knowledge our study in 2014 using PBL to teach NOS (Sousa, 2014) was pioneer and this study is the first quasi-experimental follow-up study that suggests the effective role of active pedagogies in middle school. Some limitations of this study are not knowing all the factors affecting the students during the intervention, not being able to random select them to conditions, and the novelty effect of both the interventions.

With our studies it was possible to observe and analyze students' interactions and the relevance of the interaction between students and teacher as a group facilitator, during group work. It also allows us to study the PBL process, allowing us to provide recommendations to teachers to facilitate the implementation in a diversity of contexts and grades. In fact, both the unit about the origin of life and ecological niche were designed to be easily implemented, even in unfavorable contexts for active pedagogies, due to time restrictions due to reduced number of hours for the discipline and high amount of science contents.

To the best of our knowledge our study is the first study of characterization of NOS conceptions of K-12 Portuguese students and although the sample is of convenience this research provides some contributes that can lead to changes in curricula and science teaching in order to improve NOS conceptions. An improvement could be to focus the classroom practice in the categories we found lower scores in the SECS, such as: social and cultural influence on science and imagination and creativity in scientific research.

Our results suggest that the activity of construction of the conceptual map What is Science? may constitute an effective problem for middle school students and may be added in any classroom in K-U education. Furthermore, we would like to further test the effect of this activity on students learning through PBL about NOS.

In the future, we would like to continue the analysis of NOS content in textbooks, and provide specific guidelines for textbooks, since we observed so far, for example, that none of the textbooks used by Portuguese 8$^{th}$ grade students contain the aspect of creative and imaginative aspect of NOS and our intervention shows that it is possible to promote learning of this aspect using the Pasteur episode.

Our PBL unit developed for preservice teachers is highly relevant since it allowed preservice teachers to experience PBL and NOS learning by two common approaches (HOS and SSI). Since preservice teacher education is usually focused on the practice of teaching rather than science context and technology is not frequently used, our teaching proposal is innovative in using a contextual approach for NOS (within Ecology and Biogeography themes) and technology-enhanced PBL, using a Geographic Information System (GIS), such as Google Earth, and a computer simulation. Additionally, we consider that longer interventions would be more beneficial, since we found that some misconceptions are more difficult to change, and some of the preservice science teachers' responses (in the questionnaire) were considered adequate, but in future courses we would expect them to be more informed.

In future studies, we would like to assess the implementation, by the preservice teachers, of NOS teaching through PBL by performing follow-up interviews. We are also interested in conducting an effectiveness comparison study of the two approaches (HOS *versus* SSI) on the change of NOS conceptions. Additionally, we plan to assess the impact of these PBL units in biology concepts knowledge activation with pre and in-service teachers.

We consider that our study with preservice teachers is relevant for science teacher education, in general and not just the Portuguese biology and geology teaching course context, because we were able to gather evidences that it is possible to include NOS in context with Biology themes in a teaching methods course and these courses are included in teacher education programs around the world. We consider that teacher education should be a priority in developing students' scientific literacy since they are the ones who profit at the end.

In conclusion, since the objective of teaching about NOS is not to indoctrinate (Mattwews, 1998) our proposal of using Problem-Based Learning is suitable since we promoted critical thinking and the suggestion of different solutions to the problems.

# References

## References

Abd-El-Khalick, F. (2012). Examining the Sources for our Understandings about Science: Enduring conflations and critical issues in research on nature of science in science education. *International Journal of Science Education, 34*(3), 353-374.

Abd-El-Khalick, F., & Akerson, V. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education, 88*, 785-810.

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The Nature of Science and Instructional Practice: Making the Unnatural Natural. *Science Education, 82*, 417–436.

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: a critical review of the literature. *International Journal of Science Education, 22*(7), 665-701.

Abd-El-Khalick, F., Myers, J. Y., Summers, R., Brunner, J., Waight, N., Wahbeh, N., . . . Belarmino, J. (2017). A longitudinal analysis of the extent and manner of representations of nature of science in U.S. high school biology and physics textbooks. *Journal of Research in Science Teaching, 54*(1), 82-120.

Acevedo-Díaz, J., García-Carmona, A., & del Mar Aragón, M. (2017). Historia de la ciencia y naturaleza de la ciencia: una línea de investigación en didáctica de las ciencias. *Boletim da AIA-CTS, 5*, 36-39.

Adedoyin, A., & Bello, G. (2017). Conceptions of The Nature of Science Held By Undergraduate Pre-Service Biology Teachers In South-West Nigeria. *Malaysian Online Journal of Educational Sciences, 5*, 1-9.

Akerson, V. L., Weiland, I., Rogers, M., Pongsanon, K., & Bilican, K. (2014). Exploring Elementary Science Methods Course Contexts to Improve Preservice Teachers' NOS of Science Conceptions and Understandings of NOS Teaching Strategies. *EURASIA Journal of Mathematics, Science and Technology Education, 10*(6), 647-665.

Allchin, D. (2011). Evaluating Knowledge of the Nature of (Whole) Science. *Science Education, 95*(3), 518–542.

Allchin, D. (2013). *Teaching the Nature of Science: Perspectives & Resources*. Minneapolis, MN: ShiPS Education Press.

Allchin, D. (2017). Beyond the Consensus View: Whole Science. *Canadian Journal of Science, Mathematics and Technology Education, 17*(1), 18-26.

Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary Approaches to Teaching Nature of Science: Integrating Student Inquiry, Historical Cases, and Contemporary Cases in Classroom Practice. *Science Education, 98* (3), 461–486.

Allwood, A. C., Rosing, M. T., Flannery, D. T., Hurowitz, J. A., & Heirwegh, C. M. (2018). Reassessing evidence of life in 3,700-million-year old rocks of Greenland. *Nature, 563*, 241–244.

Aristotle The History of Animals, B. I. (Producer). (4th century BC). The History of Animals, Book IX. Retrieved from http://bit.ly/2UFggXF

Arndt, N. T., & Nisbet, E. G. (2012). Processes on the Young Earth and the Habitats of Early Life. *Annual Review of Earth and Planetary Sciences, 40* 521–549.

Arrhenius, S. (1908). *Worlds in the Making*. New York: Harper and Row.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning, 68*, 3-12.

Bell, R. L., Matkins, J. J., & Gansneder, B. M. (2011). Impacts of Contextual and Explicit Instruction on Preservice Elementary Teachers' Understandings of the Nature of Science. *Journal of Research in Science Teaching, 48*(4), 414-436.

Bell, R. L., Mulvey, B., & Maeng, J. (2016). Outcomes of nature of science instruction along a context continuum: preservice secondary science teachers' conceptions and instructional intentions. *International Journal of Science Education, 38*, 493-520.

Ben-Menahem, A. (2009). Historical encyclopedia of natural and mathematical sciences. Berlin, DE: Springer.

Betts, H. C., Puttick, M. N., Clark, J. W., Williams, T. A., Donoghue, P. C. J., & Pisani, D. (2018). Integrated genomic and fossil evidence illuminates life's early evolution and eukaryote origin. *Nature Ecology & Evolution, 2*, 1556–1562.

Bonito, J., Morgado, M., Silva, M., Figueira, D., Serrano, M., Mesquita, J., & Rebelo, H. (2013). *Metas Curriculares do Ensino Básico - Ciências Naturais [Curriculum guidelines for middle school Natural Sciences].* Lisbon Ministry of Education and Science. .

Borgerding, L. A., & Dagistan, M. (2018). Preservice science teachers' concerns and approaches for teaching socioscientific and controversial issues. *Journal of Science Teacher Education, 29*, 283-306.

Brigati, J. (2018). Student Attitudes toward Active Learning vs. Lecture in Cell Biology Instruction. *The American Biology Teacher, 80*(8), 584–591.

Brown, J. H., & Lomolino, M. V. (2000). Concluding remarks: historical perspective and the future of island biogeography theory. *Global Ecology & Biogeography, 9*, 87-92.

Burgin, S. R., & Sadler, T. D. (2016). Learning Nature of Science Concepts Through a Research Apprenticeship Program: A Comparative Study of Three Approaches. *Journal of Research in Science Teaching, 53*(1), 31–59

Cattaneo, K. H. (2017). Telling Active Learning Pedagogies Apart: from theory to practice. *Journal of New Approaches in Educational Research, 6*(2), 144-152.

Chan, Q., Zolensky, M., Kebukawa, Y., Fries, M., Ito, M., Steele, A., . . . Mase, K. (2018). Organic matter in extraterrestrial water-bearing salt crystals. *Science Advances, 4*, eaao3521. doi:10.1126/sciadv.aao3521

Chase, J. M. (2011). Ecological Niche Theory In S. M. Scheiner & M. R. Willig (Eds.), *The Theory of Ecology.*: The University of Chicago Press.

CICES (Producer). (2019). Towards a Common International Classification of Ecosystem Services (CICES) for Integrated Environmental and Economic Accounting. Retrieved from https://cices.eu/resources/

Clough, M. P. (2006). Learners' Responses to the Demands of Conceptual Change: Considerations for Effective Nature of Science Instruction. *Science Education, 15* 463-494.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research Methods in Education*. New York, E. U. A.: Routledge.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research Methods in Education*. New York: Routledge.

Conant, J. B. (1947). *On Understanding Science: An historical approach.* New Haven, USA: Yale University Press.

Conant, J. B. (1957). Introduction. In J. B. Conant (Ed.), *Harvard Case Histories in Experimental Science* (Vol. 1, pp. vii-xvi). Cambridge, MA, USA: Harvard University Press.

Conley, A. M., Pintrich, P. R., Vekiri, I., & Harrison, D. (2004). Changes in epistemological beliefs in elementary science students. *Contemporary Educational Psychology, 29*(2), 186–204.

Corliss, J., Baross., J., & Hoffman, S. (1981). An hypothesis concerning the relationship between submarine hot springs and the origin of life on Earth. *Oceanologic Acta*( Special Issue), 59-69.

Coutinho, C. P. (2011). *Metodologia de Investigação em Ciências Sociais e Humanas: Teoria e Prática.* Coimbra: Almedina.

Creswell, J. W. (2014). *Research design: qualitative, quantitative, and mixed methods approaches.* USA: SAGE Publications, Inc.

Crick, F. H. C., & Orgel, L. E. (1973). Directed panspermia. *Icarus, 19*, 341–346.

Dagher, Z. R., & Erduran, S. (2016). Reconceptualizing the Nature of Science for Science Education - Why Does it Matter? *Science & Education, 25*, 147–164.

Damer, B. (2016). A Field Trip to the Archaean in Search of Darwin's Warm Little Pond. *Life, 6*(21), doi:10.3390/life6020021.

Damer, B., & Deamer, D. (2015). Coupled Phases and Combinatorial Selection in Fluctuating Hydrothermal Pools: A Scenario to Guide Experimental Approaches to the Origin of Cellular Life. *Life 5*, doi:10.3390/life3350x3000x.

Darwin, C. R. (1836). Zoology notes. In R. Keynes (Ed.), *Charles Darwin's Zoology Notes & Specimen Lists from H.M.S. Beagle.* Available on-line: http://darwin-online.org.uk/content/frameset?itemID=F1840&viewtype=text&pageseq=1.

Darwin, C. R. (1837-8). *Notebook B [Transmutation of Species]*. Darwin Online. Available online https://bit.ly/2KfEdBn.

Darwin, C. R. (1859). *On the Origin of Species, by means of Natural Selection; or the Preservation of Favoured Races in the Struggle for Life*. London: Penguin.

Darwin, C. R. (1860). *On the Origin of Species, by means of Natural Selection; or the Preservation of Favoured Races in the Struggle for Life*. London: John Murray. Available at https://bit.ly/2DrjoBy.

Darwin, C. R. (1861). *On the Origin of Species, by means of Natural Selection; or the Preservation of Favoured Races in the Struggle for Life*. London: : John Murray, Available at https://bit.ly/2Kb3SLh.

Darwin, C. R. (1871). Letter to J. D. Hooker. Available at https://bit.ly/2oY9Vr4.

de Beer, G. (1960). Darwin's notebooks on transmutation of species. Part I. First notebook [B] (July 1837-February 1838). *Bulletin of the British Museum (Natural History). Historical Series,, 2*(23-73.), Available at https://bit.ly/2Py2xnQ.

De Winter, J. C. F. (2013). Using the Student's t-test with extremely small sample sizes. *Practical Assessment, Research & Evaluation, 18*(10), 1-12.

Deichmann, U. (2012). Origin of Life. The Role of Experiments, Basic Beliefs, and Social Authorities in the Controversies about the Spontaneous Generation of Life and the Subsequent Debates about Synthesizing Life in the Laboratory. *History and Philosophy of the Life Sciences, 34*, 341-359.

del Moral, R., & Magnússon, B. (2014). Surtsey and Mount St. Helens: a comparison of early succession rates. *Biogeosciences, 11*, 2099–2111.

Deng, F., Chen, D.-T., Tsai, C.-C., & Chai, C. S. (2011). Students' Views of the Nature of Science: A Critical Review of Research. *Science Education, 95*(6), 961-999.

Dewey, J. (1910). What is thought? *How we think* (pp. 1-13). New York, USA: D. C. Heath & Co, Publishers.

DGE. (2018a). Aprendizagens Essenciais – Articulação com o perfil do aluno, Ciências Naturais, 8º ano [Essencial Learning – articulation with the student profile, Natural Sciences, 8th grade] Available at https://www.dge.mec.pt/sites/default/files/Curriculo/Aprendizagens_Essenciais/3_ciclo/ciencias_naturais_3c_8a_ff.pdf.

DGE. (2018b). Aprendizagens Essenciais – Articulação com o perfil do aluno, Biologia e Geologia, 11º ano [Essencial Learning – articulation with the student profile, Biology and Geology, 11th grade]. Available in https://www.dge.mec.pt/sites/default/files/Curriculo/Aprendizagens_Essenciais/11_biologia_e_geologia.pdf.

DiCarlo, S. E. (2006). Cell biology should be taught as science is practised. *Nature Reviews Molecular Cell Biology, 7*, 290-296.

Ding, X., Zhao, L., Chu, H., Tong, N., Ni, C., Hu, Z., . . . Wang, M. (2014). Assessing the Effectiveness of Problem-Based Learning of Preventive Medicine Education in China. *Scientific Reports, 4*, 5126-5130.

Djokic, T., Kranendonk, M., Campbell, K., Walter, M. R., & Ward, C. (2017). Earliest signs of life on land preserved in ca. 3.5 Ga hot spring deposits. *Nature Communications, 8*, DOI: 10.1038/ncomms15263.

Dodd, M., Papineau, D., Grenne, T., Slack, J., Rittner, M., Pirajno, F., . . . Little, C. (2017). Evidence for early life in Earth's oldest hydrothermal vent precipitates. *Nature, 543*, 60-64.

Dogan, N., & Abd-El-Khalick, F. (2008). Turkish Grade 10 Students' and Science Teachers' Conceptions of Nature of Science: A National Study. *Journal of Research in Science Teaching, 45* (10), 1083-1112.

Dolmans, D., De Grave, W., Wolfhagen, I., & van der Vleuten, C. (2005). Problem-based learning: future challenges for educational practice and research. *Medical Education, 39*, 732-741.

Dolmans, D. H. J. M., Gijselaers, W. H., Moust, J. H. C., de Grave, W. S., Wolfhagen, I. H. A. P., & van der Vleuten, C. (2002). Trends in research on the tutor in problem-based learning: conclusions and implications for educational practice and research. *Medical Teacher, 24*(2), 173-180.

Dolmans, D. H. J. M., Snellen-Balendong, H., & van der Vleuten, C. (1997). Seven principles of effective case design for a problem-based curriculum *Medical Teacher, 19*(3), 185-189.

Doolittle, W. (1999). Phylogenetic classification and the universal tree. *Science, 284*, 2124-2128.

Eastwood, J. L., Sadler, T. D., Zeidler, D. L., Lewis, A., Amiri, L., & Applebaum, S. (2012). Contextualizing Nature of Science Instruction in Socioscientific Issues. *International Journal of Science Education*, DOI:10.1080/09500693.09502012.09667582.

Emran, A., Spektor-levy, O., Tal, O. P., & Assaraf, O. B. Z. (2020). Understanding Students' Perceptions of the Nature of Science in the Context of Their Gender and Their Parents' Occupation. *Science & Education*, https://doi.org/10.1007/s11191-11020-00103-z.

Erduran, S., & Dagher, Z. (2014). *Reconceptualizing the nature of science in science education.* Dordrecht, The Netherlands: Springer.

Ertmer, P. A., & Simons, K. D. (2006). Jumping the PBL Implementation Hurdle: Supporting the Efforts of K–12 Teachers. *Interdisciplinary Journal of Problem-based Learning, 1*(1), 40-54.

Espinoza, F. (2012). The Need for Scientific Literacy. In F. Espinoza (Ed.), *The Nature of Science: Integrating Historical, Philosophical, and Sociological Perspectives* (pp. 5-13). United Kingdom: Plymouth: Rowman & Littlefield Publishers.

Field, A. (2009). *Discovering Statistics using SPSS*: SAGE.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America, 111*(23), 8410-8415.

Fry, I. (1995). Are the Different Hypotheses on the Emergence of Life as Different as they Seem? *Biology and Philosophy, 10*, 389-417.

Furukawa, Y., Chikaraishib, Y., Ohkouchic, N., Ogawac, N., Glavind, D., Dworkind, J., . . . Nakamura, T. (2019). Extraterrestrial ribose and other sugars in primitive meteorites. *Proceedings of the National Academy of Sciences of the United States of America*, https://doi.org/10.1073/pnas.1907169116.

Galili, I. (2019). Towards a Refined Depiction of Nature of Science. Applications to Physics Education. *Science & Education*, https://doi.org/10.1007/s11191-11019-00042-11194.

Galvão, C., Neves, A., Freire, A. M., Lopes, A. M. S., Santos, M. d. C., Vilela, M. d. C., . . . Pereira, M. (2001). *Orientações curriculares para o 3º ciclo do ensino básico [Curriculum guidelines for middle school – Physical and Natural Sciences].* . Lisbon: Ministry of Education.

Garabet, M., & Miron, C. (2010). Conceptual map – didactic method of constructivist type during the physics lessons *Procedia Social and Behavioral Sciences, 2*, 3622-3631.

Garcia, I., James, R., Bischof, P., & Baroffio, A. (2017). Self-Observation and Peer Feedback as a Faculty Development Approach for Problem-Based Learning Tutors: A Program Evaluation. *Teaching and Learning in Medicine, 29*, 313-325.

Gardner, J., & Belland, B. R. (2017). Problem-Centered Supplemental Instruction in Biology: Influence on Content Recall, Content Understanding, and Problem Solving Ability. *Journal of Science Education and Technology, 26*, 383–393.

Gause, G. F. (1932). Experimental Studies on the Struggle for Existence. *Journal of Experimental Biology, 9*, 389-402.

Gawrylewski, A. (2018). From the Editor: Science, Upended. In Revolutions in Science: 13 discoveries that could change everything. Special Collector's Edition, . *Scientific American, 27*(3), 1.

Glansdorff, N., Xu, Y., & Labedan, B. (2009). The origin of life and the last universal common ancestor: do we need a change of perspective? *Research in Microbiology, 160*, 522-528.

Glass, D. H., & McCartney, M. (2014). Explaining and Explaining Away in Science and Religion. *Theology and Science, 12*, 338-361.

Godfrey-Smith, P. (2014). *Philosophy of Biology*. Princeton, NJ, USA: Princeton University Press.

Griesemer, J. (1992). Niche: Historical perspectives In E. F. Keller & E. A. Lloyd (Eds.), *The keywords in evolutionary biology*. Cambridge, MA, USA: Harvard University Press.

Grinnell, J. (1917). The niche-relationships of the California Thrasher. *The Auk, 34*, 427-433.

Hammer, D. (1997). Discovery Learning and Discovery Teaching. *Cognition and Instruction, 15*(4), 485-529.

Hansma, H. (2010). Possible origin of life between mica sheets. *Journal of Theoretical Biology, 266*, 175–188.

Hansma, H. G., Revenko, I., Kim, K., & Laney, D. E. (1996). Atomic force microscopy of long and short double-stranded, single-stranded and triple-stranded nucleic acids. *Nucleic Acids Research, 24*, 713–720.

Harold, F. (2014). *In search of cell history: The evolution of life's building blocks*. Chicago, USA The University of Chicago Press.

Harwood, W. S. (2004). A new model for inquiry: is the scientific method dead? . *Journal of College Science Teaching, 33*(7), 29–33.

Higgins, S. I., & Richardson, D. M. (2014). Invasive plants have broader physiological niches. *Proceedings of the National Academy of Sciences USA, 111*, 10610-10614.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and Achievement in Problem-Based and Inquiry Learning: A Response to Kirschner, Sweller, and Clark (2006) *Educational Psychologist, 42*(2), 99-107.

Hodson, D., & Wong, S. L. (2017). Going Beyond the Consensus View: Broadening and Enriching the Scope of NOS-Oriented Curricula. *Canadian Journal of Science, Mathematics and Technology Education, 17*(1), 3-17.

Holbrook, J., & Rannikmae, M. (2007). The Nature of Science Education for Enhancing Scientific Literacy. *International Journal of Science Education, 29*(11), 1347-1362.

Holt, R. D. (2009). Bringing the Hutchinsonian niche into the 21st century: Ecological and evolutionary perspectives. *Proceedings of the National Academy of Sciences USA, 106*, 19659-19665.

Hubbell, S. P. (2001). *The unified neutral theory of biodiversity and biogeography*. Princeton: Princeton University Press. .

Hug, L., Baker, B., Anantharaman, K., Brown, C., Probst, A., Castelle, C., . . . Banfield, J. F. (2016). A new view of the tree of life. *Nature Microbiology, 1*, 1-6.

Hull, D. (1992). A matter of individuality In M. Ereshefsky (Ed.), *The units of evolution. Essays on the nature of species* (pp. 119-227). Cambridge, MA, USA: The MIT Press.

Institute Pasteur. (2017). The middle years 1862-1877. Available at https://bit.ly/2RU5kEo.

Johnson, R. H. (1910). *Determinate evolution in the color-pattern of the lady-beetles.* . Washington: Carnegie Institution, Available at: http://bit.ly/2UGARuM.

Justus, J. (2013). Philosophical Issues in Ecology. In K. Kampourakis (Ed.), *The Philosophy of Biology: A Companion for Educators.*: Springer.

Kampourakis, K. (2016a). (The) Nature(s) of Science(s) and (the) Scientific Method(s). *Science & Education, 25*, 1-2.

Kampourakis, K. (2016b). The “General Aspects” Conceptualization as a Pragmatic and Effective Means to Introducing Students to Nature of Science. *Journal of Research in Science Teaching, 53*(5), 667–682.

Kampourakis, K. (2020). Uncertainty in Scientific Predictions. *Uncertainty* (pp. 178-191). USA: Oxford University Press. .

Kartal, E. E., Cobern, W. W., Dogan, N., Irez, S., Cakmakci, G., & Yalaki, Y. (2018). Improving science teachers’ nature of science views through an innovative continuing professional development program. *International Journal of STEM Education, 5*(30), https://doi.org/10.1186/s40594-40018-40125-40594.

Kaya, E., Erduran, S., Aksoz, B., & Akgun, S. I. (2019). Reconceptualised family resemblance approach to nature of science in pre-service science teacher education. *International Journal of Science Education, 41*(1), 21-47.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of Explicit and Reflective versus Implicit Inquiry-Oriented Instruction on Sixth Graders’ Views of Nature of Science. *Journal of Research in Science Teaching, 39*(7), 551–578.

Khishfe, R., Alshaya, F. S., BouJaoude, S., Mansour, N., & Alrudiyan, K. I. (2017). Students’ understandings of nature of science and their arguments in the context of four socioscientific issues. *International Journal of Science Education, 39*(3), 299-334.

Khishfe, R., & Lederman, N. G. (2007). Relationship between Instructional Context and Views of Nature of Science. *International Journal of Science Education, 29* (8), 939–961.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist, 41*(2), 75-86.

Kraft, N. J., Godoy, O., & Levine, J. M. (2015). Plant functional traits and the multidimensional nature of species coexistence. *Proceedings of the National Academy of Sciences USA, 112*, 797-802.

Kuçuk, M., & Çepni, S. (2015). A Qualitative Study to Explain Middle School Student's Understandings of Nature of Science. *Journal of Turkish Science Education, 12*(3), 3-20.

Kueffer, C. (2017). Plant invasions in the Anthropocene. *Science 358*, 724-725.

Kuhn, T. (1993). Afterwords. In P. Horwich (Ed.), *World Changes: Thomas Kuhn and the Nature of Science* (pp. 311-341). Pittsburgh, USA: University of Pittsburgh Press.

Laplane, L., Mantovani, P., Adolphs, R., Chang, H., Mantovani, A., McFall-Ngai, M., . . . Pradeu, T. (2019). Why science needs philosophy. *Proceedings of National Academy of Sciences, 116*, 3948–3952.

Lederman, J. S., Lederman, N. G., Bartels, S., Jimenez, J., Akubo, M., Aly, S., . . . Zhou, Q. (2019). An international collaborative investigation of beginning seventh grade students' understandings of scientific inquiry: Establishing a baseline *Journal of Research in Science Teaching, 56*(4), 486-515.

Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Meyer, A. A., & Schwartz, R. S. (2014). Meaningful Assessment of Learners' Understandings About Scientific Inquiry—The Views About Scientific Inquiry (VASI) Questionnaire. *Journal of Reasearch in Science Teaching, 51*(1).

Lederman, N. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*, 331-359.

Lederman, N. G. (1999). The State of Science Education: Subject Matter Without Context. *Electronic Journal of Science Education, 3*(2), 1-6.

Lederman, N. G. (2007). Nature of Science: Past, Present, and Future. . In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 831-879): Lawrence Erlbaum Associates.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of Nature of Science Questionnaire: Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science. *Journal of Research in Science Teaching, 39*(6), 497–521.

Lederman, N. G., & Lederman, J. (2019). Teaching and learning nature of scientific knowledge: Is it Déjà vu all over again? *Disciplinary and Interdisciplinary Science Education Research, 1*(6), https://doi.org/10.1186/s43031-43019-40002-43030.

Lederman, N. G., & Lederman, J. S. (2014). Is Nature of Science Going, Going, Going, Gone? . *Journal of Science Teacher Education, 25* 235-238.

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of Science and Scientific Inquiry as Contexts for the Learning of Science and Achievement of Scientific Literacy. *International Journal of Education in Mathematics, Science and Technology, 1*(3), 138-147.

Lederman, N. G., Schwartz, R., & Abd-El-Khalick, F. (2015). Nature of Science, Assessing of. In R. Gunstone (Ed.), *Encyclopedia of Science Education*. Netherlands: Springer.

Lee, S. W.-Y., Liang, J.-C., & Tsai, C.-C. (2016). Do sophisticated epistemic beliefs predict meaningful learning? Findings from a structural equation model of undergraduate biology learning. *International Journal of Science Education, 38*(15), 2327–2345.

Leite, L. (2002). History of science in science education: development and validation of a checklist for analysing the historical content of science textbooks. *Science & Education, 11*, 333–359.

Levine, J. M., & HilleRisLambers, J. (2009). The importance of niches for the maintenance of species diversity. *Nature, 461*, 254–257.

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2006). *Student Understanding of Science and Scientific Inquiry (SUSSI): Revision and Further Validation of an Assessment Instrument.* Paper presented at the 2006 Annual Conference of the National Association for Research in Science Teaching (NARST), San Francisco, CA.

