# Evolution in European and Israeli school curricula - A comparative analysis

# Evolution in European and Israeli school curricula - A comparative analysis

Evangelia Mavrikaki,
*Department of Pedagogy and Primary Education, National and Kapodistrian University of Athens, Athens, Greece,* https://orcid.org/0000-0001-9029-6340
*Marasli 4, 10676 Athens, Greece*
*Tel.+30 6932421918*
*emavrikaki@primedu.uoa.gr*

Giulia Realdon,
*Geology Section, UNICAMearth Group, University of Camerino, Camerino, Italy,*
https://orcid.org/0000-0001-8269-4269

Tuomas Aivelo,
*Faculty of Biological and Environmental Sciences, University of Helsinki, Helsinki, Finland,*
https://orcid.org/0000-0003-4285-7179

Ani Bajrami,
*Museum of Natural Sciences 'Sabiha Kasimati', University of Tirana, Tirana, Albania*,
https://orcid.org/0000-0001-5349-2510

Çiçek Dilek Bakanay,
*Faculty of Education, Department of Elementary education, University of Istanbul Aydın, Istanbul, Turkiye.* https://orcid.org/0000-0001-9491-2569

Anna Beniermann,
*Department of Biology, Humboldt-Universität zu Berlin, Berlin, Germany,*
https://orcid.org/0000-0001-5123-5588

Jelena Blagojević,
*Department of Genetic Research, Institute for Biological Research "Siniša Stanković" - National Institute of the Republic of Serbia, University of Belgrade, Belgrade, Serbia,*
https://orcid.org/0000-0001-7102-5510

Egle Butkeviciene,
*Faculty of Social Sciences, Arts and Humanities, Kaunas University of Technology, Kaunas, Lithuania,* https://orcid.org/0000-0002-5631-360X

Bento Cavadas,
*CeiED - Lusófona University, Polytechnic Institute of Santarém, Santarém, Portugal.*
https://orcid.org/0000-0001-6021-6581

Costantina Cossu,

*Équipe Formativa Territoriale Regione Sardegna, Sardegna, Ministry of Education, Italy,* https://orcid.org/0000-0002-0113-1657

Dragana Cvetković,
*Chair of Genetics and Evolution, Faculty of Biology, University of Belgrade, Serbia,* https://orcid.org/0000-0002-1311-7481

Szymon M. Drobniak,
*Institute of Environmental Sciences, Jagiellonian University, Kraków, Poland;*
*School of Biological, Environmental & Earth Sciences, University of New South Wales, Sydney, Australia,* https://orcid.org/0000-0001-8101-6247

Zelal Özgür Durmuş
*Graduate School of Science and Engineering, Hacettepe University, Ankara, Turkey.* https://orcid.org/0000-0003-3091-4279

Radka Marta Dvořáková,
*Faculty of Science, Department of Biology Education, Charles University, Prague, Czech Republic,* https://orcid.org/0000-0002-0118-829

Marcel Eens,
*Behavioural Ecology and Ecophysiology group, Department of Biology, University of Antwerp, Antwerp, Belgium.* https://orcid.org/0000-0001-7538-3542

Esra Eret,
*Center for Advancing Teaching and Learning, Middle East Technical University, 06800 Ankara, Turkey,*

Seckin Eroglu,
*Department of Biological Sciences, Middle East Technical University, 06800 Ankara, Turkey,*

Małgorzata Anna Gazda,
*CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO, Universidade do Porto, Vairão, Portugal;*
*Comparative Functional Genomics group, Institut Pasteur, Université de Paris, Paris, France* https://orcid.org/0000-0001-8369-1350

Martha Georgiou,
Department of Biology, *National and Kapodistrian University of Athens, Athens, Greece.* https://orcid.org/0000-0003-2762-5150

Neil J. Gostling,
*Faculty of Environmental and Life Sciences, The School of Biological Sciences, Southampton, United Kingdom* https://orcid.org/0000-0002-5960-7769

Tanja Gregorčič,

*Faculty of Education, Department of Biology, Chemistry and Home Economics, University of Ljubljana, Ljubljana, Slovenia*, https://orcid.org/0009-0007-6679-245X

Vanda Janštová,
*Faculty of Science, Department of Biology Education, Charles University, Prague, Czech Republic*, https://orcid.org/0000-0002-5950-5738

Tania Jenkins,
*Science II, University of Geneva, Geneva, Switzerland*. https://orcid.org/0000-0002-6816-3848