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2009). Preservice Teachers' Views about Nature of Scientific Knowledge Development: An International Collaborative Study. *International Journal of Science and Mathematics Education, 7*, 987-1012.

Lin, C.-C., & Tsai, C.-C. (2008). Exploring the Structural Relationships between High School Students' Scientific Epistemological Views and their Utilization of Information Commitments toward Online Science Information. *International Journal of Science Education, 30*(15), 2001-2022.

Liu, S. Y., & Tsai, C. C. (2008). Differences in the Scientific Epistemological Views of Undergraduate Students. *International Journal of Science Education, 30*(8), 1055-1073.

Loyens, S. M. M., Jones, S. H., Mikkers, J., & van Gog, T. (2015). Problem-based learning as a facilitator of conceptual change. *Learning and Instruction, 38*, 34-42.

MacArthur, R. H., & Wilson, E. O. (1963). An equilibrium theory of insular zoogeography. *Evolution, 17*, 373-387.

MacArthur, R. H., & Wilson, E. O. (1967, reprinted 2001). *The Theory of Island Biogeography*. USA: Princeton University Press.

Maeng, J. L., Bell, R. L., St. Clair, T., Gonczi, A., & Whitworth, B. A. (2018). Supporting Elementary Teachers' Enactment of Nature of Science Instruction: A Randomized Controlled Trial. *International Journal of Science Education, 40*(18), 2245-2264.

Marco-Casanova, P., & Peretó, J. (2015). Monograph interview - John Sutherland. *Mèthode, available at https://bit.ly/2QNNTFA*.

Matthews, M. R. (1998). Forword and introduction. In W. F. McComas (Ed.), *The nature of science in science education. Rationales and strategies* (pp. xi-xxi). Dordrecht, The Netherlands: Kluwer.

Matthews, M. R. (2012). Changing the focus: From nature of science to features of science. In M. S. Khine (Ed.), *Advances in nature of science research*. Dordrecht: Springer.

Matthews, M. R. (2015). *Science Teaching: The Contribution of History and Philosophy of Science*. New York: Routledge.

Maynard-Smith, J., & Szathmáry, E. (2000). *The origins of life: from the birth of life to the origins of language*. Oxford: Oxford University Press.

Mayr, E. (2004). *What Makes Biology Unique? Considerations on the Autonomy of a Scientific Discipline*. Cambridge, UK: Cambridge University Press.

McCaughan, K. (2013). Barrows' Integration of Cognitive and Clinical Psychology in PBL Tutor Guidelines. *Interdisciplinary Journal of Problem-based Learning, 7*(1), 11-23.

McComas, W. F. (2002). The Principal Elements Of The Nature Of Science: Dispelling The Myths. In W. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 53-70). USA: Kluwer Academic Publishers.

McComas, W. F. (2004). Keys to Teaching the Nature of Science. *Science Teacher, 71*(24-27).

McComas, W. F. (2008). Seeking historical examples to illustrate key aspects of the nature of science. *Science & Education, 17*, 249-263.

McComas, W. F. (2014). *The Language of Science Education: An Expanded Glossary of Key Terms in Science Teaching and Learning*. Boston: Sense Publishers. .

McComas, W. F. (2017). Understanding how science works: the nature of science as the foundation for science teaching and learning. *The School Science Review, 98*(365), 71-76.

McComas, W. F., Clough, M. P., & Almazroa, H. (2002). The Role and Character of the Nature of Science in Science Education. In W. F. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 3-39). New York: Springer.

McComas, W. F., & Hayward, J. (2014). Problem Based Learning. In W. F. McComas (Ed.), *The Language of Science Education: An Expanded Glossary of Key Terms in Science Teaching and Learning* (pp. 76). Boston: Sense Publishers.

McComas, W. F., & Kampourakis, K. (2015). Using the History of Biology, Chemistry, Geology, and Physics to illustrate general aspects of Nature of Science. *Review of Science, Mathematics and ICT Education, 9*, 47-76.

McComas, W. F., & Nouri, N. (2016). The nature of science and the Next Generation Science Standards: analysis and critique. *Journal of Science Teacher Education, 27*, 555-576.

Merritt, J., Lee, M. Y., Rillero, P., & Kinach, B. M. ( 2017). Problem-Based Learning in K–8 Mathematics and Science Education: A Literature Review. *Interdisciplinary Journal of Problem-based Learning, 11*(2), https://doi.org/10.7771/1541-5015.1674.

Mesci, G., & Schwartz, R. S. (2017). Changing Preservice Science Teachers' Views of Nature of Science: Why Some Conceptions May be More Easily Altered than Others. *Research in Science Education*, DOI 10.1007/s11165-11015-19503-11169.

Miller, G. T. (2007). *Essentials of Ecology*: Thomson Learning Inc.

Mojzsis, S., Harrison, T., & Pidgeon, R. (2001). Oxygen-isotope evidence from ancient zircons for liquid water at the Earth's surface 4,300 Myr ago. *Nature, 409*, 178-181.

Moore, J. A. (1984). Science as a Way of Knowing—Evolutionary Biology. . *American Zoologist, 24*, 467-534.

Morris, D. W., & Lundberg, P. (2011). *Pillars of evolution: fundamental principles of the eco-evolutionary process*. New York, USA: Oxford University Press. .

Mulvey, B. K., & Bell, R. L. (2016). Making learning last: teachers' long-term retention of improved nature of science conceptions and instructional rationales. *International Journal of Science Education*, doi:10.1080/09500693.09502016.01267879.

Murie, K. (2014). Context-based Science Education. In W. F. McComas (Ed.), *The Language of Science Education: An Expanded Glossary of Key Terms in Science Teaching and Learning,* (pp. 25). Boston: Sense Publishers.

Nijhuis, M. (2013). How Climate Change is Helping Invasive Species Take Over: Longer seasons and warmer weather have combined to be a game-changer in the plant wars. Available in https://www.smithsonianmag.com/science-nature/how-climate-change-is-helping-invasive-species-take-over-180947630/.

Novak, J. D. (2002). Meaningful Learning: The Essential Factor for Conceptual Change in Limited or Inappropriate Propositional Hierarchies Leading to Empowerment of Learners. *Science Education, 86*, 548–571.

Novoa, A., González, L., Moravcova, L., & Pysek, P. (2013). Constraints to native plant species establishment in coastal dune communities invaded by Carpobrotus edulis: Implications for restoration. *Biological Conservation, 164*, 1-9.

Novoa, A., Rodríguez, R., Richardson, D., & González, L. (2014). Soil quality: a key factor in understanding plant invasion? The case of Carpobrotus edulis (L.) N.E.Br. . *Biological Invasions*, DOI 10.1007/s10530-10013-10531-y.

Nunnally, J. C., & Bernstein, I. H. (1994). *Psychometric theory*: McGraw-Hili, Inc.

Nutman, A. P., Bennett, V. C., Friend, C. R. L., Van Kranendonk, M. J., & Chivas, A. R. (2016). Rapid emergence of life shown by discovery of 3,700-million-year-old microbial structures. *Nature, 537*, 535-538.

Nutman, A. P., Bennett, V. C., Friend, C. R. L., Van Kranendonk, M. J., Rothacker, L., & Chivas, A. R. (2019). Cross-examining Earth's oldest stromatolites: Seeing through the effects of heterogeneous deformation, metamorphism and metasomatism affecting Isua (Greenland) ~3700 Ma sedimentary rocks. . *Precambrian Research*, doi.org/10.1016/j.precamres.2019.105347.

O'Hanlon, F. (2018). Mixed-Methods Research: Achieving a Robust Design. In L. Hamilton & J. Ravenscroft (Eds.), *Building Research Design in Education: Theoretically Informed Advanced Methods*. UK: Bloomsbury Academic.

Oguz-Unver, A., & Arabacioglu, S. (2014). A comparison of inquiry-based learning (IBL), problem-based learning (PBL) and project-based learning (PJBL) in science education. *Academia Journal of Educational Research, 2*(7), 120-128.

Olson, J. K. (2018). The inclusion of the nature of science in nine recent international science education standards documents. *Science & Education,, 27*, 637-660.

Oparin, A. I. (1938). *The Origin of Life. Translated by Sergius Morgulis.* . NY, USA: The Macmillan Company.

Osborne, J. (2017). Going Beyond the Consensus View: A Response. *Canadian Journal of Science, Mathematics and Technology Education, 17*(1), 53-57.

Park, H., Nielsen, W., & Woodruff, E. (2014). Students' Conceptions of the Nature of Science: Perspectives from Canadian and Korean Middle School Students. *Science & Education, 23* 1169–1196.

Parker, E. T., Cleaves, H. J., Dworkin, J. P., Glavin, D. P., Callahan, M., Aubrey, A., . . . Bada, J. L. (2011). Primordial synthesis of amines and amino acids in a 1958 Miller H2S-rich spark discharge experiment. *Proceedings of the National Academy of Sciences of the United States of America, 108*, 5526–5531.

Pearce, B., Pudritz, R., Semenov, D., & Henning, T. (2017). Origin of the RNA world: The fate of nucleobases in warm little ponds. *Proceedings of the National Academy of Sciences of the United States of America, 114*, 11327–11332.

Pease, M. A., & Kuhn, D. (2011). Experimental Analysis of the Effective Components of Problem-Based Learning. *Science Education, 95*(1), 57-86.

Peretó, J., Bada, J. L., & Lazcano, A. (2009). Charles Darwin and the Origin of Life. *Origins of life and evolution of the biosphere, 39*, 395–406.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change *Review of Educational Research, 63*(2), 167-199.

PISA. (2018). Portugal. Available in http://www.compareyourcountry.org/pisa/country/prt?lg=en.

Pocheville, A. (2015). The Ecological Niche: History and Recent Controversies. In T. Heams, P. Huneman, G. Lecointre, & M. Silberstein (Eds.), *Handbook of Evolutionary Thinking in the Sciences* (pp. 547-586): Springer.

Polechová, J., & Storch, D. (2019). Ecological niche *Encyclopedia of Ecology* (Vol. 3, pp. 72-80).

Popper, K. R. (1962). *Conjectures and Refutations: The Growth of Scientific Knowledge*. New York, USA: Basic Books.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Puigbò, P., Wolf, Y. I., & Koonin, E. V. (2013). Seeing the Tree of Life behind the phylogenetic forest. . *BMC Biology, 11*, 46.

Raymann, K., Brochier-Armanet, C., & Gribaldo, S. (2015). The two-domain tree of life is linked to a new root for the Archaea. *Proceedings of the National Academy of Sciences of the United States of America, 112*, 6670–6675.

Rogers, K. (2018). Scientific hypothesis *Encyclopædia Britannica, Inc.* Available online in https://www.britannica.com/science/scientific-hypothesis. .

Ruse, M. (1997). The Origin of Life: Philosophical Perspectives. *J. Theor. Biol., 187*, 473-482.

Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching, 41*, 513–536.

Sadler, T. D., Romine, W. L., & Topçu, M. S. (2016). Learning science content through socio-scientific issues-based instruction: a multi-level assessment study. *International Journal of Science Education, 38*(10), 1622-1635.

Sagan, C. (1996). *Antiscience in The Demon-Haunted World: Science as a Candle in the Dark*. New York: Random House Publishing Group.

Savery, J. R. (2006). Overview of problem-based learning: definitions and distinctions. *The Interdisciplinary Journal of Problem-based Learning, 1*(1), 9-20.

Schmidt, H. G., Rotgans, J. I., & Yew, E. (2011). The process of problem-based learning: what works and why. *Medical Education, 45*(8), 792-806.

Schmitt-Kopplin, P., Gabelica, Z., Gougeon, R. D., Fekete, A., Kanawati, B., Harir, M., . . . Hertkorn, N. (2010). High molecular diversity of extraterrestrial organic matter in Murchison meteorite revealed 40 years after its fall. *Proceedings of the National Academy of Sciences of the United States of America, 107*(7), 2763-2768.

Schwartz, R., & Lederman, N. (2007). What Scientists Say: Scientists' views of nature of science and relation to science context. *International Journal of Science Education, 30*(6), 727 - 771.

Schwartz, R. S., Lederman, N. G., & Crawford, B. (2012). A Series of Misrepresentations: A Response to Allchin's Whole Approach to Assessing Nature of Science Understandings. *Science Education, 96*(4), 685-692.

Schwarz, C., Reiser, B., Davis, E., Kenyon, L., Archér, A., Fortus, D., . . . Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632-654.

Senocak, E. (2009). Development of an Instrument for Assessing Undergraduate Science Students' Perceptions: The Problem-Based Learning Environment Inventory. *Journal of Science Education and Technology, 18*(6), 560–569.

Service, R. F. (2015). Origin-of-life puzzle cracked. *Science, 347*(6228), 1298.

Simberloff, D., & Wilson, E. O. (1969). Experimental Zoogeography of islands: colonization of empty islands. *Ecology, 50*(2), 278–296.

Smith, K. G. (2017). 100 Years Ago in the American Ornithologists' Union. *The Auk, 134*, 474-476.

Sober, E. (2008). *Evidence and Evolution: the logic behind the science*. CA, USA: Cambridge University Press.

Sousa, C. (2007). *Abordagem por resolução de problemas em aulas práticas de disciplinas na área da Biologia: PBL e resolução de problemas [Using problem solving in practical classes of disciplines in the area of Biology: PBL and problem solving].* Paper presented at the Colóquio da Investigação à prática: Interacções e debates [Proceedings of the Colloquium on Research to Practice: Interactions and debates], Aveiro, Portugal.

Sousa, C. (2013). *Implementation of problem-based learning in the context of celebrating the centenary of Alfred Wegener's first publication on continental drift and bridging the evolution science – biology and geology teaching practice gap. Paper presented at the* Paper presented at the Congress of the European Society for Evolutionary Biology, Lisboa, Portugal.

Sousa, C. (2014). History and nature of science enriched problem-based learning on the origins of biodiversity and of continents and oceans. *Multidisciplinary Journal for Education, Social and Technological Sciences, 1*(2), 142–159.

Sousa, C. (2015). *Aprendizagem baseada em problemas integrativa dos temas mobilismo geológico e biodiversidade à luz da evolução [Integrative problem-based learning of the themes of geological mobilism and biodiversity in the light of evolution].* (Master), Universidade do Porto, Porto, Portugal.

Sousa, C. (2016a). Problem-Based Learning on Cell Biology and Ecophysiology using integrated laboratory and computational activities. *Multidisciplinary Journal for Education, Social and Technological Sciences, 3*(1), 118-132.

Sousa, C. (2016b). The Scientific Methods of Biology, Starting with Charles Darwin. *The American Biology Teacher, 78*(2), 109-117.

Sousa, C. (2016c). Inquiry learning for gender equity using History of Science in Life and Earth Sciences' learning environments. *Multidisciplinary Journal for Education, Social and Technological Sciences, 3*(1), 84-99.

Sousa, C. (2016d). Bridging Darwin's Origin of Species & Wegener's Origin of Continents and Oceans: Using Biogeography, Phylogeny, Geology & Interactive Learning. *The American Biology Teacher, 78*(1), 24-33.

Sousa, C. (2016e). *Biodiversidade, nicho ecológico e seres humanos. [Biodiversity, ecological niche and human beings].* Bubok.

Sousa, C. (2019). The potential of Problem-Based Learning to promote NOS understanding: using a History of Science enriched problem. In P. Lindholm (Ed.), *Understanding the Nature of Science* (pp. 109-138). New York, USA: NOVA Science Publishers.

Sousa, C., & Chagas, I. (2018). *Using Nature of Science enriched-PBL in pre-service science teacher education.* Paper presented at the New perspectives in science education 7th edition, Florence, Italy.

States, N. L. (2013). *Next generation science standards: For states, by states.* . Washington, DC: National Academies Press.

Strobel, J., & van Barneveld, A. (2009). When is PBL More Effective? A Meta-synthesis of Meta-analyses Comparing PBL to Conventional Classrooms. *Interdisciplinary Journal of Problem-based Learning, 3*(1), 44-58.

Sutherland, J. D. (2016). The Origin of Life — Out of the Blue. *Angewandte Chemie International Edition, 55*, 104 – 121.

Tashiro, T., Ishida, A., Hori, M., Igisu, M., Koike, M., Méjean, P., . . . Komiya, T. (2017). Early trace of life from 3.95 Ga sedimentary rocks in Labrador, Canada. *Nature, 549*, 516-518.

The Royal Society. (2018). Philosophical Transactions − the world's first science journal. Available at http://rstl.royalsocietypublishing.org.

Theobald, D. L. (2010). A formal test of the theory of universal common ancestry. *Nature, 465*, 219–222.

Thompson, J. N. (2010). Four Central Points About Coevolution. *Evolution: Education and Outreach, 3*, 7-13.

Thyveetil, M.-A., Coveney, P. V., Greenwell, H. C., & Suter, J. L. (2008). Computer Simulation Study of the Structural Stability and Materials Properties of DNA-Intercalated Layered Double Hydroxides. *Journal of American Chemical Society, 130*, 4742-4756.

Tidemand, S., & Nielsen, J. A. (2017). The role of socioscientific issues in biology teaching: from the perspective of teachers. *International Journal of Science Education, 39*(1), 44-61.

Tillman, D. (2004). Niche tradeoffs, neutrality, and community structure: A stochastic theory of resource competition, invasion, and community assembly. *Proceedings of the National Academy of Sciences of the United States of America, 101*(30), 10854-10861.

Torres, J., & Vasconcelos, C. (2016). Views of nature of science: adaptation of a questionnaire for Portuguese prospective science teachers. *Journal of Science Education, 2*(17), 48-52.

Travest, A., & Richardson, D. M. (2014). Mutualistic Interactions and Biological Invasions. *Annual Review of Ecology, Evolution, and Systematics, 45*, 89-113.

Triantis, K. A., & Bhagwat, S. A. (2011). Applied Island Biogeography. In R. J. Ladle & R. J. Whittaker (Eds.), *Conservation Biogeography*: Wiley-Blackwell.

Tsai, C.-C. (2006). Biological knowledge is more tentative than physics knowledge: Taiwan high school adolescents' views about the nature of biology and physics. *Adolescence, 41* (164), 691–703.

Tsai, C.-C. (2007). Teachers' Scientific Epistemological Views: The Coherence with Instruction and Students' Views. *Science Education, 91*, 222-243.

Tsai, C. C., & Liu, S. Y. (2005). Developing a Multi-dimensional Instrument for Assessing Students' Epistemological Views toward Science. *International Journal of Science Education, 27*(13), 1621-1638.

Turnbull, L. A., Isbell, F., Purves, D. W., Loreau, M., & Hector, A. (2016). Understanding the value of plant diversity for ecosystem functioning through niche theory. *Proceedings Royal Society B, 283*(1844), https://doi.org/10.1098/rspb.2016.0536.

Uno, G. E., & Bybee, R. W. (1994). Understanding the dimensions of biological literacy. *BioScience, 44*(8), 553-557.

Valladares, F., Bastias, C. C., Godoy, O., Granda, E., & Escudero, A. (2015). Species coexistence in a changing world. *Frontiers in Plant Science, 6*, https://doi.org/10.3389/fpls.2015.00866.

Van Kranendonk, M. J., Deamer, D. W., & Djokic, T. (2017). Life Springs. *Scientific American, 317*, 28-35.

Wacey, D., Noffke, N., Saunders, M., Guagliardo, P., & Pyle, D. M. (2018). Volcanogenic Pseudo-Fossils from the 3.48Ga Dresser Formation, Pilbara, Western Australia. *Astrobiology, 18*(5), 539-555.

Wang, J., Xu, Y., Liu, X., Xiong, W., Xie, J., & Zhao, J. (2016). Assessing the effectiveness of problem-based learning in physical diagnostics education in China: a meta-analysis. *Scientific Reports, 6*, 36279-36286.

Warfa, A.-R. M. (2016). Mixed-Methods Design in Biology Education Research: Approach and Uses. *CBE—Life Sciences Education, 15*(4), 1–11.

Weiss, M., Preiner, M., Xavier, J., Zimorski, V., & Martin, W. F. (2018). The last universal common ancestor between ancient Earth chemistry and the onset of genetics. *PLOS Genetics, 14*, e1007518.

Weiss, M. C., Sousa, F. L., Mrnjavac, N., Neukirchen, S., Roettger, M., Nelson-Sathi, S., & Martin, W. F. (2016). The physiology and habitat of the last universal common ancestor. *Nature Microbiology, 1*(9), 16116.

Wennekes, P. L., Rosindell, J., & Etienne, R. S. (2012). The Neutral-Niche Debate: A Philosophical Perspective. *Acta Biotheoretica, 60*(3), 257–271.

Wheeldon, J. (2010). Mapping Mixed Methods Research: Methods, Measures, and Meaning. *Journal of Mixed Methods Research, 4*, 87-102.

Wijnia, L., Loyens, S., & Rikers, R. (2019). The Problem-Based Learning Process: An Overview of Different Models. In M. Moallem, W. Hung, & N. Dabbagh (Eds.), *The Wiley Handbook of Problem-Based Learning*. New York, USA: John Wiley & Sons.

Wilder, S. (2015). Impact of problem-based learning on academic achievement in high school: a systematic review. *Educational Review, 67*(4), 414-435.

Williams, C., & Rudge, D. (2015). Mendel and the Nature of Science. *The American Biology Teacher, 77*(7), 492–499.

Williams, C. T., & Rudge, D. W. (2016). Emphasizing the History of Genetics in an Explicit and Reflective Approach to Teaching the Nature of Science: A Pilot Study. *Science & Education, 25*, 407–427.

Wilson, E. O. (2006). *The Creation: An Appeal to Save Life on Earth*. New York, NY, USA: W.W. Norton.

Wirkala, C., & Kuhn, D. (2011). Problem-Based Learning in K-12 Education: Is it Effective and How Does it Achieve its Effects? . *American Educational Research Journal, 48*(5), 1157-1186.

Woese, C. (1998). The universal ancestor. *Proceedings of the National Academy of Sciences of the United States of America, 95*(12), 6854–6859.

Woese, C. (2000). Interpreting the universal phylogenetic tree. *Proceedings of the National Academy of Sciences of the United States of America, 97*(15), 8392–8396.

Woese, C., & Fox, G. (1977). Phylogenetic structure of the prokaryotic domain: The primary kingdoms. *Proceedings of the National Academy of Sciences of the United States of America, 74*(11), 5088–5090.

Woese, C., Kandler, O., & Wheelis, M. (1990). Towards a natural system of organisms: proposal for the domains Archaea, Bacteria, and Eucarya. *Proceedings of the National Academy of Sciences of the United States of America, 87*(12), 4576-4579.

Wood, L. (2014). Scientific Literacy. In W. F. McComas (Ed.), *The language of science education* (pp. 92). Boston: Sense Publishers.

Xu, J., Green, N. J., Gibard, C., Krishnamurthy, R., & Sutherland, J. D. (2019). Prebiotic phosphorylation of 2-thiouridine provides either nucleotides or DNA building blocks via photoreduction. *Nature Chemistry, 11*, 457-462

Yip, D. Y. (2004). Questioning skills for conceptual change in science instruction. *Journal of Biological Education, 38*, 76-83.

Zeidler, D. L., Herman, B. C., & Sadler, T. D. (2019). New directions in socioscientific issues research. *Disciplinary and Interdisciplinary Science Education Research, 1*(11), https://doi.org/10.1186/s43031-43019-40008-43037.

Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education, 86*(3), 343-367.

Zimmermann, H., Brandt, P., Fischer, J., Welk, E., & von Wehrden, H. (2014). The Human Release Hypothesis for biological invasions: human activity as a determinant of the abundance of invasive plant species. *F1000Research, 3*, 109.

Zoric, J. (2017). Tara Djokic: From Skipping Classes To Finding The Oldest Traces Of Life On Earth. *Magazine Youth Time,* Available at https://bit.ly/2RZwTfK.

# Appendices

# Appendix 1



## Situação-problema Origem da vida e ancestral comum

Em Biologia e talvez em toda a Ciência não existe maior mistério do que a origem da vida[1].

Charles Darwin (1809-1882), em 1837, ao pensar nas semelhanças entre os seres vivos atuais que observou, propôs, de forma criativa, a teoria do ancestral comum a todos os seres vivos[2], segundo a qual todos os seres vivos são descendentes de uma espécie existente no passado distante. Esta sua teoria foi registada pela 1ª vez num dos seus cadernos numa figura em forma de árvore que representa o parentesco entre espécies - a árvore da vida (um modelo científico) - que representa as linhas evolutivas (ramos) que se extinguiram, enquanto outras linhas originaram as espécies atuais (A, B, C e D), indicando com o algarismo "1" o ancestral comum[2] (Fig. 1). Darwin incluiu esta sua teoria do ancestral comum no seu livro sobre Origem das Espécies, publicado em 1859: "Portanto, eu poderei inferir da analogia que provavelmente todos os seres orgânicos que já viveram nesta terra descenderam de uma forma primordial…"

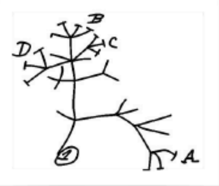

Fig. 1 – Modelo de árvore da vida (Darwin, 1837)[2].

Na época, em 1838-1839, Matthias Schleiden (1804–1881) e Theodor Schwann (1810–1882) proposeram a teoria celular[3] que explica que todos os seres vivos são compostos de células. As evidências desta teoria - semelhanças de todos os seres vivos a nível celular e molecular (ADN) - apoiam a teoria de Darwin do ancestral comum.

Em 1977, Carl Woese (1928-2012) usando novas tecnologias da Biologia Molecular encontrou evidências que confirmam a teoria de Darwin[4].

**Quando surgiu o ancestral comum?** Recentemente, em 2017, uma equipa de investigadores liderada por Tsuyoshi Komiya propôs que o ancestral comum a todos os seres vivos mais recente (também designado o último ancestral comum universal) teria surgido há pelo menos 3950 milhões de anos[5] (publicaram estes resultados na revista científica Nature).

**Então e o início? O que existia antes do ancestral comum mais recente?** Darwin também pensou sobre isto… Em 1871, Darwin, numa carta a outro cientista, Hooker, escreve uma hipótese, após leitura de experiências de Pasteur: "Mas, se (e que grande se) pudéssemos conceber que num pequeno e quente charco com amónia, sais fosfóricos, luz, calor, eletricidade e etc. se formasse quimicamente um composto proteico que estaria pronto para sofrer complexas alterações, no presente este composto seria ingerido ou absorvido, o que não seria o caso antes de existirem os seres vivos."[6] **E que teorias existiam antes de Darwin? O que diziam Aristóteles, Lamarck e Pasteur? Quais as suas evidências?**


Fig. 2 - Imagem representativa de ambiente de origem da vida[*].

**Que outras teorias foram propostas no século XX e no início do século XXI? Quais as teorias/hipóteses de Svante Arrhenius, Aleksandr Oparin, John Haldane, Stanley Miller, Louis Lerman, Helen Hansma e John Sutherland? Quais as evidências mais recentes destas teorias/hipóteses?**

**Que teorias foram sugeridas nos últimos 2 anos?**

Allen P. Nutman e colaboradores, em 2016, sugeriram a teoria da origem da vida em águas marinhas pouco profundas[7] (Fig. 3) através de publicação numa revista científica.

Fig. 3 - Fotografia de estromatólitos atuais*.

Fig. 4 – Fotografia de fonte hidrotermal atual*.

A teoria de origem da vida em fontes hidrotermais no fundo do oceano (Fig. 4) foi proposta pela investigadora Madeline Weiss e colaboradores[8] e também por outra equipa de investigadores constituída por Matthew Dodd[9] e colaboradores.