Anttoni Kervinen,
*Faculty of Educational Sciences, Faculty of Biological and Environmental Sciences, University of Helsinki, Helsinki, Finland*, https://orcid.org/0000-0003-1689-6457

Konstantinos Korfiatis,
*Department of Education, University of Cyprus, Nicosia, Cyprus*, https://orcid.org/0000-0003-0297-6499

Paul Kuschmierz,
*Institute for Biology Education, Justus Liebig University Giessen, Giessen, Germany*, https://orcid.org/0000-0001-8530-4342

Ádám Z. Lendvai,
*Department of Evolutionary Zoology and Human Biology, University of Debrecen, Debrecen, Hungary*, https://orcid.org/0000-0002-8953-920X

Joelyn de Lima,
*EvoKE (Evolutionary Knowledge for Everyone), Paris, France*, https://orcid.org/0000-0001-9235-9704

Fundime Miri,
*Department of Biology, University of Tirana, Tirana, Albania*, https://ocid.org/0000-0003-3817-4615

Teresa Nogueira,
*INIAV - National Institute for Agrarian and Veterinary Research, Vairão, Portugal; cE3c Center for Ecology, Evolution and Environmental Change & CHANGE - Global Change and Sustainability Institute, Faculdade de Ciências, Universidade de Lisboa, Lisbon, Portugal*, *https://orcid.org/0000-0002-0059-5177*

Andreas Panayides,
*Department of Education, University of Cyprus, Nicosia, Cyprus.* https://orcid.org/0000-0003-2607-7957

Sylvia Paolucci,
*Laboratorio di Scienze Sperimentali, Foligno, Italy*

Penelope Papadopoulou,
*Department of Early Childhood Education, University of Western Macedonia, Florina, Greece.*
https://orcid.org/0000-0001-9644-8798

Patrícia Pessoa,
*University of Trás-os-Montes e Alto Douro, Vila Real, Portugal,*
*Research Centre on Didactics and Technology in the Education of Trainers, Department of Education and Psychology, University of Aveiro,* Portugal https://orcid.org/0000-0001-8114-795X

Rianne Pinxten,
*Research Unit Didactica, Antwerp School of Education, Faculty of Social Sciences, University of Antwerp, Antwerp, Belgium*. https://orcid.org/0000-0001-5686-3284

Joana Rios Rocha,
*University of Trás-os-Montes e Alto Douro, Vila Real, Portugal,*
*Research Centre on Didactics and Technology in the Education of Trainers, Department of Education and Psychology, University of Aveiro, Aveiro, Portugal.* https://orcid.org/0000-0003-3106-8553

Andrea Fernández Sánchez,
*Department of Pedagogy & Didactics, Faculty of Educational Sciences, University of A Coruña, A Coruña, Spain,* https://orcid.org/0000-0002-8625-8955

Merav Siani,
*Department of Science Teaching, Weizmann Institute of Science, Rehovot, Israel;*
*Herzog College, Alon Shvut, Israel.* https://orcid.org/0000-0003-4321-3068

Elvisa Sokoli,
*Faculty of Social Sciences, University of Tirana, Tirana, Albania*.

Bruno Sousa,
*Alpoente - Albufeira Poente School Group, Albufeira, Portugal*. https://orcid.org/0000-0003-1497-030X

Panagiotis K. Stasinakis,
*Ampelokipoi Laboratory Centre for Natural Sciences (EKFE),* Athens, Greece,
https://orcid.org/0000-0002-3396-6464

Gregor Torkar,
*Faculty of Education, Department of Biology, Chemistry and Home Economics, University of Ljubljana, Ljubljana, Slovenia,* https://orcid.org/0000-0003-4125-8529

Asta Valackiene,
*Faculty of Public Governance and Business, Mykolas Romeris University, Vilnius, Lithuania,*
https://orcid.org/0000-0002-0079-9508

Máté Varga,
*Department of Genetics, ELTE Eötvös Loránd University, Budapest, Hungary,*
https://orcid.org/0000-0003-4289-1705

Lucía Vázquez Ben,
*Department of Pedagogy & Didactics, Faculty of Educational Sciences, University of A Coruña, A Coruña, Spain,* https://orcid.org/0000-0003-1685-5671

Anat Yarden,
*Department of Science Teaching, Weizmann Institute of Science, Rehovot, Israel.*
https://orcid.org/0000-0002-3948-9400

Xana Sá-Pinto,
*Research Centre in Didactics and Technology in Teacher Training (CIDTFF.UA), Department of Education and Psychology, University of Aveiro, Portugal,* https://orcid.org/0000-0002-6049-110X

**Word count**: **10.746**

## Abstract

The contribution of school curricula to public understanding and acceptance of evolution is still mostly unknown, due to the scarcity of studies that compare the learning goals present in different curricula. To overcome this lack of data we analysed 19 school curricula (18 European and one from Israel) to study the differences regarding the inclusion of learning goals targeting evolution understanding. We performed a quantitative content analysis using the Framework for the Assessment of school Curricula on the presence of Evolutionary concepts (FACE). For each country/region we analysed what this educational system considered the minimum evolution education a citizen should get. Our results reveal that: *i)* the curricula include less than half of the learning goals considered important for scientific literacy in evolution; *ii)* the most frequent learning goals address basic knowledge of evolution; *iii*) learning goals related with the processes that drive evolution are often not included or rarely mentioned; *iv*) evolution is most often not linked to its applications in everyday life. These results highlight the need to rethink evolution education across Europe.

Keywords: Evolution learning goals, Biology Education, Education Policy

## Introduction

Sustainability problems require long term solutions that account for the species' and populations' evolutionary potential and are informed by their past evolutionary history (Jørgensen et al., 2019). However, despite its undoubted importance, evolution is still poorly understood by many (Asghar et al., 2007; Athanasiou & Mavrikaki, 2014; Kuschmierz, Meneganzin, et al., 2020; Nehm, Poole et al., 2009; Pinxten et al., 2020; Prinou et al., 2008; 2011) and rejected by some (Weisberg et al., 2018; Brenan, 2019; but see Kuschmierz et al., 2021 for different results in European countries and Beniermann et al., 2022, for validity issues of measuring evolution acceptance). Understanding of evolutionary theory is both variable, and low across countries, even among biology teachers and university students enrolled in biology-related programs (Glaze & Goldston, 2019; Kuschmierz et al., 2021).

Several reasons have been put forward to explain this widespread lack of evolution understanding and acceptance including: *i)* evolution is perceived as being in conflict with religious beliefs (Asghar et al., 2007; Beniermann, 2019; Kuschmierz et al., 2021; Siani & Yarden, 2020); *ii)* cognitive biases that result in evolution misconceptions (Kelemen, 1999; Kelemen, 2012); *iii)* teachers' low pedagogical content knowledge and willingness to teach evolution (Gresch & Martens, 2019; Prinou et al., 2011; Stasinakis & Athanasiou, 2016; Cavadas & Sá-Pinto, 2021; Venetis & Mavrikaki, 2017; Ziadie & Andrews, 2018); *iv)* educational resources, including textbooks, that present evolution in isolated chapters (Bakanay & Durmuş, 2013; Cavadas, 2017; Nehm, Kim et al., 2009; Prinou et al., 2011; Sanders & Makotsa, 2016).

The way evolution is presented and articulated in school curricula may also affect students' understanding of the topic (Pinxten et al., 2020). A curriculum both identifies the learning goals that are considered relevant by a society (in a given context and time), and obliges school systems to implement instruction that enables students to meet those goals (Roldão & Almeida, 2018). In this paper, we define learning goals as the knowledge or skills a student should be able to demonstrate at the end of the course or topic, (Chasteen et al., 2011) and as such they can be either ‘content or practice learning goals’ (Fortus & Krajcik, 2012). Curricula should provide guidance i) at the administrative level, by setting the political-judicial as well as the institutional-organisational conditions for education, and ii) at the educational level, providing teachers with subject matter that is ordered and assigned to distinct periods, and a framework that is aligned within and between disciplines (Scholl, 2012). According to Reiser et al. (2007) and the National Research Council [NRC] (2012), evolutionary concepts should be integrated into the curricula of all grades, starting from kindergarten as introducing evolution at earlier stages may facilitate its understanding (Brown et al., 2020; Pinxten et al., 2020). The feasibility and benefits of doing so has been demonstrated by various researchers. Kindergarten and primary school students were shown to be able to learn about evolutionary processes such as natural selection and use that knowledge to explain or predict biological phenomena (Campos & Sá-Pinto, 2013; Kelemen et al., 2014; Emmons et al., 2017; Brown et al., 2020; Sá-Pinto, Pinto et al., 2021 ). Additionally, younger students easily overcome evolution misconceptions, which is more challenging for older students (Brown et al., 2020).