A teoria teoria da origem terrestre da vida em fontes termais terrestres junto a vulcões em pequenos charcos (Fig. 5) foi proposta pela equipa da investigadora Tara Djokic, em 2017.[10, 11, 12]

Fig. 5 – Imagem representativa de ambiente de origem da vida*.

**Qual a teoria/hipótese da origem da vida que consideram mais explicativa? E porquê? E foi ou poderá ser provada? Afinal o que é uma teoria?**

Em síntese, há grande diversidade de explicações sobre a origem da vida. Os diversos investigadores elaboram publicações teóricas, publicações com modelos computacionais ou simulações laboratoriais, realizam experiências com diversos reagentes em meio aquoso, fazem trabalho de campo incluindo visitas a locais semelhantes a possíveis locais de origem da vida e também incluindo visitas a locais onde se encontram fósseis do período de tempo de origem da vida[12].

**<u>Problema:</u> Como se carateriza o ancestral comum de todos os seres vivos?**

**Referências**

1. Harold, F. M. (2014). In Search of Cell History: The Evolution of Life's Building Blocks. Chicago, USA: The U. of Chicago Press.
2. Darwin, C. (1837–38). Notebook B [Transmutation of Species]. Darwin Online. Available at http://darwin-online.org.uk/content/frameset?itemID=CUL-DAR121.-&viewtype=side&pageseq=1.
3. https://www.the-scientist.com/foundations/sketching-out-cell-theory-circa-1837-38927
4. Woese, C. R. & Fox, G. E. (1977) Phylogenetic structure of the prokaryotic domain: The primary kingdoms. Proceedings of the National Academy of Sciences USA, 74, 5088–5090.
5. Tashiro, T., Ishida, A., Hori, M., Igisu, M., Koike, M., Méjean, P., Takahata, N., Sano, Y. & Komiya, T. (2017). Early trace of life from 3.95 Ga sedimentary rocks in Labrador, Canada. ***Nature, 549***, 516-518.
6. https://www.darwinproject.ac.uk/letter/DCP-LETT-7471.xml
7. Nutman, A. P., Bennett, V. C., Friend, C. R. L., Van Kranendonk, M. J. & Chivas, A. R. (2016). Rapid emergence of life shown by discovery of 3,700-million-year-old microbial structures. Nature, 537, 535-538.
8. Weiss, M. C., Sousa, F. L., Mrnjavac, N., Neukirchen, S., Roettger, M., Nelson-Sathi, S. & Martin, W. F. (2016). The physiology and habitat of the last universal common ancestor. Nature Microbiology, 1, 1-8.
9. Dodd, M. S., Papineau, D., Grenne, T., Slack, J. F., Rittner, M., Pirajno, F., O'Neil, J. & Little, C. T. S.. (2017). Evidence for early life in Earth's oldest hydrothermal vent precipitates. Nature, 543, 60-64.
10. Djokic, T., Van Kranendonk, M. J., Campbell, K. A., Walter, M. R. & Ward, C. R. (2017). Earliest signs of life on land preserved in ca. 3.5 Ga hot spring deposits. Nature Communications, 8. DOI:10.1038/ncomms15263.
11. Van Kranendonk, M. J., Deamer, D. W. & Djokic, T. (2017). Life Springs. Scientific American, 317, 28-35.
12. Damer, B. (2016). A Field Trip to the Archaean in Search of Darwin's Warm Little Pond. Life, 6, doi:10.3390/life6020021.

***Fonte das figuras:** Fig. 2. http://www.bbc.com/earth/story/20161026-the-secret-of-how-life-on-earth-began; Fig. 3. https://en.wikipedia.org/wiki/Stromatolite#/media/File:Stromatolites_in_Sharkbay.jpg; Fig. 4. http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/vents/welcome.html; Fig. 5. https://www.youtube.com/watch?v=6qiW4aUqtvA.

Appendix 2

**Situação-problema: Nicho ecológico e evolução**

A ideia de nicho ecológico foi apresentada pela primeira vez em 1859, por Charles Darwin, que na sua obra referiu "place in nature"[1], significando forma de vida ou papel no ecossistema de dada espécie. Nesta obra, Darwin estudou várias espécies, como os tentilhões das ilhas Galápagos (Fig. 1) e descreveu diferenças entre as espécies, nomeadamente no formato do bico, e observou que cada espécie tinha um tipo de alimento preferencial.

Fig. 1 – Tentilhões nas ilhas Galápagos (In https://onday6.wordpress.com/2011/12/26/13/).

Atualmente, o nicho ecológico é definido como a forma de vida ou o papel de uma dada espécie num ecossistema e inclui todos os aspetos relativos à sua sobrevivência e reprodução[2].

A teoria do nicho ecológico explica que espécies em competição ou evoluem no sentido de uma menor sobreposição do seu nicho ecológico, ou todas - excepto uma - sofrerão extinção[3]. Esta teoria não é consensual apesar de já ter 100 anos. Foi sugerida por Joseph Grinnell (1877-1939), em 1917, que estudou 3 subespécies de aves da Califórnia, ***Toxostoma redivivum***, e descreveu que cada uma tinha o seu nicho. Concluiu que duas espécies não podem ocupar o mesmo nicho[4].

Várias espécies de animais e plantas que existem em Portugal na atualidade foram trazidas, pelo ser humano, de outras áreas geográficas e por isso são denominadas espécies exóticas. Algumas plantas exóticas que existem no nosso país são classificadas como invasoras, tais como: o eucalipto, a acácia, a austrália e o chorão-da-praia. Algumas têm potencial invasor como a hortense.

Há ecossistemas em Portugal que estão em perigo devido à introdução de plantas invasoras. Sabe-se que manutenção de dada espécie num ecossistema ao longo do tempo é devido à capacidade de produzir descendentes como Darwin sugeriu na sua teoria de evolução por seleção natural[1].

Uma das espécies invasoras atualmente nas regiões mediterrânicas, na Austrália e na Califórnia (nos E.U.A.) é o chorão-da-praia (Fig. 2), com o nome científico ***Carpobrotus edulis***. É uma espécie nativa da África do Sul e reproduz-se por semente ou vegetativamente a partir de caules cortados[5].

Fig. 2 - Chorão-da-praia, ***Carpobrotus edulis***, (cc BY-NC Jonh Peter Moyles III, ***In:*** http://www.eol.org/ pages/ 588586/overview).

O chorão-da-praia interage com as plantas nativas de ecossistemas costeiros, nomeadamente das dunas, como o goiveiro-da-praia (Fig. 3).

Fig. 3 - Goiveiro-da-praia, ***Malcolmia littorea*** (in: http://flora-on.pt/#/1malcolmia+littorea).

Os ecossistemas naturais contribuem para a regulação da biosfera, o que é benéfico para os seres humanos através do que se designa serviços dos ecossistemas[6], tais como: fornecer água e ar limpos e regular o clima. Por isso, os ecossistemas têm valor económico e a perda de uma dada espécie pode diminuir esse valor[3]. Na Europa há estimativas dos custos anuais devido a invasões biológicas de ecossistemas de pelo menos 12,7 mil milhões de euros, pelo que os estudos sobre espécies invasoras, tais como formas de eliminar essas espécies e de recuperação das áreas invadidas são considerados linhas de investigação importantes e promissoras[7]. Hoje em dia há grupos internacionais de cientistas em que participam oriundos de países com problemas devido a espécies invasoras. Os seus projetos de investigação incluem trabalhos de campo e de laboratório, para melhor explicar qual o papel das espécies invasoras na distribuição geográfica das espécies nativas.

Cientistas estudaram a composição físico-química das areias nos locais invadidos pelo chorão-da-praia e publicaram em artigo científico a comparação dos valores obtidos em áreas invadidas e não invadidas[7] (Tabela 1).

Tabela 1 – Propriedades físico-químicas da areia da duna invadida ou não-invadida por chorão-da-praia

| | Areia de local invadido | Areia de local não-invadido |
|---|---|---|
| pH | 6.99 (0.16) | 9.15 (0.05) |
| Salinidade (mgNaCl$g^{-1}$) | 0.75 (0.03) | 0.52 (0.04) |
| Matéria orgânica (g $kg^{-1}$) | 6.32 (0.35) | 3.02 (0.21) |

Valores apresentados: média (erro padrão). Fonte: artigo científico por Novoa e colaboradores (2013)[7].

Este grupo de cientistas[7] também realizou uma experiência com sementes de goiveiro-da-praia de forma a estudar se há algum efeito na germinação (Fig. 4).

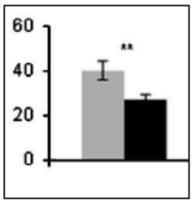


Fig. 4 – Gráfico que compara a germinação de sementes (%) de goiveiro-da-praia em locais invadidos (barra negra) e não-invadidos (barra cinza) pelo chorão-da-praia[7].

Nos ecossistemas onde ocorre a ***Malcolmia littorea*** existem outras espécies nativas que ocupam a mesma área geográfica.

Segundo alguns cientistas o chorão-da-praia representa uma das maiores ameaças à biodiversidade costeira em regiões com clima mediterrânico a nível mundial[7]. **Que solução propõem para evitar a extinção de espécies nativas como o goiveiro-da-praia?**

***Fontes de informação a consultar:***
- Guia prático para a Identificação de Plantas Invasoras em Portugal,
- Website Invasoras, in: http://invasoras.pt,
- Website Flora-On, in: http://flora-on.pt/#b,
- Google Earth Pro (com camadas de distribuição geográfica em Portugal das espécies).

Referências:
1. Darwin, C. (1859). ***On the Origin of Species.*** [Reprint edition, 1985. London, UK: Penguin Classics.]
2. Miller, G. T. (2007). Essentials of Ecology. Thomson Learning Inc, Canada.
3. Turnbull, L. A., Isbell, F., Purves, D. W., Loreau, M. & Hector, A. (2016). Understanding the value of plant diversity for ecosystem functioning through niche theory. ***Proc. R. Soc. B, 283,*** 20160536.
4. Grinnell, J. (1917). The Niche-Relationships of the California Thrasher. ***The Auk, 34(4),*** 427-433.
5. Carpobrotus edulis ***in*** http://www.eol.org/pages/588586/details.
6. Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.
7. Novoa, A., González, L., Moravcova, L. & Pysek, P. (2013). Constraints to native plant species establishment in coastal dune communities invaded by Carpobrotus edulis: Implications for restoration. ***Biological Conservation,164,*** 1-9.

# Appendix 3

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## Situação-problema Biogeografia insular

Os cientistas Robert H. MacArthur (1930-1972) e Edward O. Wilson (1929-) observaram o número de espécies de aves presentes em algumas ilhas do Pacífico e relacionaram este número com a área da ilha onde essas espécies se encontram[1]. Em 1963, publicaram estas suas evidências numa revista científica (Evolution), incluindo o seu modelo sobre o equilíbrio dinâmico entre o número de espécies de aves que imigram para uma dada ilha e o número de espécies de aves que se extinguem nessa ilha (Fig. 1) [1].

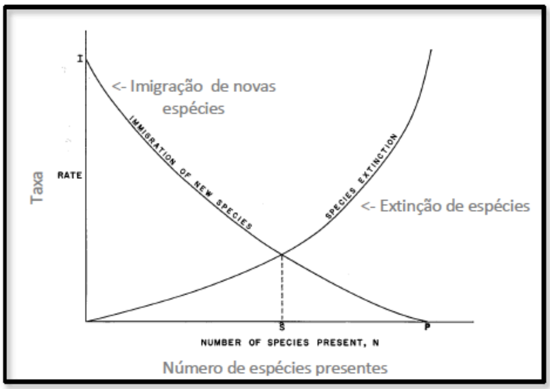


Fig. 1 – Modelo de MacArthur-Wilson (1963) de equilíbrio da fauna de uma dada ilha [1].

A explicação alternativa que existia antes desta nova proposta por MacArthur & Wilson era a de Ernst Mayr, publicada em 1940, que referia que o número de espécies em dada ilha remota, ao longo do tempo, aumentaria até valores idênticos ao número de espécies em ilhas mais próximas do continente[1]. Um modelo semelhante ao de MacArthur-Wilson foi sugerido em simultâneo por F. W. Preston[2].

Em 1967, MacArthur & Wilson expandiram as suas ideias a todas as ilhas e a todas as espécies propondo a teoria sobre o equilíbrio da biodiversidade em ilhas no seu livro intitulado "The Theory of Island Biogeography"[2]. Segundo MacArthur & Wilson uma "boa teoria aponta para possíveis fatores e relações no mundo real que, de outra forma, permaneceriam ocultos e, assim, estimula novas formas de investigação." (MacArthur & Wilson, 1967, p5).

Edward O. Wilson e o seu aluno Daniel S. Simberloff (1942-) testaram esta teoria, em 1969, no sul da Flórida, em pequenas ilhas de manguezal, fumigando a área, com um pesticida, de forma a eliminar todos os artrópodes, sem afetar a vegetação, e depois estudando a diversidade de artrópodes ao longo dos anos[3].

Atualmente fazem-se estudos sobre as sucessões ecológicas usando ilhas vulcânicas recém-formadas, como por exemplo em Surtsey[4,5] e também outras áreas geográficas, por exemplo áreas florestais que sofreram incêndios.

A teoria da biogeografia das ilhas tem aplicação relativamente a vários problemas ambientais, por exemplo a fragmentação de habitats e a constituição de áreas protegidas[6].

O estudo da biodiversidade de ilhas foi também realizado por Charles Darwin (1809-1882) sendo as suas observações no Arquipélago de Galápagos fundamentais para a sua teoria da evolução por seleção natural. Darwin escreveu no seu livro de notas[7] sobre os tentilhões que aí observou: "Quando vejo estas ilhas à vista uma da outra, e possuindo apenas um stock escasso de animais, ocupadas por estas aves, mas ligeiramente diferentes em estrutura e preenchendo o mesmo lugar na Natureza, devo suspeitar que são apenas variedades. [...] Se houver o menor fundamento para estas observações, valerá a pena examinar a zoologia dos Arquipélagos; pois tais factos enfraqueceriam a estabilidade das Espécies."

**Problema: Quais os fatores que influenciam a colonização e a biodiversidade observada numa ilha? E como as influenciam?** *(use a simulação computacional* e desenhe as linhas correspondentes a taxas de imigração e extinção de espécies para cada fator na Fig. 1)* **Simulação computacional in:*
http://virtualbiologylab.org/NetWebHTML_FilesJan2016/IslandBiogeographyModel.html

Cristina Sousa & Isabel Chagas (FCUP, 03/10/2018) 1

**Referências:**

1) MacArthur, R. H. & Wilson, E. O. (1963). An equilibium theory of insular zoogeography. Evolution, 17, 373-387.

2) MacArthur, R. H. & Wilson, E. O. (1967). ***The Theory of Island Biogeography***. Princeton, N.J.: Princeton University Press. 203 pp.

3) Simberloff, D. & Wilson, E. O. (1969). Experimental Zoogeography of islands - colonization of empty islands. Ecology. 50 (2): 278–296.

4) https://whc.unesco.org/en/list/1267

5) del Moral, R. & Magnússon, B. (2014). Surtsey and Mount St. Helens: a comparison of early succession rates. Biogeosciences, 11, 2099–2111.

6) Brown, J. H. & Lomolino, M. V. (2000). Concluding remarks: historical perspective and the future of island biogeography theory. Global Ecology & Biogeography, 9, 87–92.

7) http://darwin-online.org.uk/content/frameset?itemID=F1840&viewtype=text&pageseq=1

8) http://bio1100.nicerweb.com/Locked/media/ch10/speciation-allopatric.html.

**Informações complementares:**

- O modelo MacArthur-Wilson permite prever o número de espécies de aves de determinada ilha, sendo necessário desenhar estas curvas (da Fig. 1) relativas à ilha e verificar onde se intersetam[1]. Este modelo considera alguns factores como a área e a distância ao continente da ilha no equilíbrio da biodiversidade, sendo diferente para grupos de espécies (taxa) e ilhas diferentes[1] e segundo os seus autores só se aplica a espécies de aves de ilhas do Pacífico.
- A teoria da biogeografia insular explica a distribuição geográfica das espécies em ilhas, incluindo ilhas oceânicas e áreas geográficas mais ou menos uniformes diferentes do seu redor (por exemplo uma gruta e um rio), e os vários factores que a influenciam tais como: a imigração, a extinção, a especiação e as interações ecológicas entre as espécies residentes e as colonizadoras[2].
- Darwin considerou que uma espécie de tentilhões existente no continente se dispersou para o Arquipélago de Galápagos e em cada ilha encontrou diferentes alimentos disponíveis (Fig. 2 e animação computacional sobre como ocorre a evolução em ilhas em https://vimeo.com/22037192).


Fig. 2 – Tentilhões no Arquipélago de Galápagos[8]

Appendix 4

Questionário pré-validação

## Questionário Compreensão dos alunos sobre a Natureza da Ciência

Ao preencheres este questionário estás a contribuir para um estudo sobre a opinião dos alunos sobre aspetos diversos relacionados com a Ciência. Não há respostas certas ou erradas. Estamos interessadas em saber a tua opinião sobre cada uma das afirmações. A confidencialidade dos dados encontra-se assegurada. Solicitamos a maior sinceridade no seu preenchimento. Agradecemos a tua colaboração.

**Parte A – Dados pessoais**

Preenche os espaços com os teus dados e coloca uma cruz (X) onde seja adequado.

Idade: ____ anos Sexo: F ___ M ___ Data de preenchimento: ___ /____ /______

Última classificação na disciplina de Ciências Naturais: 1___ 2___ 3____ 4____ 5____

Qual a tua disciplina favorita? ________________________________.

**Parte B – Afirmações**

Assinala com uma cruz (X) de forma a indicares a tua opinião sobre cada uma das afirmações (1 a 36) de acordo com a seguinte escala: discordo totalmente, discordo, não tenho a certeza, concordo, concordo totalmente.

| | Discordo totalmente | Discordo | Não tenho a certeza | Concordo | Concordo totalmente |
|---|---|---|---|---|---|
| 1. As teorias científicas existem no mundo natural e são descobertas através das investigações científicas. | | | | | |
| 2. Ao contrário das teorias, as leis científicas não mudam. | | | | | |
| 3. As leis científicas são teorias que foram comprovadas. | | | | | |
| 4. Os factos científicos são teorias que foram comprovadas. | | | | | |
| 5. As observações do mesmo evento, realizadas por diferentes cientistas, podem ser diferentes, porque o que os cientistas já sabem pode afetar as suas observações. | | | | | |
| 6. As observações do mesmo evento, realizadas por diferentes cientistas, são sempre iguais porque as observações são factos. | | | | | |
| 7. As observações do mesmo evento, realizadas por diferentes cientistas, são sempre iguais porque os cientistas são objetivos. | | | | | |
| 8. Os cientistas podem realizar observações totalmente objetivas, que não são influenciadas por outros fatores. | | | | | |
| 9. As atividades de investigação dos cientistas são afetadas pelas suas teorias. | | | | | |

Cristina Sousa & Isabel Chagas (27/04/2017) 1 (de 3)

| | | | | | |
|---|---|---|---|---|---|
| 10. As teorias científicas que os cientistas aceitam não interferem no desenvolvimento do conhecimento científico. | | | | | |
| 11. A investigação científica não é influenciada pela sociedade nem pela cultura porque os cientistas são treinados a realizar estudos "puros" e imparciais. | | | | | |
| 12. A sociedade e a cultura determinam *qual* a ciência que é realizada e aceite. | | | | | |
| 13. A sociedade e a cultura determinam *como* a Ciência é realizada e aceite. | | | | | |
| 14. A investigação científica em todo o o mundo é realizada da mesma forma, porque a Ciência é universal e independente da sociedade e da cultura. | | | | | |
| 15. Os cientistas usam a sua imaginação e criatividade para recolherem dados. | | | | | |
| 16. Os cientistas usam a sua imaginação e criatividade quando analisam e interpretam os dados. | | | | | |
| 17. Os cientistas não usam a sua imaginação e criatividade porque isso contraria o seu raciocínio lógico. | | | | | |
| 18. Os cientistas não usam a sua imaginação e criatividade porque podem interferir com a objetividade. | | | | | |
| 19. O desenvolvimento do conhecimento científico envolve frequentemente a mudança de conceitos. | | | | | |
| 20. O conhecimento científico atual fornece explicações provisórias para os fenómenos naturais. | | | | | |
| 21. O conhecimento científico atual pode ser alterado ou totalmente rejeitado no futuro. | | | | | |
| 22. Os cientistas, em diferentes épocas, podem usar teorias e métodos diferentes para interpretar o mesmo fenómeno natural. | | | | | |
| 23. Os cientistas usam diferentes métodos para realizarem investigações científicas. | | | | | |
| 24. Os cientistas seguem o mesmo método passo-a-passo. | | | | | |
| 25. Quando os cientistas usam o método científico corretamente, os seus resultados são verdadeiros e precisos. | | | | | |
| 26. As experiências científicas não são o único recurso para o desenvolvimento do conhecimento científico. | | | | | |
| 27. Todas as investigações científicas começam com uma questão. | | | | | |
| 28. As investigações científicas não testam necessariamente uma hipótese. | | | | | |
| 29. A Ciência é uma forma de conhecimento que fornece explicações baseadas em evidências. | | | | | |
| 30. As crenças religiosas são uma forma de conhecimento que a Ciência não consegue explicar. | | | | | |
| 31. Um pressuposto em que as investigações científicas se baseiam é que o mundo natural é compreensível. | | | | | |
| 32. A Ciência é uma forma de procura de respostas a questões sobre fenómenos naturais. | | | | | |
| 33. A argumentação científica usa evidências científicas. | | | | | |

Questionário pré-validação

| | | | | | |
|---|---|---|---|---|---|
| 34. Uma das atividades da investigação científica é a comunicação com outros cientistas. | | | | | |
| 35. O conhecimento científico é publicado em revistas científicas depois de ser revisto e aceite por outros cientistas. | | | | | |
| 36. O conhecimento científico torna-se credível através do reconhecimento por outros cientistas da área. | | | | | |

Agradecemos a tua colaboração!

# Appendix 5

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## Avaliação do processo de aprendizagem

O preenchimento desta grelha de observação enquadra-se num estudo de doutoramento da investigadora/professora Cristina Sousa da FCUP sobre a aprendizagem de aspetos de Natureza da Ciência contextualizada em temas da área da Biologia. Os dados obtidos com este instrumento serão apenas usados no contexto do referido estudo e está assegurada a confidencialidade. Agradecemos a sua colaboração!

Classifique as afirmações de acordo com a seguinte escala:
1 – nunca, 2 – raramente, 3 – às vezes, 4 – frequentemente, 5 – sempre

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| A professora colocou questões pertinentes. | | | | | |
| A professora incentivou-nos a usarmos conhecimentos prévios. | | | | | |
| A professora deu-nos pistas, não respondendo diretamente às questões colocadas. | | | | | |
| A professora promoveu o questionamento pelos alunos em cada grupo. | | | | | |
| A professora incentivou-nos a expressar as nossas ideias de forma clara. | | | | | |
| A professora questionou-nos sobre o raciocínio seguido para chegar à solução. | | | | | |
| A situação-problema que nos foi apresentada admitia várias soluções. | | | | | |
| A situação-problema que nos foi apresentada estava em linguagem compreensível. | | | | | |
| A situação-problema construída que nos foi apresentada é interessante e motivadora de aprendizagens. | | | | | |
| Os recursos disponibilizados para a pesquisa eram adequados. | | | | | |
| Participei no trabalho de grupo. | | | | | |
| Quando tive dúvidas consultei colega(s) do grupo primeiro e só depois a professora. | | | | | |
| Recolhi e selecionei informação relevante para o trabalho. | | | | | |
| Coloquei questões-problema pertinentes. | | | | | |
| Respondi às questões-problema que coloquei. | | | | | |
| Discuti com os colegas do grupo respeitando as suas ideias diferentes. | | | | | |
| Desempenhei um papel importante na minha própria aprendizagem definindo os objetivos da minha aprendizagem. | | | | | |
| Justifiquei as minhas opiniões com recurso a argumentos científicos. | | | | | |
| Consegui propor uma solução para a situação-problema. | | | | | |

Agradecemos a sua colaboração!

Outras observações relevantes: ____________________________________________
______________________________________________________________
______________________________________________________________

Cristina Sousa & Isabel Chagas (FCUP, 02/10/2018)

# Appendix 6

*Nº estudante:* ____________ *Data:* ___/10/2018

## Questionário

## Compreensão sobre Natureza da Ciência e assuntos sociocientíficos e controversos

O preenchimento deste questionário enquadra-se num estudo de doutoramento da investigadora/professora Cristina Sousa da FCUP sobre a aprendizagem de aspetos de Natureza da Ciência contextualizada em temas da área da Biologia. Os dados obtidos com este instrumento serão apenas usados no contexto do referido estudo e está assegurada a confidencialidade.

Agradecemos a sua colaboração!

**I - Dados pessoais**

Idade: _____ anos

Género: ___ feminino ___ masculino

Formação académica: ________________________________________________

**II – Questões sobre Natureza da Ciência**

**1.** As teorias científicas são explicações sobre uma ampla variedade de fenómenos relacionados entre si e que já foram sujeitas a testagem. Concorda com a afirmação?________ Justifique. _____________
_______________________________________________________________________________
______________________________________________________________________________.

**2.** Como se iniciam todas as investigações científicas: colocando uma questão ou testando uma hipótese? __________________. Justifique. ___________________________________________
_______________________________________________________________________________
______________________________________________________________________________.

**3.** Concorda com a afirmação: "Os cientistas, em diferentes épocas, podem usar teorias e métodos diferentes para interpretar o mesmo fenómeno natural." _____________. Justifique. _____________
_______________________________________________________________________________
_______________________________________________________________________________
______________________________________________________________________________.

**4.** Concorda com a afirmação "A investigação científica em Biologia em todo o mundo é realizada da mesma forma, porque a Biologia é universal e independente da sociedade e da cultura"? _____________. Justifique. ____________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
______________________________________________________________________________.

**5.** Comente a seguinte afirmação: "A investigação científica não é influenciada pela sociedade nem pela cultura porque os cientistas são treinados para realizar estudos imparciais." _____________
_______________________________________________________________________________
_______________________________________________________________________________
______________________________________________________________________________.

**6.** Concorda com a afirmação: " A ciência é uma forma de conhecimento que fornece explicações baseadas em evidências."? ________________. Justifique. ________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

**7.** Concorda com a afirmação: "O conhecimento científico torna-se credível através do reconhecimento por outros cientistas da área."? ________________. Justifique, explicando como se processa o reconhecimento. ____________________________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

**8.** Concorda com a afirmação: "As teorias científicas podem ser testadas, mas não podem ser provadas.". ___________________. Justifique._____________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

**9.** Concorda com a seguinte afirmação: "Quando os cientistas usam o método científico corretamente, os seus resultados são verdadeiros e precisos."? ___________________.Justifique. ._______________
______________________________________________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

**III – Questões sobre assuntos científicos controversos e sociocientíficos**

**1.** Quais os assuntos científicos que considera controversos? Distinga aqueles:

**a)** em que a sociedade nega a ciência: ______________________________________________________
____________________________________________________________________________
____________________________________________________________________________,

**b)** que são controversos dentro da comunidade científica: _____________________________________
____________________________________________________________________________
____________________________________________________________________________,

**c)** sociocientíficos:______________________________________________________________________
____________________________________________________________________________
____________________________________________________________________________.

**2.** Quais destes assuntos (referidos na sua resposta à questão 1) considera que devem ser incluídos no Ensino Básico e Secundário? _______________________________________________________________.
Quais considera serem as vantagens da sua inclusão? __________________________________________
______________________________________________________________________________
____________________________________________________________________________.