However, few studies have analysed how different school curricula integrate evolutionary concepts within the learning goals. Some explored the curricula for the presence/absence of evolution as a topic (Barberá et al., 1999; Tidon & Lewontin, 2004), the presence/absence of specific topics related to evolution (e.g., Quessada & Clement, 2011) or the relationship between religious views and scientific topics in the curricula (Asghar et al., 2010). While other studies analysed whether concepts required for understanding evolution were present in the curricula, these: *i)*only focused on a single curriculum (Asghar et al., 2015; Kuschmierz, Meneganzin et al. , 2020; Sanders & Makotsa, 2016; Skoog & Bilica, 2002); *ii)* used different analytical frameworks precluding comparative analyses across curricula (Asghar et al., 2015; Kuschmierz, Benierman et al., 2020; Sanders & Makotsa, 2016; Vázquez-Ben & Bugallo-Rodríguez, 2018); *iii)* focused on a limited set of concepts (Skoog & Bilica, 2002); *iv)* focused on higher grades excluding initial years of education (Skoog & Bilica, 2002). Despite their contribution to understanding how school curricula address evolution in specific countries or grades and to inform policy changes, the reported studies do not however allow us to compare how much emphasis is given to evolution in each country. A comparative analysis of the school curricula is needed to both evaluate the potential effects of curricula design on the understanding and acceptance of evolution, and the identification of lacunae related to key learning goals that are missing in some countries. Here, we present the first large-scale study of school curricula from Europe and Israel focusing on biological evolution, which aims to answer the following research questions:

1) Which evolutionary key concepts are present in European and Israeli school curricula?
2) From these, which are the most and least covered in these curricula?

## Methodology

### ***Sample***

We examined the school curricula of 17 European countries, Kosovo[1] and Israel (n=19, see

---

[1] Within the COST (European COoperation in Science & Technology) programme, Kosovo is considered a Near Neighbour Country (NNC) by the Committee of Senior Officials of COST. This designation is without prejudice to positions on status and is in line with UNSCR (United Nations Security

Table 1) that guided the respective educational systems in the school year 2018-19. The choice of curricula was based on the authors' response to an open call made at //// (removed for anonymity) (convenience sampling). In countries where there is no national school curriculum we analysed the curriculum of one of its regions: the curriculum from Flanders for Belgium, the curriculum from the state of Hesse for Germany, and the curriculum from England for the UK. The Kosovo curriculum refers to the Albanian population only. Information about the corresponding school systems can be found in Appendix A.

We decided to focus on the minimum evolutionary education, as defined by each educational system, received by a citizen within that system. Therefore, we analysed the school curricula from the 1st to 9th/10th grades (depending on the educational system, in some cases learning goals for 9th and 10th grades are combined in a single education cycle). This choice of grades corresponds to the Programme for International Student Assessment ( PISA) surveys which measure 15-year-olds' ability to use their reading, mathematics and science knowledge and skills to meet real-life challenges (Harlen, 2001). In most countries from the Organisation for Economic Co-operation and Development (OECD), students complete the compulsory education at age 15, and, in many countries, branch out from a common curriculum and start attending specialised educational programs (some with a strong science-based curriculum and others without). For England, we exceptionally included the 11th grade curriculum since it is combined with the 10th grade in Key Stage 4, and is common for all students (see Appendix B). We analysed the biology curriculum, if it existed, or in its absence, the Science or 'Study the Environment' or whatever discipline included the biology learning goals in each country.

---

Council Resolutions) 1244/1999 and the ICJ (International Court of Justice) Opinion on the Kosovo declaration of independence.

***Data analysis, framework and procedures***

Using quantitative content analysis (Patrick & Matteson, 2018) we analysed the 19 school curricula, using the Framework for the Assessment of school Curricula on the presence of Evolutionary concepts (FACE) as our coding scheme (for validity information see Table 1 in Sá-Pinto, Realdon et al., 2021). Inspired by the 'Understanding Evolution Conceptual Framework' (University of California, Museum of Paleontology, 2020), FACE provides insights into the evolution learning goals included in school curriculum. The instrument has six categories that represent conceptual dimensions that are important to ensure scientific literacy in evolution: History of Life (category 1), Evidence for Evolution (category 2), Mechanisms of Evolution (category 3), Studying Evolution (category 4), Nature of Science (NoS; category 5) and Development of Scientific Practices (category 6) (Sá-Pinto, Realdon et al., 2021). Learning goals can be further sorted into 35 subcategories (7 subcategories in the History of Life, 6 in Evidence for Evolution, 12 in Mechanisms of evolution, 4 in Studying evolution, 5 in the Nature of Science (NoS) and 1 in development of Scientific Practices; see the description of categories and subcategories of FACE at Table 2 and the guidelines of how to use it in Sá-Pinto, Realdon et al., 2021).

The unit of analysis was the 'meaning unit' – 'the constellation of words or statements that relate to the same central meaning' (Graneheim & Lundman, 2004, p. 106) - that could be a curriculum's learning goal - or a part of it - that fitted a FACE subcategory (e.g. '...they gradually realise that in nature there is a wide variety of living organisms…' was characterised as subcategory 2.1). Some learning goals might be repeated in a curriculum, e.g. due to its spiral development. We counted these learning goals as many times as they appeared as their repetition is indicative of the importance attributed to them by the curriculum designers.

Each curriculum was analysed by a team of two or more researchers - among the authors. These teams, composed by experts in evolutionary biology and/or in science education, included people who were born or lived where the school curriculum was applied. The exceptions were the UK and Kosovo, for which the analysis was performed by native speakers. The teams were instructed on how to use FACE by the project leaders before starting the analysis, following which each researcher independently analysed each curriculum, identifying meaning units, and assigning to them a FACE subcategory. Researchers then compared their coding within the teams, discussed possible disagreements and reached a consensus. The analyses were done by the national teams with the learning goals in the original language. When needed for discussion with the international team or for exemplifying one idea in the present paper, the native speakers translated specific learning goals to English. The national coordinators sent the final data from each country to the coordinators of the project, who compiled, processed and analyzed it. Although the above described process - given that coders were experts in evolutionary biology and/or evolution education and were trained to apply the FACE framework - establishes the credibility of our findings (Harris et al., 2006; Morgan, 2022), we further estimated the percentage of agreement between coders (Krippendorff, 2004), which, except for Albania and Kosovo (65% and 69% respectively), ranged between 76% to 98%.

Chi-square test were used to test for the differences in the distribution of the FACE categories and subcategories among the curricula. Significance level was set to $\alpha = 0.05$.

## Results

### *Analysis at the categories' level*

Our results show statistically significant differences between the absolute frequencies of each category among the analysed curricula ($\chi^2$ = 675.87, df=90, p<.001) (Table 1). One major difference is in the absolute number of goals that target evolution, with curricula from Hungary, Israel, Slovenia and Spain having more than 100 goals targeting evolution (n=109, 103, 135, and 227, respectively), while those from Belgium, Cyprus and Kosovo have 22 or less (n=15, 19, and 22, respectively). Another major difference was in the degree to which the FACE categories were represented in the different curricula, with 'Evidence for Evolution', and 'Studying Evolution' being, respectively, the categories with the highest and lowest representation of learning goals . The school curricula also varied in the absolute frequencies of FACE subcategories ($\chi^2$=1793.10, df=630 p<.001).

[Table 1 around here]

Strong variation between curricula can also be observed regarding the relative importance of each category (Figure 1): in eight of the 19 curricula the majority of learning goals are related to 'Evidence for Evolution', five curricula emphasise the 'Development of Scientific Practices', four emphasise 'Mechanisms of Evolution' and one emphasises 'History of Life''. In the Turkish curriculum, learning goals relative to 'Mechanisms of Evolution' and 'NoS' appear with equal frequency.

[Figure 1 around here]

***Analysis by subcategories***

With the exception of 'Evidence for evolution' all the categories had, on average, less than half of their subcategories covered in the curricula (Figure 2). Of these, 'Mechanisms of evolution' is the category with the lowest percentage (38% in average) of subcategories represented in the curricula's learning goals.

[Figure 2 around here]

[Table 2 around here]

Of the total 35 FACE subcategories, 18 are present, on average, less than once across the analysed curricula (when we divide the total number of times that a given FACE subcategory occurs in all the analyzed curricula by 19 - the number of the different curricula we analysed - we observe that eighteen subcategories are present, on average, less than once per curricula) (Table 2). In contrast, learning goals targeting the 'Development of Scientific Practices' (category 6), or '*Similarities and/or differences among existing organisms provide evidence for evolution*' (subcategory 2.1) and '*Organisms' features, when analysed in relation to their environment provide evidence for evolution*' (subcategory 2.6) appear more than five times on average.