**3.** Quais destes assuntos (referidos na sua resposta à questão 1) terá mais dificuldade de ensinar? __________________________________________________________________________ Justifique.______
______________________________________________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

# Appendix 7

*Nº estudante:* ________________ *Data:* ___/10/2018

A elaboração deste mapa de conceitos enquadra-se num estudo de doutoramento da investigadora/professora Cristina Sousa da FCUP sobre a aprendizagem de aspetos de Natureza da Ciência contextualizada em temas da área da Biologia. Os dados obtidos com este instrumento serão apenas usados no contexto do referido estudo e está assegurada a confidencialidade.

Agradecemos a sua colaboração!

## Mapa de conceitos *O que é a Ciência?*

***Inclua pelo menos os seguintes conceitos***: 1) teoria, 2) hipótese, 3) experiências, 4) observações, 5) inferências, 6) lei, 7) corpo de conhecimentos, 8) mutáveis, 9) comunicação entre cientistas, 10) explicações de fenómenos naturais, 11) imaginação e criatividade, 12) cientistas, 13) forma de conhecimento sobre o mundo natural, 14) mundo natural é compreensível, 15) investigações científicas, 16) sociedade, 17) cultura, 18) trabalho de campo, 19) teorias que aceitam, 20) modelos computacionais, 21) questão, 22) hipótese, 23) vários métodos científicos, 24) ciência, 25) podem ser alteradas ou rejeitadas no futuro.

Cristina Sousa & Isabel Chagas (01/10/2018)

Appendix 8

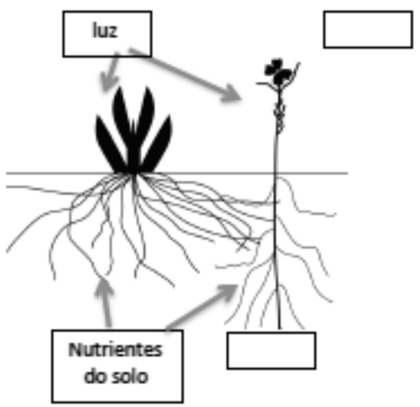
**FICHA DE TRABALHO DE GRUPO - Nicho ecológico e evolução**

**Grupo: ________ Nº: ________________________**

**Problema: Que solução propõem para evitar a extinção de espécies nativas como o goiveiro-da-praia?**

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| – Darwin referiu o nicho como forma de vida ou papel no ecossistema.<br>- Atualmente o nicho ecológico é definido como a forma de vida ou o papel de uma dada espécie num ecossistema e inclui todos os aspetos relativos à sua sobrevivência e reprodução.<br>- A teoria do ____________________ foi proposta em 1917 por Grinnell. | - O que é o nicho ecológico?<br>- Qual a teoria do nicho ecológico?<br>- O que é uma teoria? | - As várias espécies de tentilhões têm nichos diferentes.<br>- A teoria do nicho ecológico explica que ____________<br>____________________<br>- Uma teoria é uma ____________________ sobre uma variedade de fenómenos relacionados entre si e que já foi sujeita a testagem. |
| - Uma espécie exótica é uma espécie introduzida pelo ser humano em local diferente de onde é originária.<br>- Uma espécie invasora é ____________________<br>____________________. | - ____________________?<br>- O que é uma espécie invasora?<br>(Dica: pesquisa em Guia Prático). | - Uma das formas de perturbação do equilíbrio dos ecossistemas, que alguns cientistas consideram ser uma catástrofe de origem antrópica, é ____________<br>____________________. |
| - A manutenção de dada espécie num ecossistema ao longo do tempo é devido à ____________________<br>____________________.<br>- O chorão-da-praia ____________________<br>____________________<br>____________________. | - Qual a relação entre a teoria da evolução por seleção natural e ____________________<br>____________________?<br>- Quais as características do chorão-da-praia que o tornam uma espécie invasora?<br>(Dica: pesquisa em http://invasoras.pt) | - Uma espécie invasora produz mais/menos descendentes que as espécies nativas e por isso ao longo do tempo vai aumentando/diminuindo a proporção dos seus indivíduos no ecossistema. *(risca o que não interessa)* |
| - Há iniciativas de participação pública na ciência, por exemplo a identificação de locais onde existem espécies invasoras (no website http://invasoras.pt), em que estas observações são depois confirmadas por ____________________. | - O que é a Ciência-cidadã? | - Como cidadãos podemos participar na ____________________ dos ecossistemas fazendo observações de espécies invasoras e depois em ações de voluntariado organizadas por especialistas. |

Cristina Sousa & Isabel Chagas (FCUP, 03/01/2018) 1

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| - Ambas as espécies são produtores no ecossistema.<br><br><br>Fig. – Esquema de interações entre espécies e o ambiente, adapt.* (Dica: completem com fatores abióticos e setas).<br>- O intervalo de valores de distância à costa e altitude onde ocorre o goiveiro-da-praia ____________________.<br>- A temperatura mínima ____________________.<br>- O intervalo de valores de precipitação onde ocorre o goiveiro-da-praia ____________________. | - Qual a função de cada espécie no ecosssitema?<br>- ____________________?<br>- ____________________?<br>(Dica: pesquisem *Quais os locais onde ocorrem ambas as espécies? Quais os locais de menor risco para o goiveiro-da-praia?* - usando o Google Earth que permite identificar os locais onde existe apenas o goiveiro e locais onde ocorrem ambas as espécies e também; *Quais as características dos locais onde ocorrem?* - usando o Explorador bioclimático, disponível em http://flora-on.pt/ - b). | - A ____________________ que ocorre entre o chorão-da-praia e o goiveiro-da-praia é ____________ porque ____________________.<br>- Os locais de menor risco para o goiveiro-da-praia são aqueles onde este ocorre sem/com a presença do chorão-da-praia, por exemplo ____________________.<br>- Conclusão: O nicho do chorão-da-praia é semelhante/diferente ao/do nicho do goiveiro-da-praia. |
| - Os serviços dos ecossistemas podem ser classificados como: de regulação (por exemplo regulação do clima), de suporte (por exemplo circulação de nutrientes), de produção (por exemplo ____________________) e culturais (por exemplo lazer, ciência e educação). | - ____________________? | - Serviços dos ecossistemas são funções dos ecossistemas que são benéficas para ____________.<br>- O valor de dado ecossistema pode ser quantificado se contabilizados os serviços do ecossistema fornecidos. Por isso a perda de uma dada espécie diminui/aumenta o valor do ecossistema. |

Cristina Sousa & Isabel Chagas (FCUP, 03/01/2018) 2

U.PORTO FACULDADE DE CIÊNCIAS UNIVERSIDADE DO PORTO

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| - ________________ elevados ________________<br>- ________________<br>-<br><br>- Tipos de investigação a serem realizados: ________ e ________ para explicar o papel do chorão-da-praia na distribuição geográfica do goiveiro-da-praia.<br><br>- Alguns cientistas estudaram a composição físico-química das areias nos locais invadidos pelo chorão-da-praia e publicaram em artigo científico a comparação dos valores obtidos em áreas invadidas e não invadidas.<br>- A presença do chorão-da-praia está associada a aumento/diminuição do pH do solo (acidificação), aumento/diminuição da salinidade e a aumento/diminuição de matéria orgânica.<br>- Cada resultado apresentado é a média de várias ________.<br>- A presença de chorão-da-praia reduz/aumenta a germinação de sementes de goiveiro-da-praia. | - Porque motivo os estudos de espécies invasoras são________________<br>- ________________<br>________________?<br><br>- ________________<br>________________?<br><br>- ________________<br>________________?<br><br>- Qual a questão científica que começou esta investigação?<br><br>- Como são apresentados os resultados?<br><br>- ________________<br>________________-?<br> | - A seleção de temas a serem estudados é realizada pelos cientistas, mas também pela ________, uma vez que há atribuição de financiamento preferencialmente a problemas que afetam os cidadãos.<br>- A investigação científica em Biologia pode ser realizada de diversas formas, dependendo do objetivo do estudo a fazer, podendo ser trabalho de campo ou experiência científica.<br><br>- A publicação em artigo científico é uma forma de ________________.<br><br>- Qualquer investigação em Biologia inicia-se com________________ _ e neste estudo ________________ ________________.<br><br>- O chorão-da-praia ao reduzir/aumentar a germinação de sementes do goiveiro-da-praia pode provocar a sua ________. |
| - Os ecossistemas dunares, e outros, são compostos por diferentes espécies que coexistem.<br>- As espécies que ocorrem no mesmo ecossistema geralmente têm nichos ecológicos diferentes/iguais.<br><br>- Algumas espécies poderão ter ________________, por exemplo dada espécie de planta e o inseto seu polinizado. | - Como se explica a ________________ ________________? | - Duas espécies que coexistem poderão ter evoluído por seleção natural de forma a dividirem/não dividirem os recursos disponíveis no ecossistema.<br>- Entre espécies no mesmo ecossistema, ocorrendo competição interespecífica esta poderá ser igual/maior/menor ou igual/maior/menor que a competição intraespecífica.<br>- A evolução por seleção natural poderá ter selecionado relações bióticas que ________________ |

Cristina Sousa & Isabel Chagas (FCUP, 03/01/2018) 3

**PROBLEMA: Que solução propõem para evitar a extinção de espécies nativas como o goiveiro-da-praia?**

| **Proposta final de solução:** |
|---|
| |

Fontes de informação a consultar:
- Guia prático para a Identificação de Plantas Invasoras em Portugal,
- Website Invasoras, in: http://invasoras.pt,
- Website Flora-On, in: http://flora-on.pt/#b,
- Google Earth Pro (com camadas de distribuição geográfica em Portugal das espécies Malcolmia littorea e Carpobrotus edulis, obtidas em http://flora-on.pt/ - b) com download gratuito em https://www.google.com/earth/download/gep/agree.html).

Referências:

- Darwin, C. (1859). *On the Origin of Species*. [Reprint edition, 1985. London, UK: Penguin Classics.]
- Miller, G. T. (2007). Essentials of Ecology. Thomson Learning Inc., Canada.
- Turnbull, L. A., Isbell, F., Purves, D. W., Loreau, M. & Hector, A. (2016). Understanding the value of plant diversity for ecosystem functioning through niche theory. *Proc. R. Soc. B, 283*, 20160536.
- Grinnell, J. (1917). The Niche-Relationships of the California Thrasher. *The Auk, 34(4)*, 427-433.
- Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.
- Novoa, A., González, L., Moravcova, L. & Pysek, P. (2013). Constraints to native plant species establishment in coastal dune communities invaded by Carpobrotus edulis: Implications for restoration. *Biological Conservation,164*, 1-9.
- *Novoa Perez, A. (2012). Carpobrotus edulis (L.) N.E.Br: a threat to the conservation of coastal dune ecosystems. Tese de doutoramento. Universidade de Vigo.
- http://www.eol.org/pages/588586/details
- http://invasoras.pt
- http://flora-on.pt/#b.

# Appendix 9

**Questionário de desempenho dos alunos em Biologia e em Natureza da Ciência**

Este questionário enquadra-se num estudo de doutoramento da investigadora/ professora Cristina Sousa da FCUP sobre a aprendizagem da Natureza da Ciência no contexto da Biologia. Estamos interessadas em saber a sua opinião sobre cada uma das afirmações. Os dados obtidos serão apenas usados no contexto do referido estudo e está assegurada a confidencialidade. Agradecemos a sua colaboração.

Nº: ________ Data: ____/_____/2018

**1.** Qual a idade do fóssil mais antigo que conhece? Selecione (com uma X) abaixo a opção que considera correta.

- ☐ 3 800 milhões de anos,
- ☐ 400 milhões de anos,
- ☐ 4 milhões de anos.

**2.** As teorias científicas são explicações sobre uma ampla variedade de fenómenos relacionados entre si e que já foram sujeitas a testagem. Concorda com a afirmação? ___________. Justifique. ____________________________________________________________
______________________________________________________________________________
______________________________________________________________________________.

**3.** Charles Darwin é considerado o pai da Biologia. Indique o nome de uma das suas teorias. ______________________________________________________________________.

**4.** Algumas teorias da origem da vida referem a produção de compostos orgânicos a partir de moléculas químicas mais simples que existiriam na atmosfera terrestre. Relaciona qual (quais) a(s) fonte(s) de energia primitiva que existiria(m) na atmosfera terrestre primitiva com esta produção de compostos orgânicos? _____________________
______________________________________________________________________________.

**5.** As leis e as teorias são importantes aspetos da Biologia. Selecione (com uma X) abaixo a opção que considera correta.

- ☐ as leis da Biologia são mais importantes que as teorias da Biologia,
- ☐ as leis da Biologia são teorias da Biologia que foram comprovadas,
- ☐ uma das leis da Biologia é que todas as propriedades conhecidas da vida obedecem às leis da física e da química.

**6.** Pesquisar evidências científicas sobre determinado assunto é uma parte importante na tomada de decisões sobre assuntos científicos na sala de aula e também no dia-a-dia. Concorda com a afirmação? _________ Justifique. ___________________________________
_______________________________________________________________________________
_______________________________________________________________________________.

**7.** Todos os seres vivos na Terra estão relacionados entre si porque partilham um ancestral comum que existiu há milhares de milhões de anos. Concorda com a afirmação? _________. Justifique. __________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________.

**8.** Concorda com a afirmação "A investigação científica em Biologia em todo o mundo é realizada da mesma forma, porque a Biologia é universal e independente da sociedade e da cultura"? Justifique. __________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________.

**9.** Charles Darwin, em 1871, numa carta a outro cientista sugere uma hipótese de origem da vida em que esta teria surgido num pequeno charco quente.

**9.1.** Argumente *a favor* desta hipótese com base em evidências científicas atuais.
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________.

**9.2.** Argumente *contra* esta hipótese com base em evidências científicas atuais.
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________.

**10.** Imagine que é um cientista da NASA que pretende encontrar evidências de existência de vida noutro planeta. Como realizaria essa investigação? __________________________
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________.

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UNIVERSIDADE DO PORTO

**11.** Comente a seguinte afirmação: "A investigação científica não é influenciada pela sociedade nem pela cultura porque os cientistas são treinados para realizar estudos imparciais." ____________________________________________

____________________________________________

____________________________________________.

**12.** Indique (colocando uma X) qual das afirmações está de acordo com a teoria evolução por seleção natural descrita por Darwin sobre os tentilhões das ilhas Galápagos.

☐ os tentilhões desenvolveram características diferentes, nomeadamente o formato do bico, porque o alimento disponível era diferente em cada ilha,

☐ em cada ilha reproduziram-se mais os tentilhões que tinham um bico adequado ao alimento disponível,

☐ em cada ilha existem vários tentilhões com o mesmo nicho ecológico.

**13.** Em alguns ecossistemas os seres humanos introduziram espécies com o mesmo nicho ecológico de espécies nativas. Explica as consequências que prevês desta ação.

____________________________________________

____________________________________________

____________________________________________.

**14.** Compara as duas espécies (A e B, abaixo). Indique qual a espécie que terá mais probabilidade de se extinguir devido às alterações climáticas, nomeadamente o aquecimento global. _______.

| | Temperatura óptima do seu habitat |
|---|---|
| Espécie A | 12 a 18°C |
| Espécie B | 12 a 30°C |

Justifique.____________________________________________

____________________________________________.

**15.** Concorda com a seguinte afirmação "Quando os cientistas usam o método científico corretamente, os seus resultados são verdadeiros e precisos."? ___________. Justifique.

____________________________________________

____________________________________________.

**16.** Indica quais as consequências da introdução do chorão-da-praia em ecossistemas dunares em Portugal. ____________________________________________

____________________________________________

____________________________________________.

Agradecemos a sua colaboração!

Appendix 10

U.PORTO FACULDADE DE CIÊNCIAS UNIVERSIDADE DO PORTO

**Questionário Compreensão dos alunos sobre a Natureza da Ciência**

Ao preencheres este questionário estás a contribuir para um estudo sobre a opinião dos alunos acerca de aspetos diversos relacionados com a Ciência. Não há respostas certas ou erradas. Temos interesse em saber a tua opinião sobre cada uma das afirmações. A confidencialidade dos dados encontra-se assegurada. Solicitamos a maior sinceridade no seu preenchimento. Agradecemos a tua colaboração.

Nº_____ Turma: _____ Data de preenchimento: ___/___/2018

**Parte A – Dados pessoais**

Preenche os espaços com os teus dados e coloca uma cruz (X) onde seja adequado.

Idade: ____ anos    Sexo: F ___ M ___

Última classificação na disciplina de Ciências Naturais: 1___ 2___ 3____ 4____ 5____

Qual a tua disciplina favorita? ________________________________.

**Parte B – Afirmações**

Assinala com uma cruz (X) de forma a indicares a tua opinião sobre cada uma das afirmações (1 a 37) de acordo com a seguinte escala: discordo totalmente, discordo, não tenho a certeza, concordo, concordo totalmente.

| | Discordo totalmente | Discordo | Não tenho a certeza | Concordo | Concordo totalmente |
|---|---|---|---|---|---|
| 1. As teorias científicas existem no mundo natural e são descobertas através das investigações científicas. | | | | | |
| 2. Todos os cientistas seguem o mesmo método científico passo-a-passo. | | | | | |
| 3. A ciência é uma forma de procura de respostas a questões sobre fenómenos naturais. | | | | | |
| 4. A investigação científica não é influenciada pela sociedade nem pela cultura porque os cientistas são treinados para realizar estudos não tendenciosos. | | | | | |
| 5. As observações do mesmo fenómeno, realizadas por diferentes cientistas, podem ser diferentes, porque o que os cientistas já sabem pode influenciar as suas observações. | | | | | |
| 6. O conhecimento científico é publicado em revistas científicas depois de ser revisto e aceite por outros cientistas. | | | | | |
| 7. Os cientistas podem realizar observações que não são influenciadas por outros fatores. | | | | | |
| 8. Todas as investigações científicas começam com uma questão. | | | | | |
| 9. Os cientistas não usam a sua imaginação e criatividade porque estas podem interferir na objetividade das suas investigações. | | | | | |
| 10. Uma das atividades da investigação científica é a comunicação com outros cientistas. | | | | | |
| 11. As teorias científicas aceites pelos cientistas não interferem no desenvolvimento do conhecimento científico. | | | | | |
| 12. Os cientistas não usam a sua imaginação e criatividade porque isso contraria o seu raciocínio lógico. | | | | | |

Cristina Sousa, João Paiva & Isabel Chagas (04/04/2018), baseado em Tsai & Liu (2005), Liu & Tsai (2008), Liang et al. (2006).    1 (de 2)

| | Discordo totalmente | Discordo | Não tenho a certeza | Concordo | Concordo totalmente |
|---|---|---|---|---|---|
| 13. A sociedade e a cultura determinam *qual* a ciência que é realizada e aceite. | | | | | |
| 14. As observações do mesmo fenómeno, realizadas por diferentes cientistas, de diferentes equipas, são sempre iguais porque os cientistas não se deixam influenciar. | | | | | |
| 15. A investigação científica em todo o mundo é realizada da mesma forma, porque a ciência é universal e independente da sociedade e da cultura. | | | | | |
| 16. Os cientistas usam a sua imaginação e criatividade para recolherem dados. | | | | | |
| 17. As leis científicas são teorias que foram comprovadas. | | | | | |
| 18. O conhecimento científico torna-se credível através do reconhecimento por outros cientistas da área. | | | | | |
| 19. As atividades de investigação dos cientistas são influenciadas pelas suas teorias. | | | | | |
| 20. O desenvolvimento do conhecimento científico envolve, frequentemente, a mudança de conceitos. | | | | | |
| 21. O conhecimento científico atual fornece explicações provisórias para os fenómenos naturais. | | | | | |
| 22. A sociedade e a cultura determinam *como* a ciência é realizada e aceite. | | | | | |
| 23. Os cientistas, em diferentes épocas, podem usar teorias e métodos diferentes para interpretar o mesmo fenómeno natural. | | | | | |
| 24. Os cientistas usam diferentes métodos para realizarem investigações científicas. | | | | | |
| 25. Ao contrário das teorias, as leis científicas não mudam. | | | | | |
| 26. Quando os cientistas usam o método científico corretamente, os seus resultados são verdadeiros e precisos. | | | | | |
| 27. As experiências científicas não são o único recurso para o desenvolvimento do conhecimento científico. | | | | | |
| 28. Um pressuposto em que as investigações científicas se baseiam é que o mundo natural é compreensível. | | | | | |
| 29. As investigações científicas não testam necessariamente uma hipótese. | | | | | |
| 30. A ciência é uma forma de conhecimento que fornece explicações baseadas em evidências. | | | | | |
| 31. As crenças religiosas são uma forma de conhecimento que a ciência não consegue explicar. | | | | | |
| 32. Os factos científicos são teorias que foram comprovadas. | | | | | |
| 33. O conhecimento científico atual pode ser alterado ou totalmente rejeitado no futuro. | | | | | |
| 34. A argumentação científica usa evidências científicas. | | | | | |
| 35. As observações do mesmo fenómeno, realizadas por diferentes cientistas, são sempre iguais porque as observações são factos. | | | | | |
| 36. Os cientistas usam a sua imaginação e criatividade para analisar e interpretar os dados. | | | | | |
| 37. As teorias científicas podem ser testadas, mas não podem ser provadas. | | | | | |

Cristina Sousa, João Paiva & Isabel Chagas (04/04/2018), baseado em Tsai & Liu (2005), Liu & Tsai (2008), Liang et al. (2006). 2 (de 2)

# Appendix 11

**Guião de entrevista semi-estruturada a professoras de Ciências Naturais das turmas em estudo**

Esta entrevista enquadra-se num estudo de doutoramento da investigadora/professora Cristina Sousa da FCUP sobre a aprendizagem de aspetos de Natureza da Ciência contextualizada com temas da área da Biologia. Os dados obtidos serão apenas usados no contexto do referido estudo e está assegurada a confidencialidade. Agradecemos a sua colaboração!

1. Como carateriza, em termos gerais, a escola e a turma envolvida neste conjunto de aulas PBL?
2. Já realizou alguma aula PBL com esta turma?
3. Que tipo de estratégias utiliza com esta turma?
4. Que tipo de recursos utiliza com esta turma?
5. Já realizou com esta turma alguma atividade que envolvesse a História da Ciência? Se sim, qual (quais) e como decorreu(decorreram)?
6. Já realizou com esta turma alguma atividade que envolvesse a Natureza da Ciência? Se sim, qual (quais) e como decorreu(decorreram)?
7. Como carateriza os recursos utilizados nestes conjuntos de aulas PBL?
8. Quais os aspetos que considera mais positivos destes conjuntos de aulas PBL?
9. Quais os aspetos que considera menos positivos destes conjuntos de aulas PBL?
10. Como é que os alunos se envolveram nestas aulas PBL?
11. Que atitudes os alunos demonstraram em relação a estas aulas?
12. Considera que os alunos, nas aulas PBL, aprenderam aspetos de Natureza da Ciência para além dos temas de Biologia? Em caso positivo, que aspetos?
13. Em qual dos dois conjuntos de aulas PBL considera que houve um maior envolvimento e motivação dos alunos? Como justifica essa(s) diferença(s)?
14. Por favor acrescente algo acerca das aulas PBL que, na sua opinião, não tenha sido referido até agora.

Cristina Sousa (FCUP, 14/10/2017)

# Appendix 12

## Situação-problema: origem da vida e ancestral comum

**<u>Problema:</u> Como se carateriza o ancestral comum de todos os seres vivos?**

A Terra é um sistema com vida. Há várias teorias que explicam a origem a vida. Em Biologia e talvez em toda a Ciência não existe maior mistério do que a origem da vida[1]. Todas as propriedades conhecidas da vida obedecem às leis da física e da química (1ª lei da Biologia)[2] e todos os processos biológicos evoluíram por seleção natural[3] (2ª lei da Biologia) [2]. **[1]**

Charles Darwin (1809-1882), em 1838, ao pensar nas semelhanças entre os seres vivos atuais que observou e propôs, de forma criativa, a teoria do ancestral comum a todos os seres vivos[3], segundo a qual todos os seres vivos são descendentes de uma espécie existente no passado distante. Esta sua teoria está registada num dos seus cadernos numa figura em forma de árvore que representa o parentesco entre espécies - a árvore da vida - que representa as linhas evolutivas (ramos) que se extinguiram, enquanto outras linhas originaram as espécies atuais (A, B, C e D), indicando com o algarismo "1" o ancestral comum[3] (Fig. 1). **[2] [3]**

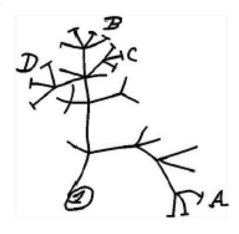


Fig. 1 - Árvore da vida[3] .

**[4] Há evidências da teoria do ancestral comum obtidas por novas tecnologias?** Em 2010, foi pela primeira vez testada a teoria do ancestral comum, comparando proteínas de organismos[4, 5].

Em 1977, Carl Woese (1928-2012) usando novas tecnologias da Biologia Molecular representou todos os seres vivos em forma de árvore em que todos partilham um ancestral comum[6]. Woese e outros cientistas, tendo por base os seus estudos anteriores e os de outros investigadores, inferiram que ao longo da sua história, na Terra surgiram os seres unicelulares simples (Arqueobactérias e Eubactérias) e posteriormente os seres unicelulares complexos e os multicelulares (Eucariotas) [6].

Contudo, atualmente não há consenso quanto à forma da árvore da vida e também quanto ao número de ramos, dadas as diferentes interpretações dos cientistas.

**[5] Quando surgiu o ancestral comum?** Há algum consenso entre cientistas relativamente ao último ancestral comum, isto é, teria surgido pelo menos há 3800 a 3400 milhões de anos[1,7]; desde então a diversidade e a complexidade dos seres vivos têm vindo, em geral, a aumentar.

Em 2017 comemoraram-se os 50 anos desde a publicação do estudo da cientista Lynn Margulis (1938-2011), em 1967, sobre a origem dos seres vivos unicelulares mais complexos (eucariotas). Margulis sugeriu a teoria da endossimbiose que descreve que alguns organelos celulares (plastos, como os cloroplastos, e mitocondrias) são descendentes de organismos unicelulares que viviam livremente e que foram envolvidos por outros organismos unicelulares através de endossimbiose[9]. As suas ideias, à época, eram inovadoras e talvez por isso tenham sido rejeitadas por várias revistas científicas, e só foram aceites pela generalidade dos cientistas 10 anos depois[1]. **[6] [7] [8] [9] [10]**

**[11]** Em 1871, Darwin, numa carta a outro cientista, Hooker, escreve uma hipótese: "Mas, se (e que grande se) pudéssemos conceber que num pequeno e quente charco com amónia, sais fosfóricos, luz, calor, eletricidade e etc. se formasse quimicamente um composto proteico que estaria pronto para sofrer complexas alterações, no presente este composto seria ingerido ou absorvido, o que não seria o caso antes de existirem os seres vivos."[9] **[12] [13]**

***Que teorias existiam antes de Darwin? O que diziam Aristóteles, Lamarck e Pasteur?*** **[14] [15] [16] [17] [18]**

**[19]** Em 1903, Arrhenius propôs a teoria da panspermia (Fig. 2) que descreve que os primeiros compostos orgânicos tiveram origem extraterrestre e que terão atingido a Terra vindos em meteoritos[10]. Estudos recentes sobre o meteorito que caiu, em 1969, em Murchison, na Austrália, descreveram a sua composição química, que inclui vários compostos orgânicos[11].

## Situação-problema: origem da vida e ancestral comum

Fig. 2 - Imagem representativa de ambiente de origem da vida*.