The curricula of England, Hungary, Serbia, Slovenia, and Lithuania cover the highest number of FACE subcategories, while the curricula from Belgium, Cyprus, and Italy cover the fewest (Figure 3).

[Figure 3 around here]

This pattern slightly changes when we analyse each FACE category independently (see Figure 4).

For the category **'History of Life'**, learning goals relating to '*Anthropogenic environmental changes and biological evolution are linked*' (subcategory 1.4) are present in 14 curricula, while learning goals focusing on '*Rates of evolution vary*' (subcategory 1.6) appear in only two curricula (Figure 4A). While Albania, Belgium, and Cyprus only include learning goals belonging to one subcategory each, the curricula of England, Hungary, and Serbia cover a higher percentage of subcategories from 'History of Life' (Figure 4A).

For **'Evidence for Evolution'**, learning goals related to '*Similarities and/or differences among existing organisms provide evidence for evolution*' and '*Organisms' features. when analysed in relation to their environment provide evidence for evolution*' (subcategories 2.1 and 2.6) are covered by almost all the curricula (Figure 4B). In contrast, learning goals focusing on '*Evolution can be directly observed*' (subcategory 2.2) is only covered in 21% of the curricula (Figure 4B). The curricula of England and Hungary cover learning goals representing all the six subcategories of this category, while the curricula of Belgium, Cyprus, Finland, Israel, Lithuania and Poland only include learning goals covering two of these subcategories (Figure 4B).

[Figure 4 around here]

For **'Mechanisms of Evolution'**, learning goals relating to '*There is variation within a population*' (subcategories 3.2) and '*Living things have offspring that inherit many traits from their parents but are not exactly identical to their parents*' (subcategories 3.3) are most commonly found across the different curricula (Figure 4C). By contrast, only two curricula mention learning goals referring '*Genetic drift acts on the variation that exists in a population*' (subcategory 3.8). Curricula of England and Hungary cover learning goals from all but one subcategory from this category, while the curricula of Belgium, Cyprus, and Spain only include learning goals from one out of the twelve (Figure 4C).

For the category **'Studying Evolution'**, learning goals focusing on '*Classification is based on evolutionary relationships*' (subcategory 4.3) are covered by most of the curricula, while learning goals relating to '*Scientists study multiple lines of evidence about evolution*' (subcategories 4.1) are only mentioned in six curricula. Three national curricula - England, Hungary, and Lithuania - cover learning goals from the three subcategories, while most of the curricula analysed, only have learning goals related to one subcategory. Kosovo's curriculum does not have any learning goals from this category (Figure 4D).

In the category **'Nature of Science'** more than half of the analysed curricula have learning goals that focus on '*Science provides explanations for the natural world*' (subcategory 5.2) and '*Science is based on empirical evidence*' (subcategory 5.3). However, less than half of the curricula have learning goals related with the other subcategories. The curricula from Spain and England cover learning goals from all subcategories of this category, while the curriculum from Belgium does not have any learning goals that relate to this category (Figure 4E).

All the analysed curricula contain learning goals related with the **'Development of Scientific Practices'** (Figure 4F), except Cyprus.

## Discussion

Our results highlight that across Europe, school curricula do not fully recognise or emphasise the importance of evolution understanding, or promote its teaching across compulsory education as advised by educational research organisations (NRC, 2012, German National Academy of Sciences Leopoldina, 2017). In fact, our data shows that most curricula include less than half of the learning goals considered important to promote scientific literacy in evolution (as described in Sá-Pinto, Realdon et al., 2021 ). Additionally, the learning goals that are frequently mentioned are mostly relate to basic knowledge (Understanding Evolution, 2020), and given the absence of other important key concepts, this can potentially reinforce some misconceptions. Furthermore, the learning goals related with processes driving evolution are often not included (e.g. genetic drift and sexual selection) or, when included, are not emphasised. Finally, many curricula do not link evolution to its everyday life applications and implications.