Este ano um grupo de cientistas publicaram estudo de meteoritos, que caíram em 1998, descrevendo que contêm compostos orgânicos e água[17].

**[20]** Alguns cientistas que defendem esta teoria consideram que os meteoritos poderão ter trazido para a Terra os primeiros organismos.

**[21] *Que outras teorias foram propostas no século XX e no início do século XXI? Quais as teorias/hipóteses de Oparin, Haldane, Miller, Lerman, Hansma e Sutherland?* [22] [23] [24] [25] [26] [27] [28] [29]**

**Que teorias foram sugeridas nos últimos 2 anos?**

**[30]** As evidências das formas de vida mais antigas no planeta foram publicadas recentemente por Nutman e colaboradores, em 2016. Esta teoria de origem da vida em águas marinhas pouco profundas descreve que as formas de vida mais antigas são estromatólitos com 3700 milhões de anos e que as formas de vida mais simples terão surgido pelo menos há 4000 milhões de anos, rapidamente após formação do planeta[12]. Esta teoria explica que os estromatólitos são estruturas sedimentares produzidas por cianobactérias (bactérias autotróficas) que são formadas atualmente em Shark Bay, na Austrália (Fig. 3). **[31]**

Fig. 3 - Fotografia de estromatólitos atuais*.

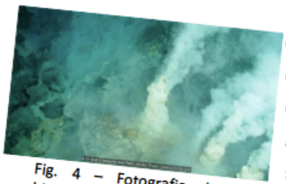


Fig. 4 – Fotografia de fonte hidrotermal atual*.

A teoria de origem da vida em fontes hidrotermais no fundo do oceano foi usada para explicar fósseis encontrados por Dodd e colaboradores com pelo menos 3770 milhões de anos, eventualmente com 4280 milhões de anos, em publicação em março de 2017[13]. **[32] [33]** As evidências que estes cientistas consideram que suportam esta teoria são fósseis de atividade de microorganismos (tubos e filamentos) em crosta oceânica, associada a vulcanismo submarino, no Quebec, Canadá e o facto de, atualmente, viverem, em fontes hidrotermais (Fig. 4), bactérias que oxidam ferro e que produzem tubos e filamentos semelhantes. Weiss e colaboradores descreveram 355 genes partilhados por organismos dos diferentes domínios[7], e por isso concluíram que estes genes provavelmente existiriam no último ancestral comum a todos os seres vivos[7]. **[34] [35]**

Novas evidências fósseis com 3500 milhões de anos, na Austrália, descritas por Djokic e colaboradores, em 2017, e que incluem estromatólitos, são a base da teoria da origem terrestre da vida que descreve que a vida poderá ter surgido, em ilhas vulcânicas, em fontes termais terrestres junto a vulcões em pequenos charcos[14, 15, 16] (Fig. 5). **[36] [37]**

Fig. 5 – Imagem representativa de ambiente de origem da vida*.

**[39] [40] *Qual a teoria/hipótese da origem da vida que consideram mais explicativa? E porquê? E pode ser provada?***

Em síntese, há grande diversidade de explicações sobre a origem da vida. Os diversos investigadores elaboram publicações teóricas, publicações com modelos computacionais ou simulações laboratoriais, realizam experiências com diversos reagentes em meio aquoso, fazem trabalho de campo incluindo visitas a locais semelhantes a possíveis locais de origem da vida e também incluindo visitas a locais onde se encontram fósseis do período de tempo de origem da vida[16].

**<u>Problema:</u> Como se carateriza o ancestral comum de todos os seres vivos?**

## Situação-problema: origem da vida e ancestral comum

### Referências

1. Harold, F. M. (2014). In Search of Cell History: The Evolution of Life's Building Blocks. Chicago, USA: The University of Chicago Press.
2. Wilson, E.O. (2006). The Creation: An Appeal to Save Life on Earth. New York, NY: W.W. Norton.
3. Darwin, C. (1837–38). Notebook B [Transmutation of Species]. Darwin Online. Available at http://darwin-online.org.uk/content/frameset?itemID=CUL-DAR121.-&viewtype=side&pageseq=1.
4. Theobald, D.L. (2010). A formal test of the theory of universal common ancestry. Nature, 465, 219–222.
5. Sousa, C. (2016). The Scientific Methods of Biology, Starting with Charles Darwin. American Biology Teacher, 78(2), 109-117.
6. Woese, C. R. & Fox, G. E. (1977) Phylogenetic structure of the prokaryotic domain: The primary kingdoms. Proceedings of the National Academy of Sciences USA, 74, 5088–5090.
7. Weiss; M. C., Sousa, F. L., Mrnjavac, N., Neukirchen, S., Roettger, M., Nelson-Sathi, S. & Martin, W. F. (2016). The physiology and habitat of the last universal common ancestor. Nature Microbiology, 1, 1-8.
8. Sagan, L. (1967). On the origin of mitosing cells. Journal of Theoretical Biology, 14, 225–274.
9. https://www.darwinproject.ac.uk/letter/DCP-LETT-7471.xml
10. Raven, P. H. & Johnson, G. B. (2016). The Origin and Early History of Life. In Biology, 6th edition. McGrawHill.
11. Schmitt-Kopplin, P., Gabelicab, Z., Gougeonc, R. D., Fekete, A., Kanawati, B., Harir, M., Gebefuegi, I., Eckeld, G., & Hertkorn, N. (2010). High molecular diversity of extraterrestrial organic matter in Murchison meteorite revealed 40 years after its fall. Proceedings of the National Academy of Sciences USA, 107, 2763-2768.
12. Nutman, A. P., Bennett, V. C., Friend, C. R. L., Van Kranendonk, M. J. & Chivas, A. R. (2016). Rapid emergence of life shown by discovery of 3,700-million-year-old microbial structures. Nature, 537, 535-538.
13. Dodd, M. S., Papineau, D., Grenne, T., Slack, J. F., Rittner, M., Pirajno, F., O'Neil, J. & Little, C. T. S.. (2017). Evidence for early life in Earth's oldest hydrothermal vent precipitates. Nature, 543, 60-64.
14. Djokic, T., Van Kranendonk, M. J., Campbell, K. A., Walter, M. R. & Ward, C. R. (2017). Earliest signs of life on land preserved in ca. 3.5 Ga hot spring deposits. Nature Communications, 8. DOI:10.1038/ncomms15263.
15. Van Kranendonk, M. J., Deamer, D. W. & Djokic, T. (2017). Life Springs. Scientific American, 317, 28-35.
16. Damer, B. (2016). A Field Trip to the Archaean in Search of Darwin's Warm Little Pond. Life, 6, doi:10.3390/life6020021.
17. Chan, Q. et al. (2018). Organic matter in extraterrestrial water-bearing salt crystals. Science Advances, DOI: 10.1126/sciadv.aao3521.

***Fonte das figuras:**

Fig. 1. Darwin, C. (1837-8)
Fig. 2. http://www.bbc.com/earth/story/20161026-the-secret-of-how-life-on-earth-began
Fig. 3. https://en.wikipedia.org/wiki/Stromatolite#/media/File:Stromatolites_in_Sharkbay.jpg
Fig. 4. http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/vents/welcome.html
Fig. 5. https://www.youtube.com/watch?v=6qiW4aUqtvA

# Appendix 13

FICHA DE TRABALHO DE GRUPO: **Origem da vida**

**Grupo: ________ Nº: ________________________**

**Problema: Como se carateriza o ancestral comum de todos os seres vivos?**

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| [1] - Todas as propriedades conhecidas da vida obedecem às leis da física e da química (1ª lei da Biologia) e todos os processos biológicos evoluíram por seleção natural (2ª lei da Biologia).<br><br>[3] - A teoria do ancestral comum a todos os seres vivos explica que ____________________________ ________________ foi proposta por Darwin tendo por base evidências de semelhanças entre todos os seres vivos.<br>[5]- Há algum consenso entre cientistas relativamente ao último ancestral comum. | [1] - Qual é a 2ª lei da Biologia?<br><br>[2] - ____________________<br><br>[3] - ____________________<br><br>[4] - Há evidências da teoria do ancestral comum obtidas por novas tecnologias?<br><br>[5] - ____________________ | [1]- A 2ª lei da Biologia diz que todos os processos biológicos evoluíram por seleção natural.<br>[2] - Uma teoria é uma explicação de determinado fenómeno natural que já foi testada.<br>[4] - Em 2010, novas tecnologias trouxeram evidências de que a teoria do ancestral comum é a mais precisa e mais provável que outras hipóteses.<br>[4]- Tecnologias de Biologia Molecular, em 1977, permitiram descrever a existência de um __________ ________________.<br>[5]- O ancestral comum terá surgido pelo menos há ________ a ________ milhões de anos. |
| [6]- Teoria da endossimbiose que descreve que alguns organelos celulares (plastos, como os cloroplastos, e mitocondrias) são descendentes de organismos unicelulares que viviam livremente e que foram englobados por outros organismos unicelulares<br>[8] - ______________________________<br>______________________________<br>[9] - O artigo científico que escreveu com a sua teoria foi rejeitado por várias revistas científicas.<br>[10] - As ideias de Margulis só foram aceites pela generalidade dos cientistas 10 anos depois. | [6]- ____________________<br>[7]- Qual é a atividade de comunicação dos cientistas? Como acontece a publicação de artigos científicos?<br><br>[8]- Qual a fase da história da Terra explicada por esta teoria?<br>[9] - ____________________<br>[10] - ____________________ | [7] - Uma das atividades dos cientistas é comunicar ______________________________<br>______________________________<br>[7] - A publicação em revistas científicas é precedida pela revisão de artigo a publicar por outros cientistas e só depois da sua aprovação é publicado.<br>[9] - As ideias de Margulis ________________<br>______________________________<br>[10] - Aceitação generalizada aconteceu após evidências de estudos de Biologia Molecular (com ADN de cloroplastos e mitocondrias). |
| [11] - "Mas, se (e que grande se) pudéssemos conceber que num pequeno e quente charco com amónia, sais fosfóricos, luz, calor, eletricidade e etc. se formasse quimicamente um composto proteico que estaria pronto para sofrer complexas alterações, no presente este composto seria ingerido ou absorvido, o que não seria o caso antes de existirem os seres vivos." | [11] - ____________________<br><br>[12] - Qual a fase da história da Terra explicada por esta hipótese? | [11] - Hipótese de oigem da vida em __________ ______________________________.<br>[12] - A hipótese proposta por Darwin (em 1871) refere-se à fase da história da Terra ____________<br>______________________________<br>______________________________ |

Cristina Sousa (FCUP, 03/01/2018) 1

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| [14] - A teoria da ______________________ foi sugerida por Aristóteles (384 a.C.-322 a.C.) e por Lamarck (1744-1829) e considerava que que os organismos mais simples estariam constantemente a ser criados e a se transformarem em seres mais complexos.<br><br>[15] - A teoria de biogénese foi proposta por _______ em 1862 e considera que qualquer ser vivo provém de outro ser vivo (por reprodução, por ex.); baseou-se em experiências científicas que realizou demonstrando que ______________________________.<br>[17] , [18] - A teoria de Pasteur foi aceite, rapidamente, quer por outros cientistas quer pela Igreja. | [13] - Que teorias existiam antes de Darwin?<br><br>[14] - Em que consiste a teoria da ______________________________?<br><br>[15] - Qual a teoria da biogénese?<br>[16] - ______________________________<br>[17] - ______________________________<br>[18] - ______________________________ | - Pelo menos até meados do século XVIII a teoria da geração espontânea era apoiada por autoridades geralmente não contestadas: a Igreja e Aristóteles.<br><br>[16] - A imaginação e criatividade de Pasteur foram importantes ______________________________.<br>[17] - Os cientistas aceitaram rapidamente a teoria porque ______________________________.<br>[18] - A Igreja aceitou a teoria da biogénese porque ______________________________ |
| [19] - Arrhenius propôs a teoria ____________ (em 1903) que descreve que ______________________________.<br><br>- Alguns cientistas que defendem esta teoria consideram que os meteoritos poderão ter trazido para a Terra os primeiros organismos. | [19] - Qual a teoria sugerida por Arrhenius no início do século XX?<br><br>[20] - Qual a fase da história da Terra explicada por esta hipótese? | [19] - Há algumas evidências que suportam a teoria de panspermia, tais como ______________________________, que descreveram que a sua composição química incluía vários compostos orgânicos.<br>[20] - A teoria da panspermia refere-se à fase da história da Terra ______________________________ (e segundo alguns cientistas dos primeiros organismos). |

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| [22] - __________ em 1936 sugere que a vida resultou da síntese de compostos orgânicos numa atmosfera primitiva e que posteriormente estes compostos teriam evoluído no sentido de formação de esferas microscópicas encerrando compostos orgânicos, conduzindo à formação dos primeiros seres vivos anaeróbicos e heterotróficos numa sopa primitiva. | **[21] - Que teorias existiam no século XX e início do século XXI?**<br>[22] - ______________________________ | [22] - A teoria da sopa primitiva foi proposta pela 1ª vez por Oparin e depois por Haldane e por isso por vezes é referida como teoria de Oparin-Haldane.<br>[22] - Segundo esta teoria a atmosfera primitiva não continha __________ e continha ________, __________, __________ e ______________. |
| - Haldane também sugeriu que a atmosfera primitiva não continha oxigénio e era rica em dióxido de carbono e que esta atmosfera promoveu a formação de compostos orgânicos numa sopa quente diluída. Segundo este cientista os primeiros seres que se formarem foram os vírus e só depois seres vivos compostos por células. | [23] - Qual a fase da história da Terra explicada por esta hipótese? | [23] - Esta teoria refere-se à fase da história da Terra em que ______________________________ ______________________________ ______________________________. |
| [24] - __________ (em 1953) pensou e construiu equipamento de vidro em que colocou na câmara de reação uma mistura de gases (hidrogénio, __________, __________ e __________) e no balão em baixo inseriu água. Na câmara de reação passava corrente elétrica, a partir de elétrodos, que produziam faíscas, enquanto o balão inferior era aquecido à chama. Após alguns dias a água estava turva e foi ficando de cor acastanhada. Miller identificou os compostos que que se formaram sendo compostos orgânicos que estão presentes em todos os seres vivos atuais. | [24] - Qual foi a primeira experiência que testou a teoria da sopa primitiva?<br>[25] - ______________________________<br>[26] - ______________________________ | [24] - Miller testou as ideias de Oparin, e de Urey, sobre a composição da atmosfera primitiva usando ____________________ concebido, de forma imaginativa e criativa, por si.<br>[25] - Esta experiência refere-se à fase da história da Terra ______________________________ ______________________________.<br>[26] - Em 2011 uma equipa de cientistas, através de novas tecnologias, identificou nas amostras de Miller uma diversidade de aminoácidos. Segundo estes cientistas a vida teria surgido em áreas junto a vulcões onde a atmosfera contém os gases hidrogénio, metano, amónia e água. |
| [27] - Em 1986, Lerman propôs a teoria __________ ______________ que descreve que os processos químicos que levaram ao aparecimento da vida ocorreram à superfície dos oceanos quando bolhas (produzidas por vulcões submarinos) libertavam o seu conteúdo que sofria modificações pela radiação ultravioleta formando compostos mais complexos que voltavam ao fundo do oceano por ação da chuva. | [27] - ______________________________ | [27] - A teoria das bolhas explica a fase da história da Terra em que ______________________________ ______________________________ ______________________________. |

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| [28] - Hansma (em 2010) ___________________________________.<br>[29] - Em 2015 Sutherland e a sua equipa, relataram o seu estudo experimental em que produziram vários tipos de compostos orgânicos essenciais à vida a partir de cianeto de hidrogénio, sulfureto de hidrogénio e na presença de radiação ultravioleta. | [28] - Em que consiste a hipótese da origem da vida entre folhas de micas?<br>[29] - Quais as evidências descritas por Sutherland? | [28] - Esta hipótese considera que o espaço reduzido entre folhas de moscovite potenciou o encontro entre moléculas, nomeadamente porque há evidências de interação de moscovite com proteínas.<br>[29] - As evidências de Sutherland apoiam a teoria ___________ e também a teoria ___________, uma vez que usaram radiação ultravioleta e compostos e que existiriam na Terra primitiva e também em cometas (por exemplo o que o cianeto de hidrogénio). |
| [30] - Nutman e colaboradores, em 2016 descrevem que as formas de vida mais antigas são estromatólitos com 3700 milhões de anos, no oeste da Austrália, e que as formas de vida mais simples terão surgido pelo menos há 4000 milhões de anos. | [30] - Que teorias foram sugeridas nos últimos 2 anos?<br>[31] - ___________________________<br>[32] - ___________________________ | [31] - Evidências de Nutman e colaboradores:<br>- estromatólitos com 3700 milhões de anos<br>- estromatólitos que são formados atualmente.<br>[32] - Esta teoria explica que os estromatólitos são ___________________________. |
| [33], [34] - As evidências que Dodd e colaboradores consideram que suportam a teoria de origem da vida em fontes hidrotermais são fósseis de atividade de microorganismos (tubos e filamentos) em crosta oceânica, associada a vulcanismo submarino e o facto de, atualmente, viverem, em fontes hidrotermais bactérias que oxidam ferro e que produzem tubos e filamentos semelhantes.<br>[35] - Weiss e colaboradores descreveram 355 genes partilhados por organismos dos diferentes domínios. E por isso concluíram que estes genes provavelmente existiriam no último ancestral comum a todos os seres vivos que terá vivido em ___________________. | [33] - ___________________________.<br>[34] - Como são interpretados as estruturas de tubos e filamentos?<br>[35] - ___________________________. | [33] - Evidências de Dodd e colaboradores:<br>- fósseis encontrados com pelo menos ___________________.<br>- bactérias que oxidam ferro existentes nas fontes hidrotermais atuais.<br>[33] Dodd e colaboradores sugeriram que ancestral comum são bactérias autotróficas que usavam $CO_2$ e $H_2$ para produzir ___________________.<br>[35] - Outras evidências são estudos de ___________ ___________ por Weiss e colaboradores que descrevem que o último ancestral comum seria um organismo unicelular ___________________. |

Cristina Sousa (FCUP, 03/01/2018) 4

| Factos | Questões-problema | O que precisamos de saber? |
| --- | --- | --- |
| [36] - A teoria da origem da vida em charcos descreve que a vida poderá ter surgido, em ilhas vulcânicas, em fontes termais terrestres junto a vulcões em pequenos charcos (Djokic e colaboradores, 2017).<br>[37] - Os primeiros organismos seriam autotróficos dependentes de luz solar e de fontes de energia como o ____________________ ____________________. | [36] - ____________________ ____________________.<br>[37] - ____________________ | [36] - Evidências de Djokic e colaboradores:<br>- ____________________<br>- ____________________ ____________________.<br>- experiências que constituem evidências de fase de ____________________. |
| - A teoria do ancestral comum refere-se ao 1º organismo ancestral de todos os seres vivos e está de acordo com ____________________.<br>- Há várias teorias sobre a origem da vida que explicam ____________________ da história da Terra. | [37], [38] - Qual a teoria/hipótese da origem da vida que consideram mais explicativa? E porquê?<br>[40] - E pode ser provada? | [37] - Os cientistas também recolhem informação sobre diferentes teorias para pensarem projetos de invetigação a realizar, para interpretar resultados obtidos em investigações, e também antes de sugerir uma nova teoria.<br>[40] - Uma teoria é uma explicação de __________ ____________________ e basea-se em __________ ____________________ ____________________.<br>[38] - A teoria/hipótese da origem da vida mais explicativa é a ____________________<br>[39] porque ____________________ ____________________ ____________________ ____________________. |

**Problema: Como se carateriza o ancestral comum de todos os seres vivos?**

**Proposta de solução:**
Há várias teorias que explicam a mesma fase da história da Terra descrevendo características do último ancestral comum, este assunto ainda não é consensual.
Consideramos que o ancestral comum a todos os seres vivos era ____________________ ____________________ ____________________.

Cristina Sousa (FCUP, 03/01/2018) 5

Appendix 14

## Guião de entrevistas semi-estruturadas a alunos

Esta entrevista enquadra-se no estudo de doutoramento da investigadora/professora Cristina Sousa da FCUP em que já participou ao responder ao questionário "Compreensão dos alunos sobre a natureza da ciência". Os dados obtidos serão apenas usados no contexto do referido estudo e está assegurada a confidencialidade. Agradecemos a sua colaboração!

*(A entrevistadora mostra uma cópia do questionário)*

1) Já tinha estudado este tipo de questões na escola? Em que disciplina(s)? Ao estudar que matéria?

*(Em seguida a entrevistadora questiona sobre as respostas dadas pelo(a) entrevistado(a) a determinados itens do questionário. Estes itens foram selecionados após análise estatística, por exemplo, abaixo)*

2) Explique as razões da sua opção discordo totalmente/discordo/não tenho a certeza/concordo/ concordo totalmente relativamente à afirmação no questionário "As teorias científicas existem no mundo natural e são descobertas através das investigações científicas.

**Cristina Sousa (27/04/2018)**

# Appendix 15

**FICHA DE TRABALHO DE GRUPO DE Problema: Como se carateriza o ancestral comum de todos os seres vivos?**

**Grupo: ________ Nº$^s$: ___________________________**

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| - Todas as propriedades conhecidas da vida obedecem às leis da física e da química (uma lei da Biologia).<br>- A teoria do ancestral comum a todos os seres vivos explica que ____________________________________ ____________________________________. foi proposta por Darwin tendo por base evidências ___ ____________________________________.<br>- Na mesma altura que Darwin desenhou a árvore da vida (modelo de árvore da vida de Darwin) Schleiden e Schwann proposeram a teoria celular. | - Conseguem dar exemplo de uma lei da Biologia?<br>- ____________________________________?<br>- O que é uma teoria?<br>- ____________________________________ ____________________________________?<br>- ____________________________________ ____________________________________? | - Teorias, leis, hipóteses e modelos são explicações construídas pelos cientistas sobre diferentes fenómenos.<br>- Uma teoria é uma ____________________________________ ____________________________________.<br>- Outras evidências que apoiam a teoria do ancestral comum de Darwin são semelhanças a nível celular e molecular dos seres vivos (todos os seres vivos são compostos por ________________ e _______).<br>- Em 1977, ____________________________________ ____________________________________ ____________________________________. |
| - O ancestral comum mais recente terá surgido pelo menos há _________ milhões de anos, segundo estudo publicado em ___________________________, em 2017, por uma ______________________________ liderada por Tsuyoshi Komiya. | **- Quando surgiu o ancestral comum?**<br>- ____________________________________ ____________________________________?<br>- Como acontece a publicação de resultados em revistas científicas? | - Há consenso entre cientistas relativamente à existência de um ancestral comum, mas não é consensual a __________ em que terá surgido.<br>- Os cientistas comunicam os seus resultados em reuniões e congressos científicos e _______________ ____________________________________.<br>- Os resultados publicados em revistas científicas são previamente aceites por ______________________ ____________________________________. |
| - Darwin propôs a hipótese de origem da vida em ____________________________________ baseando-se ______________________________ ____________________________________. | **- Então e o início? O que existia antes do ancestral comum mais recente?**<br>- ____________________________________ ____________________________________?<br>- Qual a fase da história da Terra explicada por esta hipótese? | - A hipótese proposta por Darwin (em 1871) refere-se à fase da história da Terra ____________________ ____________________________________ ____________________________________. |

Cristina Sousa & Isabel Chagas (FCUP, 10/10/2018) 1

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| - A teoria da ____________________<br>foi sugerida por Aristóteles (384 a.C.-322 a.C.) e por Lamarck (1744-1829) e considerava que os organismos mais simples ____________________<br>____________________ | - **E que teorias existiam antes de Darwin? O que diziam Aristóteles, Lamarck e Pasteur? Quais as suas evidências?**<br>- Em que consiste a teoria da ____________________<br>____________________? | - Pelo menos até meados do século XVIII a teoria da ____________________ era apoiada por autoridades geralmente não contestadas: a Igreja e Aristóteles. |
| - ____________ propôs a teoria de biogénese em 1862 que considera que qualquer ser vivo provém de outro ser vivo (por reprodução, por ex.) baseando-se em ____________________<br>____________________.<br>- As experiências de Pasteur mostraram que só surgem organismos em ____________________<br>____________________.<br>- A teoria de Pasteur foi aceite, rapidamente, quer por ____________ quer pela ____________. | - Qual a teoria da biogénese?<br>- ____________________<br>____________________?<br>- ____________________<br>____________________?<br><br>- ____________________<br>____________________? | - A imaginação e criatividade de Pasteur foram importantes ____________________<br>____________________.<br>- Outros cientistas aceitaram rapidamente a teoria porque ____________________<br>____________________<br>____________________<br>____________________.<br>- A Igreja aceitou a teoria da biogénese porque ______<br>____________________<br>____________________. |
| - Arrhenius propôs a teoria ____________________ (em 1903) que descreve que ____________________<br>____________________<br>____________________<br>____________________.<br><br>- Alguns cientistas que defendem esta teoria consideram que os meteoritos poderão ter trazido para a Terra os primeiros organismos. | - **Que outras teorias foram propostas no século XX e no início do século XXI? Quais as teorias/hipóteses de Svante Arrhenius, Aleksandr Oparin, John Haldane, Stanley Miller, Louis Lerman, Helen Hansma e John Sutherland? Quais as evidências mais recentes destas teorias/hipóteses?**<br>- Qual a teoria sugerida por Arrhenius no início do século XX?<br>- Quais as evidências da teoria ____________________?<br>- ____________________<br>____________________? | - Há algumas evidências que suportam a teoria de Arrhenius, tais como ____________________<br>____________________<br>____________________<br>que descreveram que a sua composição química incluía vários compostos orgânicos.<br>- A teoria ____________________ refere-se à fase da história da Terra ____________________<br>____________________<br>____________________ (e segundo alguns cientistas dos primeiros organismos). |

Cristina Sousa & Isabel Chagas (FCUP, 10/10/2018)

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| - ______________ em 1936 sugere que a vida resultou da síntese de compostos orgânicos numa atmosfera primitiva e que posteriormente estes compostos teriam evoluído no sentido de formação de esferas microscópicas encerrando compostos orgânicos, conduzindo à formação dos primeiros seres vivos ______________________________.<br>- Haldane também sugeriu que a atmosfera primitiva não continha ____________ e era rica em ________ ____________ e que esta atmosfera promoveu a formação de compostos orgânicos numa sopa quente diluída. Segundo este cientista os primeiros seres que se formarem foram os vírus e só depois os seres vivos compostos por células.<br>- ______________ (em 1953) pensou e construiu equipamento de vidro em que colocou na câmara de reação uma mistura de gases (__________, ________, __________ e ____________) e no balão em baixo inseriu água. Na câmara de reação passava corrente elétrica, a partir de elétrodos, que produziam faíscas, enquanto o balão inferior era aquecido à chama. Após alguns dias a água estava ________________ ____________. __________ identificou os compostos que que se formaram como __________ ______________ que estão presentes em todos os seres vivos atuais. | - ______________________________?<br>- Qual a fase da história da Terra explicada por esta teoria?<br>- Qual foi a experiência mais famosa que testou a teoria da sopa primitiva?<br>- ______________________________?<br>- ______________________________? | - A teoria ________________ foi proposta pela 1ª vez por Oparin e depois por Haldane e por isso por vezes é referida como teoria de Oparin-Haldane.<br>- Segundo esta teoria a atmosfera primitiva não continha ____________ e continha __________, ______________________________.<br>- Esta teoria refere-se à fase da história da Terra ______________________________.<br>- ______________ testou as ideias de Oparin, e de Urey, sobre a composição da atmosfera primitiva usando ______________________________ concebido, de forma imaginativa e criativa, por si.<br>- Esta experiência refere-se à fase da história da Terra ______________________________.<br>- Em 2011 uma equipa de cientistas, ______________________________.<br>Segundo estes cientistas a vida teria surgido em áreas ______________________________. |
| - Em 1986, Lerman propôs a teoria ______________ que descreve que os processos químicos que levaram ao aparecimento da vida ocorreram à superfície dos ______________ quando ______________ (produzidas por vulcões submarinos) libertavam o seu conteúdo que sofria modificações pela radiação ultravioleta formando compostos mais complexos que voltavam ao fundo do oceano por ação da chuva. | - ______________________________?<br>- ______________________________? | - A teoria ______________ explica a fase da história da Terra em que ______________________________. |

Cristina Sousa & Isabel Chagas (FCUP, 10/10/2018) 3

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| - ____________________ (em 2010) propôs que ________________________________________ ________________________________________. | - Em que consiste a hipótese da origem da vida entre folhas de micas (ou também designada hipótese de pizza)? | - Esta hipótese considera que o espaço reduzido entre folhas de moscovite ____________________ ________________________________________ ________________________________________. |
| - Em _______ Sutherland e a sua equipa, relataram o seu estudo experimental em que produziram vários tipos de compostos orgânicos essenciais à vida a partir de cianeto de hidrogénio, sulfureto de hidrogénio e na presença de ____________________.<br>- A Sociedade decide qual a Ciência a que atribui o ________________ necessário.<br>- Nas Ciências Naturais não há __________, como existe na Matemática. | - Quais as evidências descritas por Sutherland?<br>- ________________________________________ ________________________________________?<br>- Em Ciência há ___________?<br>- A Ciência e a Religião são incompatíveis? | - As evidências de Sutherland apoiam a teoria ___ ________________ e também a teoria ________, ________________ uma vez que usaram radiação ultravioleta e compostos e que existiriam na Terra primitiva e também em cometas (por exemplo o cianeto de hidrogénio).<br>- A Ciência usa ____________________ e a Religião baseia-se na fé, por isso ____________ coexistir. |
| - Nutman e colaboradores, em 2016 descrevem que as formas de vida mais antigas são ______________ com 3700 milhões de anos, no oeste da Austrália, e que as formas de vida mais simples terão surgido pelo menos há 4000 milhões de anos. | - Que teorias foram sugeridas nos últimos 2 anos?<br>- ________________________________________ ________________________________________?<br>- ________________________________________ ________________________________________? | - Evidências de Nutman e colaboradores:<br>- ______________ com 3700 milhões de anos<br>- ____________ que são formados atualmente.<br>- Esta teoria explica que os estromatólitos são ______ ________________________________________ ________________________________________. |
| - As evidências de Dodd e colaboradores sugerem a teoria de origem da vida em fontes hidrotermais.<br><br>- Weiss e colaboradores descreveram 355 genes partilhados por organismos dos diferentes domínios. E por isso concluíram que estes genes provavelmente existiriam no último ancestral comum a todos os seres vivos que terá vivido em ____________________. | - ________________________________________ ________________________________________ ________________________________________?<br>- ________________________________________ ________________________________________?<br>- Quais as evidências obtidas por novas tecnologias que apoiam a teoria da origem da vida ____________ ________________________________________ ________________________________________? | - Evidências de Dodd e colaboradores:<br>- fósseis encontrados com pelo menos ____ milhões de anos, eventualmente com ______ milhões de anos,<br>- bactérias que oxidam ferro encontradas em ______________________________ atuais.<br>- Dodd e colaboradores sugeriram que o ancestral comum são bactérias ____________ que usavam ________ e __________ para produzir ________________________________________.<br>- Outras evidências são estudos de ____________ por Weiss e colaboradores que descrevem que o último ancestral comum seria um organismo unicelular ________________________________________ ________________________________________. |

| Factos | Questões-problema | O que precisamos de saber? |
|---|---|---|
| - A teoria da origem da vida em ____________ ____________ descreve que a vida terá surgido em fontes termais terrestres junto a vulcões em pequenos ____________.<br>- Darwin propôs hipótese, em 1871, sobre a origem da vida em charco pequeno e quente.<br>- Segundo esta teoria, os primeiros organismos seriam autotróficos dependentes de luz solar e de fontes de energia como o ____________ ____________.<br>- Atualmente as investigações são realizadas por ____ ____________. | - ____________ ____________?<br>- ____________?<br>- ____________ ____________?<br>- Há um método científico ou vários métodos científicos?<br>- Quais as Ciências envolvidas nesta investigação? | - Evidências de Djokic e colaboradores:<br>- ____________,<br>- ____________<br>____________<br>- experiências em laboratório que constituem evidências de fase de ____________.<br>- Estas evidências ________ a hipótese de Darwin.<br>- Há vários métodos científicos: ____________ ____________ ____________.<br>- Há várias disciplinas científicas envolvidas nesta investigação, tais como a Bioquímica e a ________. |
| - A teoria do ancestral comum refere-se ao organismo ancestral de todos os seres vivos e está de acordo com ____________.<br>- Há várias teorias sobre a origem da vida que explicam ____________ da história da Terra. | - **Qual a teoria/hipótese da origem da vida que consideram mais explicativa? E porquê?**<br>- **E esta teoria foi ou pode vir a ser provada?**<br>- **E afinal o que é uma teoria?** ***(elaborem mapa de conceitos, na pág. seguinte)*** | - A teoria/hipótese da origem da vida mais explicativa é a ____________ porque ________ ____________ ____________.<br>- Uma teoria é uma explicação de ____________ ____________ e baseia-se em ________ e por isso novas evidências ____________ ____________.<br>- Os cientistas também recolhem informação sobre diferentes teorias para pensarem projetos de invetigação a realizar, para ____________ ____________ ____________. |

| Proposta de solução: | Desenho do ancestral comum: |
|---|---|
| Há várias teorias que explicam a mesma fase da história da Terra descrevendo características do ancestral comum, este assunto ainda não é consensual. | |

Cristina Sousa & Isabel Chagas (FCUP, 10/10/2018) 5

## Mapa de conceitos O que é uma teoria? *O que é a Ciência?*

***Inclui os conceitos:*** *1) teorias, 2) hipóteses, 3) modelos, 4) leis, 5) ciência, 6) observações, 7) inferências, 8) corpo de conhecimentos, 9) mutáveis, 10) explicações de fenómenos naturais, 11) imaginação e criatividade, 12) cientistas, 13) forma de conhecimento sobre o mundo natural, 14) mundo natural é compreensível, 15) investigações científicas, 16) sociedade, 17) cultura, 18) trabalho de campo, 19) teorias que aceitam, 20) modelos computacionais, 21) questão, 22) hipótese, 23) vários métodos científicos, 24) comunicação entre cientistas, 25) experiências, 26) podem ser alteradas ou rejeitadas no futuro.*

Appendix 16


Origem da vida
Teorias, hipóteses e evidências
Cristina Sousa & Isabel Chagas
(FCUP, 2018)
- Teoria do ancestral comum
- Hipótese de origem da vida de Darwin em pequeno charco
- Teoria da geração espontânea
- Teoria da biogénese
- Teoria da panspermia
- Teoria da sopa primitiva
- Experiência de Miller
- Teoria das bolhas
- Hipótese de origem da vida entre folhas de micas
- Experiências de Sutherland
- Teoria da origem da vida em águas marinhas pouco profundas
- Teoria da origem da vida em fontes hidrotermais
- Teoria da origem da vida em charcos quentes temporários

Em 1838

# Teoria do ancestral comum

**Charles Darwin**
(1809-1882)[1]

Charles Darwin (1809-1882), em 1838, ao pensar nas semelhanças entre os seres vivos atuais que observou, propôs, de forma criativa, a **teoria do ancestral comum a todos os seres vivos**.

O **modelo de árvore da vida** de Darwin está registado num dos seus cadernos, é uma figura em forma de árvore que representa o parentesco entre espécies - a árvore da vida - que representa as linhas evolutivas (ramos) que se extinguiram, enquanto outras linhas originaram as espécies atuais (A, B, C e D), indicando com o algarismo "1" o ancestral comum.

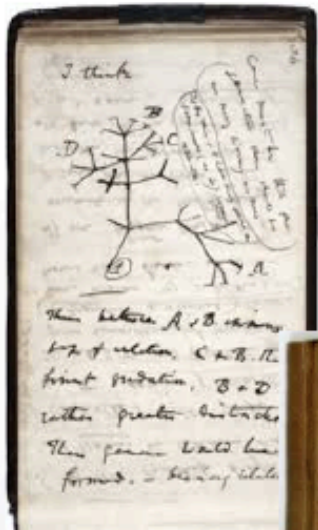




Fig. - Modelo de árvore da vida (Darwin, 1837-8)[2]

Fig. - Livro The Origin of Species[3]

Darwin incluiu a sua **teoria do ancestral comum** no seu livro sobre Origem das Espécies, publicado em 1859: "Portanto, eu poderei inferir da analogia que provavelmente todos os seres orgânicos que já viveram nesta terra descenderam de uma forma primordial..."[4]

Cristina Sousa (FCUP, setembro/2018)

2

Em 1838-1839

# Evidências de Schleiden & Schwann

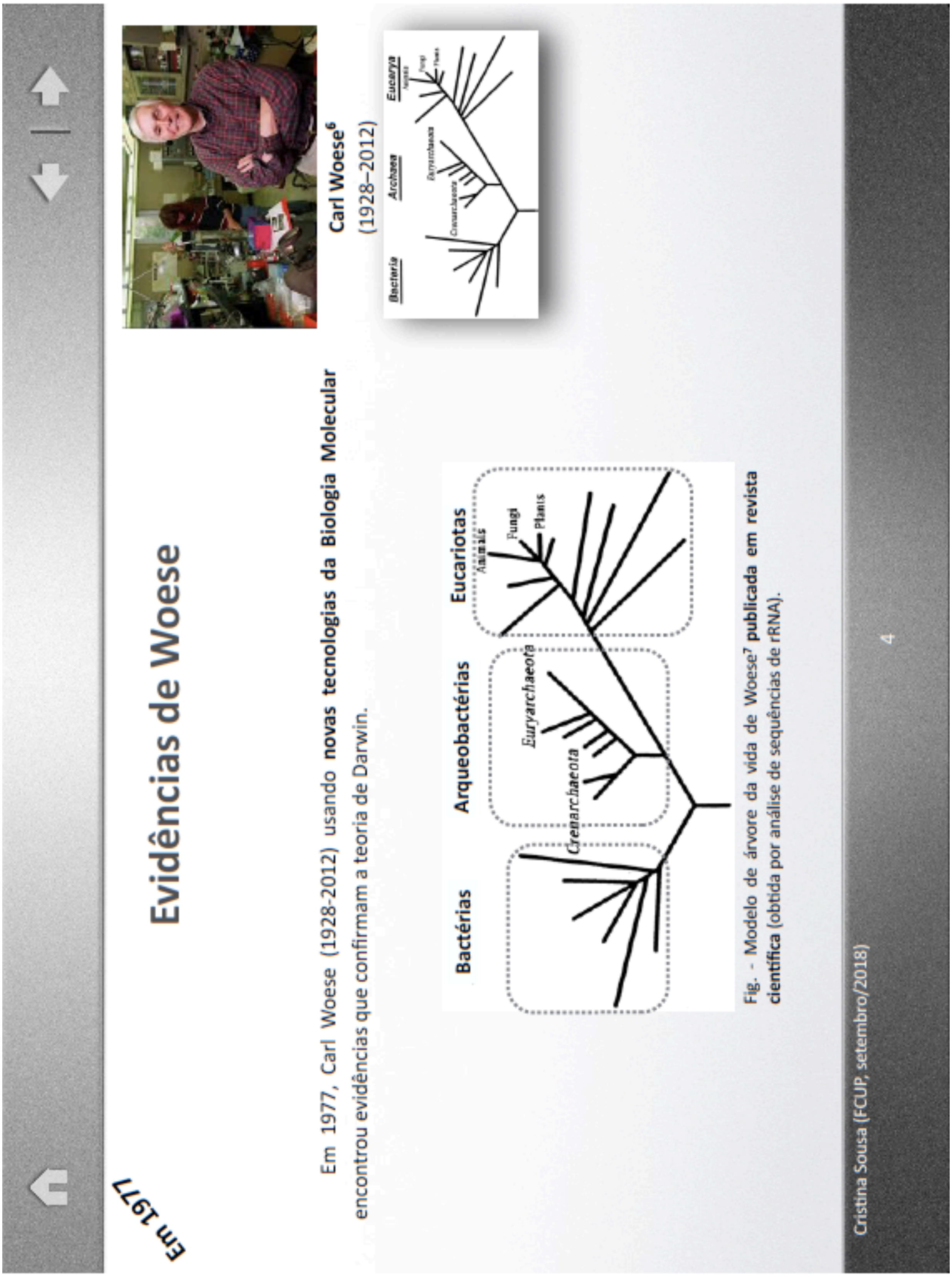

**Matthias Schleiden**[5] **Theodor Schwann**[5]
(1804–1881) (1810–1882)

Na época de Darwin, em 1838-1839, Matthias Schleiden (1804–1881) e Theodor Schwann (1810–1882) concluíram que todos os seres vivos são compostos de células (propuseram a teoria celular).

As evidências que suportam a teoria celular - as semelhanças de todos os seres vivos a nível celular - apoiam a teoria do ancestral comum de Darwin.

**Novas tecnologias** permitiram observar que há semelhanças entre todos os seres vivos a nível molecular (ADN) e estas evidências suportam a versão atual da teoria celular e apoiam a teoria do ancestral comum de Darwin.

Cristina Sousa (FCUP, setembro/2018)
3


Evidências de Woese
Em 1977
Em 1977, Carl Woese (1928-2012) usando novas tecnologias da Biologia Molecular encontrou evidências que confirmam a teoria de Darwin.
Carl Woese[6]
(1928–2012)
Bacteria
Archaea
Eucarya
Bactérias
Arqueobactérias
Eucariotas
Crenarchaeota
Euryarchaeota
Animals
Fungi
Plants
Fig. - Modelo de árvore da vida de Woese[7] publicada em revista científica (obtida por análise de sequências de rRNA).
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4

Em 2017
9 co-autores

# Evidências da equipa de Komiya

Tsuyoshi Komiya*


Fig. - Fotografia de equipa de investigadores liderados por Komiya[41]

Recentemente, em 2017, uma equipa de 9 investigadores japoneses liderada por Tsuyoshi Komiya propôs que o ancestral comum a todos os seres vivos mais recente (também designado o último ancestral comum universal) teria surgido há pelo menos **3950 milhões de anos**[5].

Estes cientistas analisaram rochas no Canadá (estudaram a sua composição química, em isótopos de C) e **publicaram os seus resultados na revista científica inglesa Nature.**

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5


Como é produzido o conhecimento científico?
Publicação em livro
Como comunicam os cientistas?
Individualmente
Publicação em revista científica
Em equipa
Questão
Investigação e escrita
Preparação de artigo
Envio de artigo a editor de revista
Artigo é enviado a 3-5 revisores especialistas
Decisão de aceitação, rejeição ou fazer correções
Fig.- Esquema do processo de revisão por pares dos artigos científicos **
6
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Hipótese de Darwin de origem da vida num pequeno charco
Em 1871
Em 1871, Darwin, numa carta a outro cientista, Hooker, escreve uma hipótese após ler resultados de experiências de Pasteur: "Mas, se (e que grande se) pudéssemos conceber que num pequeno e quente charco com amónia, sais fosfóricos, luz, calor, eletricidade e etc. se formasse quimicamente um composto proteico que estaria pronto para sofrer complexas alterações, no presente este composto seria ingerido ou absorvido, o que não seria o caso antes de existirem os seres vivos."8
Charles Darwin
(1809-1882)***
Fig. - Pequeno charco9
7
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Antes de Darwin
Teoria da geração espontânea
Aristóteles
(384 a.C.-322 a.C.)10
Jean-Baptiste Lamarck
(1744-1829)11
Segundo Aristóteles (384 a.C.-322 a.C.), um dos filósofos mais influentes da Antiguidade, os organismos vivos relacionavam-se entre si como degraus de uma escada desde formas mais simples a formas mais perfeitas. Na Idade Média a relação entre os seres vivos era esta conceção de escada da vida em que os degraus representavam os seres desde formas inanimadas a plantas e depois animais e no topo os anjos e Deus19. Lamarck (1744-1829) considerava que os organismos mais simples estariam constantemente a ser criados por ação de eletricidade e calor na lama13. Esta teoria designa-se geração espontânea e foi inicialmente proposta por Aristóteles.
Fig. 12
+
=
Os seus defensores pensavam que a vida nascia espontaneamente a partir da matéria em decomposição, por exemplo os vermes surguiam da lama e as moscas da carne podre. E surgiram listas de instruções para conseguir determinados organismos…
Pelo menos até meados do século XVIII a teoria da geração espontânea era apoiada por autoridades geralmente não contestadas: a Igreja e Aristóteles.
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8

**Antes de Darwin**

# Teoria da biogénese

**Louis Pasteur**
(1822-1895)[14]

Em 1862, Pasteur, era um católico motivado em contrariar, de forma científica, a teoria da geração espontânea (que considerava a criação de novos seres vivos muito comum e portanto sem intervenção divina).

Ele planeou - de forma criativa e imaginativa - uma experiência em que usou dois frascos com abertura em forma de S e colocou caldo de carne em ambos; em seguida ferveu ambos. A um dos frascos cortou a abertura em S e o outro ficou intacto; após algum tempo no frasco com grande abertura, em contacto com o ar, surgiram microorganismos, enquanto que o outro não continha. Assim, sugeriu que a teoria da geração espontânea não está correta, porque só apareceram seres vivos no frasco em contacto com o ar, apoiando a teoria da biogénese.[15]

Fig. - Fotografia de frasco com abertura com pescoço-de-cisne idealizado e produzido por Pasteur.[15]

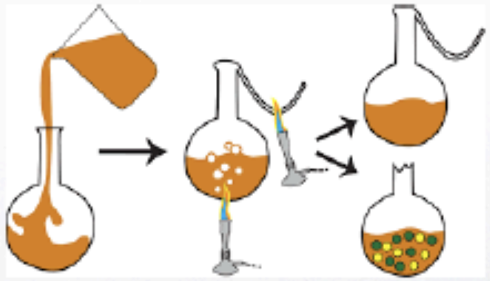

Fig. - Esquema de experiência de Pasteur[16]

A sua teoria de biogénese considera que qualquer ser vivo provém de outro ser vivo e foi aceite, rapidamente, pela Igreja, porque considerava a ação de Deus na criação de vida em algum ponto no tempo, e criação nos dias de hoje só possível a partir de outro ser vivo. E após conferências foi também aceite pir outros cientistas porque usou um método científico.

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9

Em 1903

## Teoria da panspermia

Fig. - Imagem representativa de ambiente de origem da vida[18]

**Svante Arrhenius**
(1859-1927)[17]

Em 1903, **Arrhenius** propôs a teoria da panspermia que descreve que os primeiros compostos orgânicos tiveram origem extraterrestre e que terão atingido a Terra vindos em meteoritos[19]

Alguns cientistas que apoiam esta teoria consideram que as semelhanças entre seres vivos são evidência de sua origem extraterrestre.

Estudos recentes sobre o meteorito que caiu, em 1969, em Murchison, na Austrália, descreveram a sua composição química, que inclui vários compostos orgânicos.[20]

Estudos recentes, de 10 janeiro de 2018, sobre meteoritos que caíram, em 1998, descreveram a sua composição química, sendo estes os primeiros meteoritos em que se encontraram simultaneamente vários compostos orgânicos e água[21].

Alguns cientistas que defendem esta teoria consideram que os meteoritos poderão ter trazido para a Terra os primeiros organismos.

Fig. Meteorito de Murchison[22]

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10


Séculos XX e XXI
Teoria da sopa primitiva
Oparin (1894-1980) em 1936 publicou o seu livro intitulado "Origem da vida" em que sugere que a vida resultou da síntese de compostos orgânicos a partir de gases da atmosfera primitiva sem oxigénio (com água, metano e amónia)24.
Alexander Oparin
(1894-1980)23
Segundo esta teoria os gases libertados por vulcões, sob ação de descargas elétricas, dos raios ultravioleta e energia dos vulcões transformaram-se em compostos orgânicos.24
Estes compostos acumularam-se no oceano e posteriormente teriam evoluído no sentido de formação de esferas microscópicas encerrando compostos orgânicos, conduzindo à formação dos primeiros seres vivos anaeróbicos e heterotróficos numa sopa primitiva24.
Fig. Imagem representativa de ambiente de origem da vida25
Haldane (1892-1964) sugeriu que a atmosfera primitiva não continha oxigénio e era rica em dióxido de carbono e que esta atmosfera promoveu a formação de compostos orgânicos numa sopa quente diluída. Por vezes a teoria da sopa primitiva é designada teoria de Oparin-Haldane.
Segundo Haldane os primeiros seres que se formarem foram os vírus e só depois surgiram os seres vivos compostos por células13.
John Haldane
(1892-1964)26
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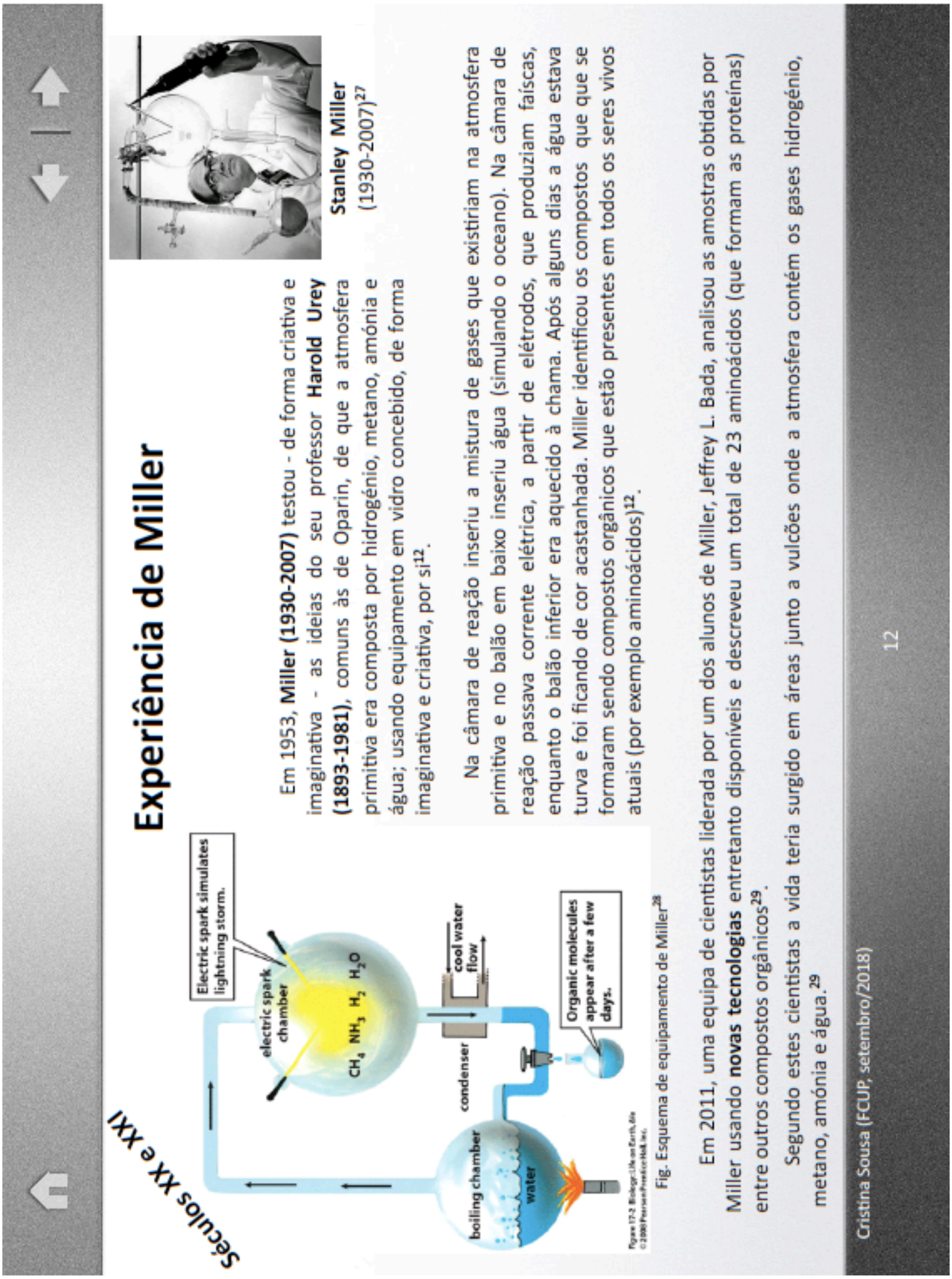
11


Experiência de Miller
Séculos XX e XXI
Em 1953, **Miller (1930-2007)** testou - de forma criativa e imaginativa - as ideias do seu professor **Harold Urey (1893-1981)**, comuns às de Oparin, de que a atmosfera primitiva era composta por hidrogénio, metano, amónia e água; usando equipamento em vidro concebido, de forma imaginativa e criativa, por si[12].
Stanley Miller (1930-2007)[27]
Na câmara de reação inseriu a mistura de gases que existiriam na atmosfera primitiva e no balão em baixo inseriu água (simulando o oceano). Na câmara de reação passava corrente elétrica, a partir de elétrodos, que produziam faíscas, enquanto o balão inferior era aquecido à chama. Após alguns dias a água estava turva e foi ficando de cor acastanhada. Miller identificou os compostos que que se formaram sendo compostos orgânicos que estão presentes em todos os seres vivos atuais (por exemplo aminoácidos)[12].
Electric spark simulates lightning storm.
electric spark chamber
$CH_4$ $NH_3$ $H_2$ $H_2O$
condenser
cool water flow
Organic molecules appear after a few days.
boiling chamber
water
Fig. Esquema de equipamento de Miller[28]
Em 2011, uma equipa de cientistas liderada por um dos alunos de Miller, Jeffrey L. Bada, analisou as amostras obtidas por Miller usando **novas tecnologias** entretanto disponíveis e descreveu um total de 23 aminoácidos (que formam as proteínas) entre outros compostos orgânicos[29].
Segundo estes cientistas a vida teria surgido em áreas junto a vulcões onde a atmosfera contém os gases hidrogénio, metano, amónia e água.[29]
Cristina Sousa (FCUP, setembro/2018)
12

Séculos XX e XXI

# Teoria das bolhas

Louis Lerman[30]

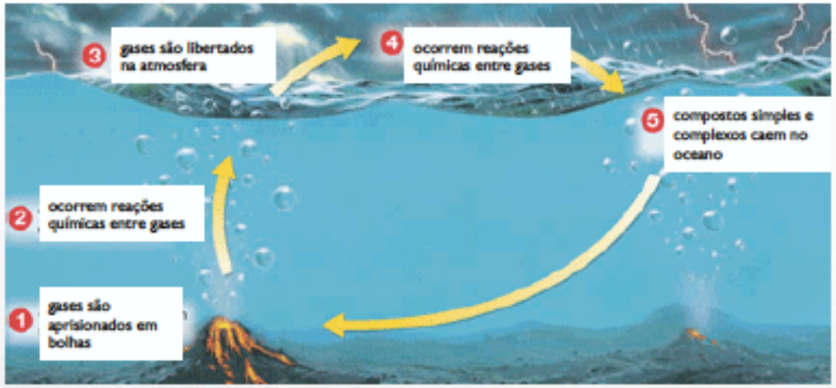



Fig. - Esquema representativo da teoria das bolhas[28]

Em 1986, **Lerman** propôs a teoria das bolhas que descreve que os processos químicos que levaram ao aparecimento da vida ocorreram à superfície dos oceanos quando bolhas (produzidas por vulcões submarinos) libertavam o seu conteúdo que sofria modificações pela radiação ultravioleta formando compostos mais complexos que voltavam ao fundo do oceano por ação da chuva.[19]

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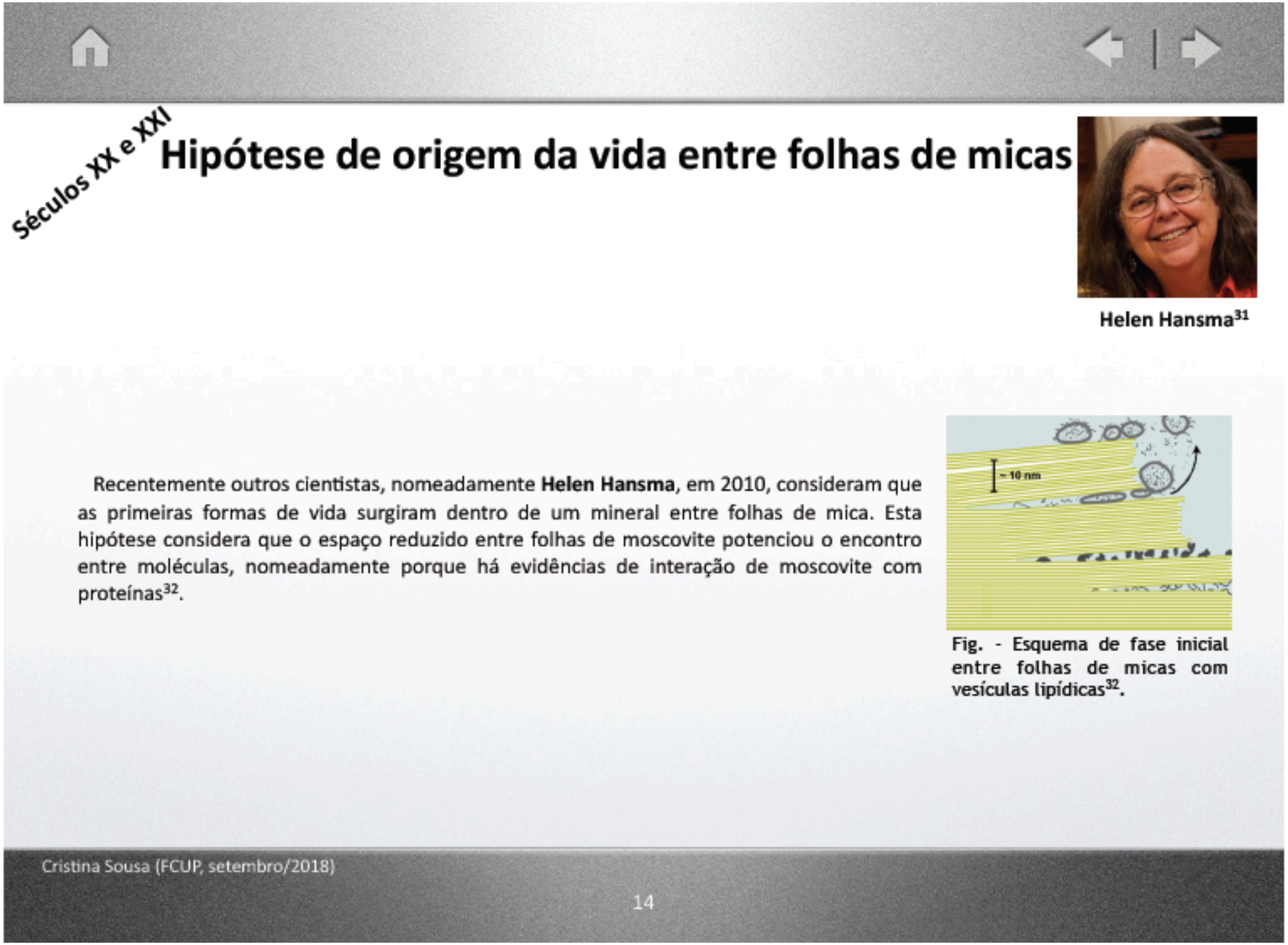
13


Séculos XX e XXI
Hipótese de origem da vida entre folhas de micas
Helen Hansma[31]
Recentemente outros cientistas, nomeadamente Helen Hansma, em 2010, consideram que as primeiras formas de vida surgiram dentro de um mineral entre folhas de mica. Esta hipótese considera que o espaço reduzido entre folhas de moscovite potenciou o encontro entre moléculas, nomeadamente porque há evidências de interação de moscovite com proteínas[32].
~10 nm
Fig. - Esquema de fase inicial entre folhas de micas com vesículas lipídicas[32].
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14

Séculos XX e XXI

# Experiências de Sutherland

Fig. - Representação de ambiente primitivo onde se produziu cianeto de hidrogénio pela queda de meteoritos[35].

John Sutherland[33]
(1962-)

**Sutherland e a sua equipa**, em 2015, relataram o seu estudo experimental em que produziram vários tipos de compostos orgânicos essenciais à vida a partir de cianeto de hidrogénio, sulfureto de hidrogénio e na presença de radiação ultravioleta[34]. Estes compostos, assim como a radiação ultravioleta, existiriam na Terra primitiva; e que o cianeto de hidrogénio é, também, abundante em cometas[34]. As reações químicas iniciais ocorreram à superfície ou em água pouco profunda[33].

**Sutherland**[33] considera que nunca se saberá o que aconteceu no início, mas será possivel saber como poderia ter acontecido o início da vida em termos químicos. Mas considera que é cedo para eventualmente considerar que a vida surgiu por panspermia.

**Sutherland numa entrevista disse**[33]:

- "Metade da minha pesquisa é **financiada** pelo MRC. Esta é uma instituição particular que, desde o início, contou com pesquisas de alta qualidade, sem se preocupar muito com publicações (....) A outra metade é **financiada** por organizações filantrópicas nos Estados Unidos, especialmente a fundação Simons... (...) Instituições europeias, como a Agência Espacial Europeia (ESA), não financiam pesquisas sobre a origem da vida.(...) Atualmente, considera-se haver financiamento apenas para a Ciência que produz resultados de curto prazo e é imediatamente lucrativa."
- "O objetivo final da nossa investigação é demonstrar experimentalmente que a vida pode começar a partir de sistemas não vivos. (...) **em todas as áreas da ciência ninguém tem prova**, por exemplo os físicos explicaram o big bang e não podem reproduzi-lo experimentalmente."
- "se alguém fizer experiências que mostram que a vida se pode originar num laboratório, eu não penso que isso exclui a existência de Deus para certas pessoas", então a **Ciência** usa métodos científicos e a **Religião** baseia-se na fé, **podem coexistir.**

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15


Em 2016
5 co-autores
Teoria da origem da vida em águas marinhas pouco profundas
As evidências das formas de vida mais antigas no planeta, encontradas na Gronelândia, foram publicadas recentemente por Allen Nutman e colaboradores, em 2016[36]. Esta teoria de origem da vida em águas marinhas pouco profundas descreve que as formas de vida mais antigas são estromatólitos com 3700 milhões de anos e que as formas de vida mais simples terão surgido pelo menos há 4000 milhões de anos, rapidamente após a formação do planeta[36].
A procura de formas de vida mais antigas é dificultada pela falta de rochas com mais de 4000 milhões de anos e que sofreram grandes deformações devido a elevadas temperaturas.
Allen Nutman & Vickie Bennet[38]
Fig. – Imagem representativa de ambiente de origem da vida em oceano pouco profundo junto a vulcões[37].
Fig. - Estromatólitos em rochas com 3 700 milhões de anos[36].
Fig. -Local de recolha de rochas na Gronelândia.
https://www.sciencedaily.com/releases/2016/08/160831172441.htm
16
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Em 2016
5 co-autores

# Teoria da origem da vida em águas marinhas pouco profundas

Fig. - Estromatólitos formados atualmente em Shark Bay, na Austrália.[39]

Esta teoria explica que estes estromatólitos com 3700 milhões de anos são estruturas sedimentares produzidas por cianobactérias (bactérias autotróficas dependentes de luz solar, e que usam dióxido de carbono para produzir compostos orgânicos) e que viveriam em águas marinhas pouco profundas, tais como estromatólitos que são formados atualmente em Shark Bay, na Austrália[36].

Em 2017
9 co-autores

Recentemente, em 2017, outros **cientistas, liderados por Komiya**, descreveram evidências de seres unicelulares autotróficos com pelo menos 3950 milhões de anos em rochas sedimentares que se formaram em meio marinho (ou em águas pouco profundas ou no fundo dos oceanos), em Labrador, Canadá. Não é consensual entre cientistas que estas estruturas tenham sido produzidas por seres vivos[40].

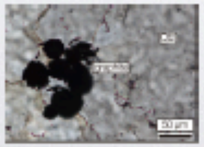

Fig. - Grafite produzida por seres autotróficos, que viviam em águas marinhas, em rochas metassedimentares em Labrador, Canadá[40].


Fig. - Fotografia de equipa de investigadores liderados por Komiya[41]

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17

Em 2017
8 co-autores

# Teoria da origem da vida em fontes hidrotermais

Matthew Dodd[42]

A teoria de origem da vida em fontes hidrotermais no fundo do oceano foi usada para explicar fósseis encontrados por **Dodd e colaboradores** com pelo menos 3770 milhões de anos, eventualmente com 4280 milhões de anos, em publicação em março de 2017[43]. As evidências que estes cientistas consideram que suportam esta teoria são fósseis de atividade de microorganismos (tubos e filamentos) em crosta oceânica, associada a vulcanismo submarino, no Quebec, Canadá e o facto de, atualmente, viverem, em fontes hidrotermais, bactérias que oxidam ferro que produzem tubos e filamentos semelhantes[43].

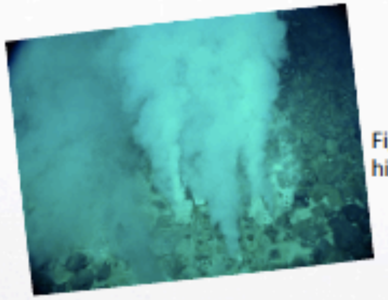

Fig. – Fotografia de fonte hidrotermal atual[44].

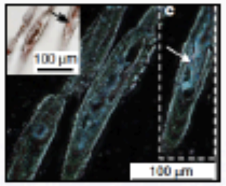


Fig. - Estruturas em forma de tubo produzidas por bactérias que oxidam ferro[43].

Em 1977 foi descrita a fauna dos riftes ligada à presença de fontes hidrotermais quentes[12].

Em 1979 foram descritas chaminés oceânicas que emitem um fluído com sulfuretos[12].

Este ambiente, com temperaturas entre 60°C e 464°C, favorece várias reações químicas e fornece de forma estável vários compostos químicos, tais como: amónia, metano, hidrogénio ($H_2$), sulfureto de hidrogénio e dióxido de carbono ($CO_2$)[12].

Neste ambiente encontram-se organismos unicelulares que convertem compostos químicos das fontes hidrotermais em energia que podem usar por quimiossíntese.

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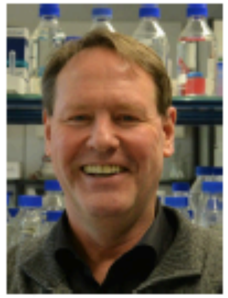
18

Em 2017
7 co-autores

# Teoria da origem da vida em fontes hidrotermais



**William Martin**
(líder da equipa)[46]

Outra equipa de cientistas, **Madeline Weiss e colaboradores**, descreveram 355 genes partilhados por organismos dos diferentes domínios. Por isso, estes genes existiriam provavelmente no último (ou o mais recente) ancestral comum a todos os seres vivos[45]. Com base no conhecimento destes genes concluem que o último ancestral comum era um organismo unicelular autotrófico anaeróbico (usando $CO_2$ e $H_2$ para produzir compostos orgânicos), hipertermófilo e dependente de hidrogénio do ambiente existente em fontes hidrotermais[45].


Fig. - Modelo de árvore da vida. (adapt. [45])

A proposta de árvore da vida de Weiss e colaboradores (Fig. à esquerda) foi obtida através de Biologia Molecular, com base na análise de genes presentes em organismos de diferentes domínios[45].

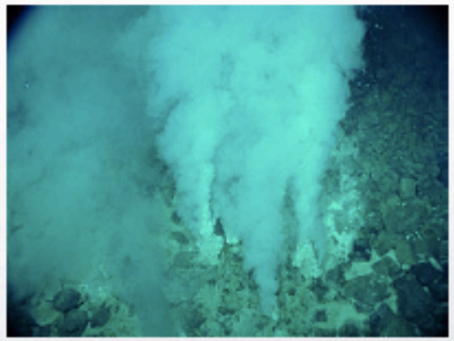


Fig. – Fotografia de fonte hidrotermal atual[44].

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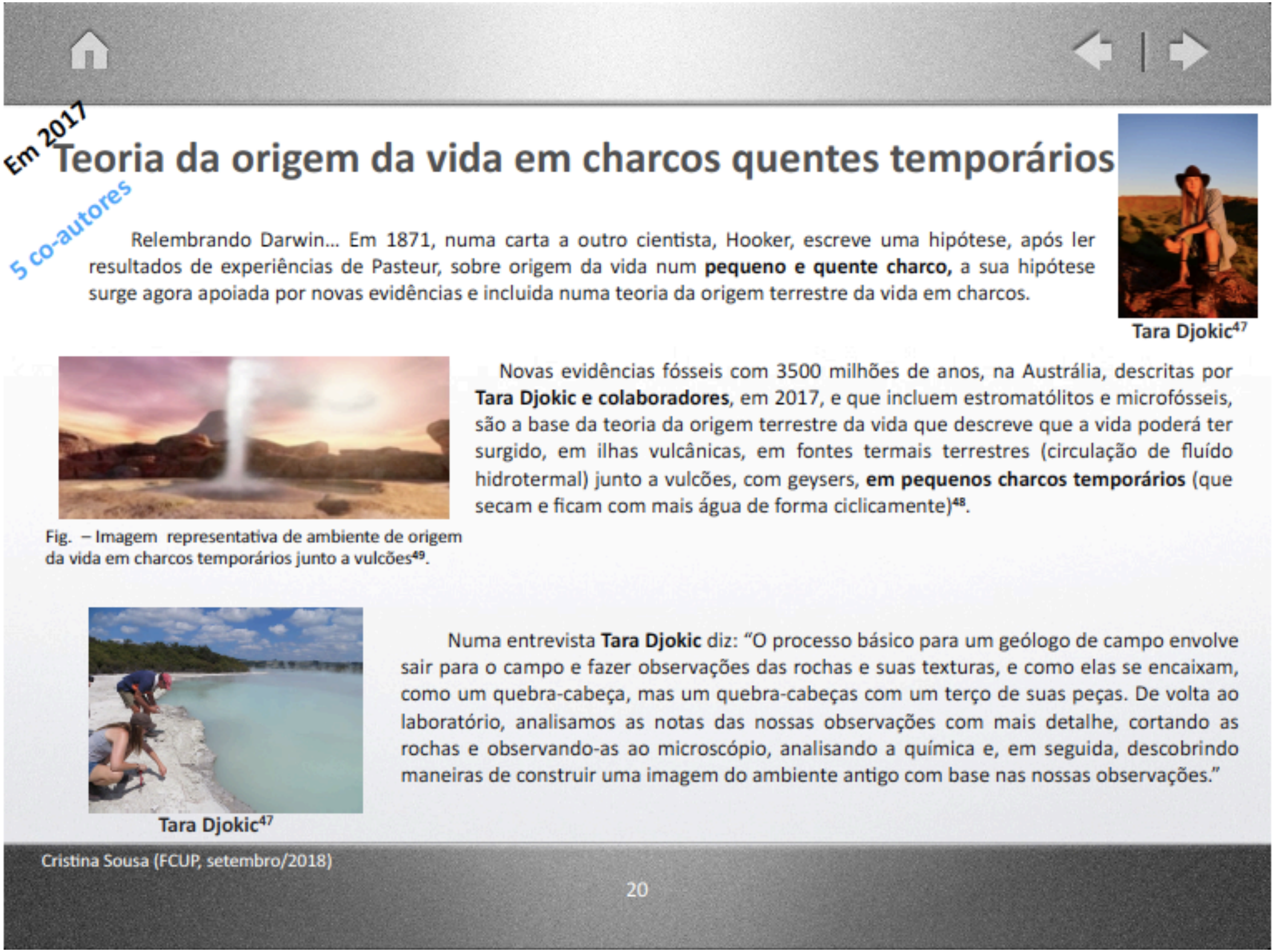
19


Em 2017
Teoria da origem da vida em charcos quentes temporários
5 co-autores
Relembrando Darwin… Em 1871, numa carta a outro cientista, Hooker, escreve uma hipótese, após ler resultados de experiências de Pasteur, sobre origem da vida num pequeno e quente charco, a sua hipótese surge agora apoiada por novas evidências e incluida numa teoria da origem terrestre da vida em charcos.
Tara Djokic[47]
Novas evidências fósseis com 3500 milhões de anos, na Austrália, descritas por Tara Djokic e colaboradores, em 2017, e que incluem estromatólitos e microfósseis, são a base da teoria da origem terrestre da vida que descreve que a vida poderá ter surgido, em ilhas vulcânicas, em fontes termais terrestres (circulação de fluído hidrotermal) junto a vulcões, com geysers, em pequenos charcos temporários (que secam e ficam com mais água de forma ciclicamente)[48].
Fig. – Imagem representativa de ambiente de origem da vida em charcos temporários junto a vulcões[49].
Numa entrevista Tara Djokic diz: "O processo básico para um geólogo de campo envolve sair para o campo e fazer observações das rochas e suas texturas, e como elas se encaixam, como um quebra-cabeça, mas um quebra-cabeças com um terço de suas peças. De volta ao laboratório, analisamos as notas das nossas observações com mais detalhe, cortando as rochas e observando-as ao microscópio, analisando a química e, em seguida, descobrindo maneiras de construir uma imagem do ambiente antigo com base nas nossas observações."
Tara Djokic[47]
Cristina Sousa (FCUP, setembro/2018)
20

Em 2017

5 co-autores

# Teoria da origem da vida em charcos quentes temporários

Fig. - Ambiente atual no Parque de Yellowstone, nos EUA, semelhante ao sugerido referente a há 3500 milhões de anos[50].

Fig. - Estruturas encontradas em Dresser, na Austrália[48].

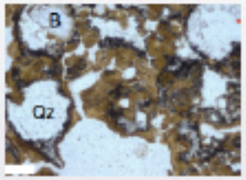



Fig. - Estruturas encontradas em Dresser, na Austrália referente a bolhas de gases eventualmente produzidas por microorganismos[48].

Djokic e colaboradores interpretam a existência de fósseis de estromatólitos como ambiente de água doce, enquanto na década de 1980 e 1990 os cientistas interpretavam como água marinha[48].

Os primeiros organismos seriam dependentes de luz solar e de fluído hidrotermal rico em hidrogénio e aquecido por vulcões[48].

Estes cientistas consideram que o aparecimento de vida em fontes hidrotermais do fundo dos oceanos é pouco provável porque os compostos necessários à vida estariam muito diluídos na grande quantidade de água e, por isso, dificilmente interagiam[48].

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21

Em 2017

5 co-autores

# Teoria da origem da vida em charcos quentes temporários

Djokic e outros cientistas (2017) explicam que a teoria se baseia na existência de charcos temporários onde ocorreriam fases secas e fases húmidas ciclicamente explica o aparecimento de protocélulas a partir de compostos orgânicos inseridos em vesículas ou bolhas[48].

Deamer, um dos cientistas desta equipa, levou garrafa com um pó branco para junto a boiling spring e colocou aí o seu conteúdo (aminoácidos, fosfatos, glicerol e um lípido). Em minutos formou-se uma espuma branca composta por imensas pequenas vesículas contendo componentes provavelmente existentes na sopa primitiva[51].

No laboratório, o bioquímico Deamer e colaboradores misturaram componentes das células (ácidos nucleicos e lípidos) e aplicaram fases secas e fases após chuva ciclicamente a altas temperaturas e conseguiram obter polímeros no interior de bolhas lipídicas (evidências de uma fase importante na história da Terra de formação de protocélulas)[51].

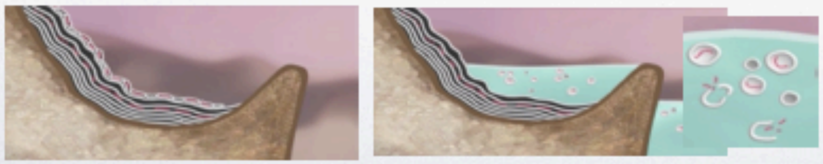

Fig. – Esquema representativo de fase seca (à esquerda) e após chuva (à direita)[48].

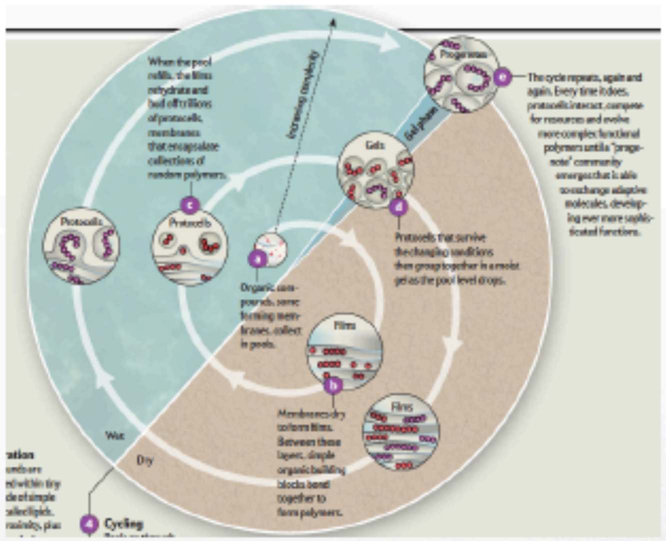


Fig. – Esquema representativo de etapas que ocorreriam em charcos temporários junto a vulcões, a fontes termais e geysers[51].

Quando em fases secas os compostos interagem e depois da chuva formam-se as bolhas ou vesículas[51].

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22

Em 2017

5 co-autores

# Teoria da origem da vida em charcos quentes temporários


Tara Djokic[47]

**Tara Djokic**[47] quando questionada ***Conte-nos mais sobre como sua descoberta e como esta pode influenciar a procura de vida extraterrestre em Marte no projeto Mars2020?*** disse que:

"Dado que um dos três principais locais de paragem do veículo espacial da NASA, na próxima exploração, é um antigo cenário de águas termais (Columbia Hills), o nosso trabalho sugere que seria um local ideal para procurar a vida antiga em Marte. Os depósitos em Pilbara têm aproximadamente a mesma idade que os depósitos em Marte, portanto, se a vida alguma vez se desenvolveu no planeta vermelho, há uma forte possibilidade de que ela seja preservada em fontes termais como aqui na Terra."

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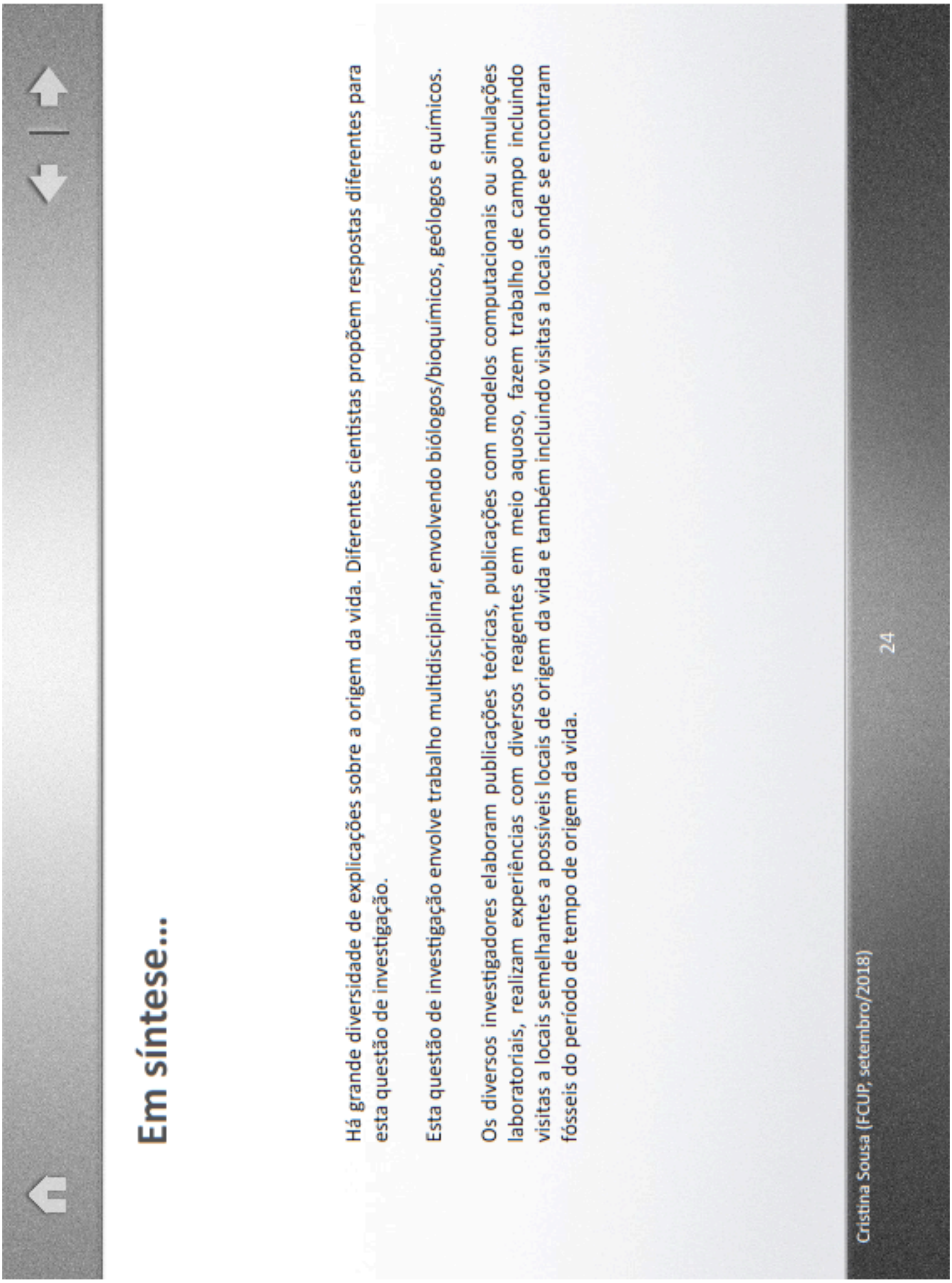
23


Em síntese...
Há grande diversidade de explicações sobre a origem da vida. Diferentes cientistas propõem respostas diferentes para esta questão de investigação.
Esta questão de investigação envolve trabalho multidisciplinar, envolvendo biólogos/bioquímicos, geólogos e químicos.
Os diversos investigadores elaboram publicações teóricas, publicações com modelos computacionais ou simulações laboratoriais, realizam experiências com diversos reagentes em meio aquoso, fazem trabalho de campo incluindo visitas a locais semelhantes a possíveis locais de origem da vida e também incluindo visitas a locais onde se encontram fósseis do período de tempo de origem da vida.
24
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## Glossário

**ADN** - Ácido desoxirribonucleico, molécula de dupla hélice que contém informação genética, com instruções que coordenam o desenvolvimento e o funcionamento de todas as células, e está presente em todas as células de todos os organismos vivos.

**Autotrófico** - qualifica um organismo capaz de elaborar matéria orgânica a partir de elementos minerais.

**Composto orgânico** - composto químico em que um ou mais átomos de carbono estão covalentemente ligados a átomos de outros elementos, geralmente hidrogénio, oxigénio ou nitrogénio. Os poucos compostos contendo carbono não classificados como orgânicos incluem carbonetos, carbonatos e cianetos.

**Estromatólitos** - estruturas sedimentares que são produzidos por comunidades de microorganismos através de aprisionamento e ligação de sedimentos e/ou precipitação de carbonato.

**Eucariótica** - qualifica um organismo que possui uma ou mais células complexas, que apresentam um núcleo individualizado, protegido por uma membrana.

**Gene** - unidade fundamental da hereditariedade, responsável por armazenar as informações hereditárias; composto por uma sequência específica de ADN (uma biomolécula fundamental dos seres vivos que define as caracteristicas da espécie).

**Heterotrófico** - qualifica um organismo que se alimenta de substâncias orgânicas e que é incapaz de elaborar matéria orgânica a partir de elementos minerais.

**Procariótica** - qualifica um organismo unicelular que não apresenta um núcleo individualizado.

**Quimiossíntese** - produção de matéria orgânica através da oxidação de substâncias minerais, sem necessidade de luz solar.

**Simbiose** - associação de 2 organismos, incapazes de viver um sem o outro, em que cada indivíduo tira partido um do outro.

Fonte: Duquet, M. (2007). Glossário de Ecologia Fundamental. Porto Editora; Encyclopaedia Britannica in https://www.britannica.com/

Cristina Sousa (FCUP, setembro/2018)

25

# Referências

1. http://darwin-online.org.uk/timeline.html
2. Darwin, C. (1837-8). Notebook B [Transmutation of Species]. Darwin Online. Available at http://darwin-online.org.uk/content/frameset?itemID=CUL-DAR121.-&viewtype=side&pageseq=1.
3. https://walkmemorylane.wordpress.com/2015/05/10/the-origin-of-species/
4. Darwin, C. (1859). Darwin, C. (1859). On the Origin of Species, by means of Natural Selection. Available online at http://darwin-online.org.uk/content/frameset?keywords= primordial%20form&pageseq=502&itemID=F373&viewtype=text.
5. http://curibiosidades.blogspot.com/2011/06/teoria-celular.html
6. https://www.nytimes.com/2013/01/01/science/carl-woese-dies-discovered-lifes-third-domain.html
7. Woese, C. R. (2000). Interpreting the universal phylogenetic tree. PNAS, 97 (15): 8392-8396.
*https://www.researchgate.net/profile/Tsuyoshi_Komiya
**https://ucsd.libguides.com/CAT3/peerreview
***. http://darwin-online.org.uk/content/frameset?itemID=A690&viewtype=text&pageseq=1
8. https://www.darwinproject.ac.uk/letter/DCP-LETT-7471.xml
9. http://www.bbc.com/earth/story/20161026-the-secret-of-how-life-on-earth-began
10. https://edukavita.blogspot.pt/2015/06/biografia-de-aristoteles-quem-e.html
11. https://www.britannica.com/biography/Jean-Baptiste-Lamarck
12. https://www.popsugar.com/fitness/Best-Laundry-Detergent-Workout-Clothes-37765167
13. Ruse, M. (1997). The Origin of Life: Philosophical Perspectives. J theor Biol, 187, 473-482.
14. https://pt.wikipedia.org/wiki/Louis_Pasteur
15. https://www.pasteur.fr/en/institut-pasteur/history/middle-years-1862-1877
16. https://blog.cmog.org/2016/07/20/savior-with-a-swans-neck-or-how-a-simple-glass-flask-saved-millions-of-lives/
17. https://www.nobelprize.org/nobel_prizes/chemistry/laureates/1903/arrhenius-bio.html
18. http://www.bbc.com/earth/story/20161026-the-secret-of-how-life-on-earth-began
19. Raven & Johnson (2016). The Origin and Early History of Life. In Biology, 6th edition. McGrawHill.

Cristina Sousa (FCUP, setembro/2018)

26

## Referências

20. Schmitt-Kopplin, P. ***et al.*** (2010). High molecular diversity of extraterrestrial organic matter in Murchison meteorite revealed 40 years after its fall. Proceedings of the National Academy of Sciences USA, 107, 2763-2768.

21. Chan, Q. et al. (2018). Organic matter in extraterrestrial water-bearing salt crystals. Science Advances, DOI: 10.1126/sciadv.aao3521.

22. https://commons.wikimedia.org/wiki/Category:Murchison_meteorite#/media/File:Murchison_meteorite_0.459g.jpg

23. http://www.eoht.info/page/Alexander+Oparin

24. Oparin, A. I. (1938) The Origin of Life. The Macmillan Company: New York.

25. https://phys.org/news/2016-09-protein-like-primordial-soup.html

26. https://www.britannica.com/biography/J-B-S-Haldane

27. http://ciencia-em-si.webnode.pt/news/a-quimica-da-vida/

28. https://projects.ncsu.edu/project/bio402_315/forweblecone/lec%20one%2011/page3/history%20of%20life%20lecture/history%20of%20life1.html

29. Parker, E. T. ***et al.*** (2011). Primordial synthesis of amines and amino acids in a 1958 Miller $H_2S$-rich spark discharge experiment. PNAS, 108, 5526–5531.

30. http://hertzfoundation.org/fellows/fellow-profile/10717/Louis-Lerman

31. https://www.researchgate.net/profile/Helen_Hansma

32. Hansma, H. G. (2010). Possible origin of life between mica sheets. ***Journal of Theoretical Biology, 266,*** 175–188.

33. https://metode.org/issues/entrevista-monografic-revistes/john-sutherland.html

34. Service, R. F. (2015). Origin-of-life puzzle cracked. ***Science, 347***, 1298.

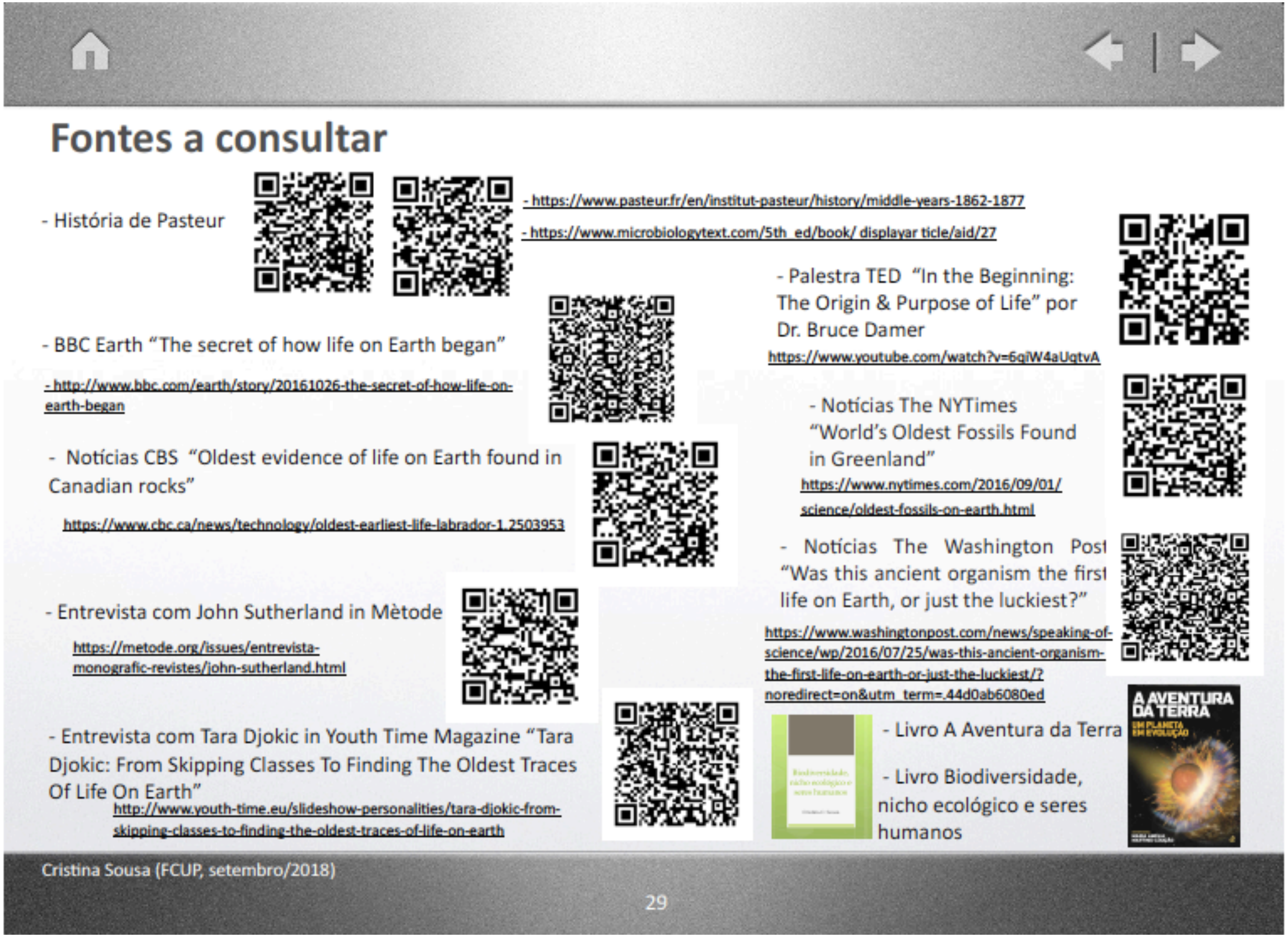
35. http://www.sciencemag.org/news/2015/03/researchers-may-have-solved-origin-life-conundrum

36. Nutman et al. (2016). Rapid emergence of life shown by discovery of 3,700-million-year-old microbial structures. ***Nature, 537***, 535-538.

37. https://www.zmescience.com/science/biology/origin-of-life-theory/

## Referências

38. https://www.nytimes.com/2016/09/01/science/oldest-fossils-on-earth.html
39. https://en.wikipedia.org/wiki/Stromatolite#/media/File:Stromatolites_in_Sharkbay.jpg
40. Tashiro, T. et al. (2017). Early trace of life from 3.95 Ga sedimentary rocks in Labrador, Canada. Nature, 549, 516-519.
41. http://www.cbc.ca/news/technology/oldest-earliest-life-labrador-1.2503953
42. https://www.ucl.ac.uk/earth-planetary-institute/people/phd-student-prof/dodd-matthew
43. Dodd, M. S. et al. (2017). Evidence for early life in Earth's oldest hydrothermal vent precipitates. Nature, 543, 60-64.
44. http://oceanexplorer.noaa.gov/okeanos/explorations/ex1605/background/vents/welcome.html
45. Weiss, M. C. et al. (2016). 1.The physiology and habitat of the last universal common ancestor. Nature Microbiology, 1, 1-8.
46. https://astrobiology.nasa.gov/news/looking-for-luca-the-last-universal-common-ancestor/
47. http://www.youth-time.eu/slideshow-personalities/tara-djokic-from-skipping-classes-to-finding-the-oldest-traces-of-life-on-earth.
48. Djokic, T. et al. (2017). Earliest signs of life on land preserved in ca. 3.5 Ga hot spring deposits. Nature Communications, 8. DOI:10.1038/ncomms15263.
49. https://www.youtube.com/watch?v=6qiW4aUqtvA
50. https://travel.usnews.com/Yellowstone_National_Park_WY/
51. Van Kranendonk, M. J. et al. (2017). Life Springs. Scientific American, 317, 28-35.


Fontes a consultar
- História de Pasteur
- https://www.pasteur.fr/en/institut-pasteur/history/middle-years-1862-1877
- https://www.microbiologytext.com/5th_ed/book/ displayar ticle/aid/27
- Palestra TED "In the Beginning: The Origin & Purpose of Life" por Dr. Bruce Damer
https://www.youtube.com/watch?v=6qiW4aUqtvA
- BBC Earth "The secret of how life on Earth began"
- http://www.bbc.com/earth/story/20161026-the-secret-of-how-life-on-earth-began
- Notícias The NYTimes "World's Oldest Fossils Found in Greenland"
https://www.nytimes.com/2016/09/01/science/oldest-fossils-on-earth.html
- Notícias CBS "Oldest evidence of life on Earth found in Canadian rocks"
https://www.cbc.ca/news/technology/oldest-earliest-life-labrador-1.2503953
- Notícias The Washington Post "Was this ancient organism the first life on Earth, or just the luckiest?"
https://www.washingtonpost.com/news/speaking-of-science/wp/2016/07/25/was-this-ancient-organism-the-first-life-on-earth-or-just-the-luckiest/?noredirect=on&utm_term=.44d0ab6080ed
- Entrevista com John Sutherland in Mètode
https://metode.org/issues/entrevista-monografic-revistes/john-sutherland.html
- Livro A Aventura da Terra
A AVENTURA DA TERRA
UM PLANETA EM EVOLUÇÃO
- Entrevista com Tara Djokic in Youth Time Magazine "Tara Djokic: From Skipping Classes To Finding The Oldest Traces Of Life On Earth"
http://www.youth-time.eu/slideshow-personalities/tara-djokic-from-skipping-classes-to-finding-the-oldest-traces-of-life-on-earth
- Livro Biodiversidade, nicho ecológico e seres humanos
Cristina Sousa (FCUP, setembro/2018)
29

# Appendix 17

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FACULDADE DE CIÊNCIAS
UNIVERSIDADE DO PORTO

## Texto de apoio - Origem da vida e ancestral comum

Em Biologia e talvez em toda a Ciência não existe maior mistério do que a origem da vida[1].

Charles Darwin (1809-1882), em 1837, ao pensar nas semelhanças entre os seres vivos atuais que observou, propôs, de forma criativa, a teoria do ancestral comum a todos os seres vivos[2], segundo a qual todos os seres vivos são descendentes de uma espécie existente no passado distante. Esta sua teoria foi registada pela 1ª vez num dos seus cadernos numa figura em forma de árvore que representa o parentesco entre espécies - a árvore da vida (um modelo científico) - que representa as linhas evolutivas (ramos) que se extinguiram, enquanto outras linhas originaram as espécies atuais (A, B, C e D), indicando com o algarismo "1" o ancestral comum[2]. Darwin incluiu esta sua teoria do ancestral comum no seu livro sobre Origem das Espécies, publicado em 1859: "Portanto, eu poderei inferir da analogia que provavelmente todos os seres orgânicos que já viveram nesta terra descenderam de uma forma primordial…"

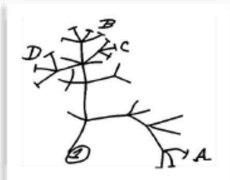


Fig. 1 – Modelo de árvore da vida (Darwin, 1837)[2].

Em 1838-1839, Matthias Schleiden (1804–1881) e Theodor Schwann (1810–1882) proposeram a teoria celular[3] que explica que todos os seres vivos são compostos de células. As evidências desta teoria - semelhanças de todos os seres vivos a nível celular e molecular (ADN) - apoiam a teoria de Darwin.

Em 1871, Darwin, numa carta a outro cientista, Hooker, escreve uma hipótese, após leitura de experiências de Pasteur: "Mas, se (e que grande se) pudéssemos conceber que num pequeno e quente charco com amónia, sais fosfóricos, luz, calor, eletricidade e etc. se formasse quimicamente um composto proteico que estaria pronto para sofrer complexas alterações, no presente este composto seria ingerido ou absorvido, o que não seria o caso antes de existirem os seres vivos."[6]

Em 1977, Carl Woese (1928-2012) usando novas tecnologias da Biologia Molecular encontrou evidências que confirmam a teoria de Darwin[4].

Recentemente, em 2017, uma equipa de investigadores liderada por Komiya propôs que o ancestral comum a todos os seres vivos mais recente (também designado o último ancestral comum universal) teria surgido há pelo menos 3950 milhões de anos[5] (publicaram estes resultados na revista científica Nature).

Allen P. Nutman e colaboradores, em 2016, sugeriram a teoria da origem da vida em águas marinhas pouco profundas[7] através de publicação numa revista científica.

A teoria de origem da vida em fontes hidrotermais no fundo do oceano foi proposta pela investigadora Madeline Weiss e colaboradores[8] e também por outra equipa de investigadores constituída por Matthew Dodd[9] e colaboradores.

A teoria teoria da origem terrestre da vida em fontes termais terrestres junto a vulcões em pequenos charcos foi proposta pela equipa da investigadora Tara Djokic, em 2017.[10, 11, 12]

Em síntese, há grande diversidade de explicações sobre a origem da vida. Os diversos investigadores elaboram publicações teóricas, publicações com modelos computacionais ou simulações laboratoriais, realizam experiências com diversos reagentes em meio aquoso, fazem trabalho de campo incluindo visitas a locais semelhantes a possíveis locais de origem da vida e também incluindo visitas a locais onde se encontram fósseis do período de tempo de origem da vida[12].

**Referências**

1. Harold, F. M. (2014). In Search of Cell History: The Evolution of Life's Building Blocks. Chicago, USA: The U. of Chicago Press.
2. Darwin, C. (1837–38). http://darwin-online.org.uk/content/frameset?itemID=CUL-DAR121.-&viewtype=side&pageseq=1.
3. https://www.the-scientist.com/foundations/sketching-out-cell-theory-circa-1837-38927.
4. Woese, C. R. & Fox, G. E. (1977) Phylogenetic structure of the prokaryotic domain: The primary kingdoms.PNAS, 74, 5088–5090.
5. Tashiro, T., Ishida, A., Hori, M., Igisu, M., Koike, M., Méjean, P., Takahata, N., Sano, Y. & Komiya, T. (2017). Early trace of life from 3.95 Ga sedimentary rocks in Labrador, Canada. ***Nature*, *549***, 516-518.
6. https://www.darwinproject.ac.uk/letter/DCP-LETT-7471.xml
7. Nutman, A. P., Bennett, V. C., Friend, C. R. L., Van Kranendonk, M. J. & Chivas, A. R. (2016). Rapid emergence of life shown by discovery of 3,700-million-year-old microbial structures. Nature, 537, 535-538.
8. Weiss, M. C., Sousa, F. L., Mrnjavac, N., Neukirchen, S., Roettger, M., Nelson-Sathi, S. & Martin, W. F. (2016). The physiology and habitat of the last universal common ancestor. Nature Microbiology, 1, 1-8.
9. Dodd, M. S., Papineau, D., Grenne, T., Slack, J. F., Rittner, M., Pirajno, F., O'Neil, J. & Little, C. T. S.. (2017). Evidence for early life in Earth's oldest hydrothermal vent precipitates. Nature, 543, 60-64.
10. Djokic, T., Van Kranendonk, M. J., Campbell, K. A., Walter, M. R. & Ward, C. R. (2017). Earliest signs of life on land preserved in ca. 3.5 Ga hot spring deposits. Nature Communications, 8. DOI:10.1038/ncomms15263.
11. Van Kranendonk, M. J., Deamer, D. W. & Djokic, T. (2017). Life Springs. Scientific American, 317, 28-35.
12. Damer, B. (2016). A Field Trip to the Archaean in Search of Darwin's Warm Little Pond. Life, 6, doi:10.3390/life6020021.

# Appendix 18

**Questionário de desempenho dos alunos em Ciências Naturais e em Natureza da Ciência**

Este questionário enquadra-se num estudo de doutoramento da investigadora/professora Cristina Sousa da FCUP sobre a aprendizagem da Natureza da Ciência no contexto de temas de Biologia. Os dados obtidos serão apenas usados no contexto do referido estudo e está assegurada a confidencialidade. Agradecemos a sua colaboração!

**Nº: _____ Turma: ______ Data: ___/__/2018**

**1.** Indique a idade das evidências da vida mais antigas que conhece. (Selecione, com uma X, abaixo a opção que considera correta).

- ☐ 3 950 milhões de anos,
- ☐ 450 milhões de anos,
- ☐ 4 milhões de anos.

**2.** Concorda com a afirmação: "As teorias científicas são explicações, construídas por cientistas, sobre uma ampla variedade de fenómenos relacionados entre si e que já foram sujeitas a testagem."? _______________. Justifique (explicando a diferença entre teoria e hipótese). ___________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

**3.** Charles Darwin é considerado o pai da Biologia. Indique o nome de uma das suas teorias. _____________________________________________________________________________.

**4.** Concorda com a afirmação: Todos os seres vivos na Terra estão relacionados entre si porque partilham um ancestral comum que existiu há milhões de anos? __________________. Justifique.
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

**5.** Concorda com a afirmação: Todas as investigações científicas realizam-se da mesma forma seguindo os mesmos passos do método científico? ______________. Justifique (*se concorda*, explique por que existe apenas uma forma de realizar uma investigação científica e descreva essa forma; *se não concorda*, descreva duas investigações que seguem métodos diferentes e explique como os métodos diferem e como ambas as investigações podem ser consideradas científicas.)
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________
_____________________________________________________________________________.

Appendix 19

Workshop proposal

# Nature of Science through PBL for K-16 science professionals

**Cristina Sousa[1] & Isabel Chagas[2]**

[1]Faculdade de Ciências, Universidade do Porto, Portugal, E-mail: up199502480@fc.up.pt ORCID ID

[2]Instituto de Educação, Universidade de Lisboa, Portugal E-mail: michagas@ie.ulisboa.pt ORCID ID

# Workshop description

| | |
|---|---|
| **Target audience** | - K-16 science teachers<br>- science education researchers<br>- anyone interested in Science and Nature of Science |
| **Goals** | Participants will learn:<br>- about the Nature of Science (NOS)<br>- how to design a PBL class to facilitate NOS learning |
| **Description of the experience** | Throughout the workshop, participants will work in teams of up to 5 elements to:<br>- analyse the problem-situations presented and propose a solution (using websites, software recommended and computer simulation),<br>- identify the NOS aspects present in the problem-situations.<br>At the end each team presents its solutions and its identified NOS aspects to the participants and a general discussion will be promoted by the facilitator. |
| **Specific technology requirements** | - Google Earth Pro (free software, preferentially downloaded before the session) and species geographic distribution files (kml files provided during the session). |

## Background

- The concept of Nature of Science (NOS) has a long history of controversy (Matthews, 1998), and has no consensus definition, it has been recently proposed as "meta-knowledge about science which emerges from interdisciplinary reflections made from the perspectives of the philosophy, history, and sociology of science, as well as from those of scientists and science teachers" (Garcia-Carmona & Acevedo-Diaz, 2018, p437).
- The promotion of scientific literacy faces several obstacles today, namely, students' (Lederman et al., 2019) and teachers' (Kartal et al., 2018) lack of informed conceptions about the Nature of Science (Khishfe & Lederman, 2007; Lederman, 2007).
- NOS aspects are included in several documents, worldwide, such as recently, in the USA, in the Next generation Science Standards (States, 2013).

## Background

- We are focused in using PBL for NOS teaching, since we hypothesize that students' analysis of purposely designed resources, including a problem situation, can induce the cognitive conflict between their prior conceptions and the more informed conceptions of NOS (Loyens et al., 2015) and because PBL is also described as developing skills such as communication and collaboration, decision making, problem solving, critical thinking and autonomous learning (Wilder, 2015).
- In our proposal we selected some NOS aspects, including the characteristics of the investigative process according to Kampourakis (2016) such as: laws, theories and facts (their meaning and differences between them), observations, objectivity and exploration based on theory, social and cultural influence on science, imagination and creativity in scientific investigations, mutable and provisional characteristics of scientific knowledge, methodology of scientific research (which includes characteristics of the investigative process), Science as a form of knowledge and social Science.

## Description of the experience

- This workshop will be mainly practical and hands-on: attendees will learn, through a PBL experience, about the Nature of Science and how to design a PBL class to facilitate NOS learning.
- Participants will have hands-on experiences with free-downloadble software, appropriate websites, computer simulations and learning strategies that we successfully use with pre-service teachers.
- Participants will be asked to reflect on the pedagogical opportunity they are experiencing as PBL learners and to provide their feedback about it as well to reflect on the implications for their own work.

## Description of the experience

- Participants will have the opportunity to use innovative NOS teaching materials, such as:
  - a socioscientific issue using hands-on activities with Google Earth Pro (Sousa & Chagas, 2018), in which each team will be asked to propose a solution to an environmental problem,
  - Charles Darwin and Alfred Wegener episodes of History of Science (Sousa, 2016), in which each team will be asked to hypothesize about to what extent has geologic mobilism influenced the evolution of ratites, using a webquest and Google Earth Pro,
  - a History of Science episode of an insular biogeography model, in which each team will be asked to represent their solution according to the model, in the blackboard, upon using a computer simulation.

# Summary

- Given the lack of guidance documents with concrete proposals for NOS inclusion in K-16 education, our research and workshop proposal are relevant from the applied point of view since include the use of innovative educational resources to facilitate teachers to integrate NOS aspects in the curriculum, through PBL.
- Throughout the workshop, participants will work in teams and learn about the Nature of Science and how to design a PBL class to facilitate NOS learning.

# References


- Garcia-Carmona, A. & Acevedo-Diaz, J. A. (2018). The Nature of Scientific Practice and Science Education: Rationale of a Set of Essential Pedagogical Principles. Science & Education, 27, 435-455.
- Kartal, E. E., Cobern, W. W., Dogan, N., Irez, S., Cakmakci, G. & Yalaki, Y. (2018). Improving science teachers' nature of science views through an innovative continuing professional development program. International Journal of STEM Education, 5, 30.
- Kampourakis, K. (2016). The "General Aspects" Conceptualization as a Pragmatic and Effective Means to Introducing Students to Nature of Science. Journal of Research in Science Teaching, 53(5), 667–682.
- Khishfe, R., & Lederman, N. (2007). Relationship between Instructional Context and Views of Nature of Science. International Journal of Science Education, 29(8), 939–961.
- Lederman, N. G. (2007). Nature of Science: Past, Present, and Future. In S. Abell & N. Lederman (Eds.), Handbook of research on science education (pp. 831-879): Lawrence Erlbaum Associates.
- Lederman, J., Lederman, N., Bartels, S., Jimenez, J. et al. (2019). An international collaborative investigation of beginning seventh grade students' understandings of scientific inquiry: Establishing a baseline. Journal of Research in Science Teaching. 2019; 1–30.
- Loyens, S. M. M., Jones, S. H., Mikkers, J., & van Gog, T. (2015). Problem-based learning as a facilitator of conceptual change. Learning and Instruction, 38(2015), 34-42.
- Matthews, M. R. (1998). Forword and introduction In W. Chomas (Ed.), The nature of science in science education. Rationales and strategies (pp. xi-xxi). Dordrecht, The Netherlands: Kluwer.
- Sousa, C. (2016). Bridging Darwin's Origin of Species & Wegener's Origin of Continents and Oceans: Using Biogeography, Phylogeny, Geology & Interactive Learning. American Biology Teacher, 78(1), 24-33.
- Sousa, C. & Chagas, I. (2018). Using Nature of Science enriched-PBL in pre-service science teacher education. In Conference proceedings "New perspectives in science education, 7th edition" (p592-595). Available in https://bit.ly/2FEkmNd.
- States, L. (2013). Next generation science standards: For states, by states. Washington, DC: National Academies Press.
- Wilder, S. (2015). Impact of problem-based learning on academic achievement in high school: a systematic review. Educational Review, 67, 414–435.