The impact of these potential gaps in curricula for European public scientific literacy is still difficult to assess given the lack of studies performed using a common evaluation instruments to compare the understanding and acceptance of evolution across multiple countries (Kuschmierz, Meneganzin et al., 2020; Kuschmierz et al., 2021). One study that attempted to fill this lacuna included only first year university students enrolled in both biology-related and non-biology-related courses, with the proportion of both student groups varying across countries (Kuschmierz et al., 2021). As students enrolled in biology related courses have significantly higher knowledge about evolution than other students, it is difficult to directly compare these data to ours.

### *Learning about the History of Life*

The lack of emphasis on learning goals relating to the History of Life, may hinder development of students' understanding of deep time, which is a difficult concept for students (Dodick & Orion, 2003; Jaimes et al., 2020) but is fundamental to understand macroevolutionary processes, and has been shown to be correlated with the acceptance of evolution (Cotner et al., 2010; Kuschmierz, Beniermann et al., 2020). Our results show that learning goals specifically related to deep time (FACE subcategories 1.1 and 1.3) are only present in half of the analysed curricula. This scarcity of learning goals related to the historical temporal scales of changes in natural environments and patterns of extinction may also be limiting students' ability to compare current and past extinction rates (Cervato & Frodeman 2012; Wyner & DeSalle, 2020), and consequently, hamper their understanding of how humans are causing the so-called 'sixth mass extinction' (Hannah, 2021).

***Learning about Evidence for Evolution***

Learning about the “Evidence for evolution” can increase acceptance of evolution (Yasri & Mancy, 2016). However, only four of the curricula we analysed had learning goals that focused on more than three of the six FACE subcategories. These results highlight the need to include additional, diversified and age-appropriate, evidence supporting evolution in the adopted curricula. Learning goals focusing on ‘*Similarities and/or differences among existing organisms provide evidence for evolution*’ (subcategory 2.1) were the most frequent, and this was the only subcategory from FACE that is present in all the analysed curricula. This subcategory includes ideas related with the existence of biodiversity, a very basic learning goal that is expected to be present from the first years of schooling. The second most frequently found learning goal relates to ‘*Organisms’ features, when analysed in relation to their environment, provide evidence for evolution*’ (subcategory 2.6), which appears in all but one curriculum. This learning goal includes (but is not limited to) understanding that form is related to function. While this goal is very important for the understanding of evolution, if students are not taught that functions result from natural processes and that selection neither has intentions nor fulfils needs, it may result in or reinforce teleological misconceptions (Kampourakis, 2020). To avoid this undesirable outcome, the nuances of the relationship between form and function should be explored, informed by the process of natural selection and individuals’ fitness, thereby ensuring that students understand that ‘*Evolution does not consist of progress in any particular direction*’ (subcategory 3.12). However, from the 18 curricula that include subcategory 2.6, six do not include learning goals targeting the understanding of fitness or natural selection. Furthermore, in each curriculum, learning goals related with subcategory 2.6 are much more frequent than learning goals related with the processes of evolution. Together these results may at least partially explain the high level of teleological misconceptions identified in European students (Kuschmierz et al., 2021).

### ***Learning about the Mechanisms of Evolution***

The learning goals relative to the 'Mechanisms of evolution', that are present in most of the curricula we analysed (subcategories 3.2 and 3.3) are key ideas fundamental to understanding evolutionary processes (Tibell & Harms, 2017). But that, *per se*, is not enough to lead to evolutionary thinking, as these learning goals do not explore the mechanisms underlying the frequency change across generations. Only 10 of the national curricula we analysed had learning goals related to natural selection and much fewer covered sexual selection (four curricula) and genetic drift (two curricula). This illustrates the previously described discrepancy in importance, given by educational policies, educators and educational researchers, to natural selection, as compared to genetic drift and sexual selection (reviewed by Andrews et al. (2012) & Sá-Pinto et al. (2017)). This is concerning because, despite the importance of genetic drift to understand evolution and address social problems (Andrews et al., 2012), studies show that students both struggle to understand genetic drift, and also have multiple misconceptions about genetic drift (Andrews et al., 2012; Beggrow & Nehm, 2012). This problem is further exacerbated as teachers often have difficulties understanding drift themselves, or they fail to recognise the significance of drift and random processes in the context of evolution (Cavadas & Sá-Pinto, 2021; Hartelt et al., 2022; Venetis & Mavrikaki, 2017).

Even among the curricula that do have learning goals that relate to natural selection, most only mention it once. Additionally, as the concept of fitness is only addressed in four out of the 19 curricula, this may result in the strengthening of misconceptions about natural selection. Studies have shown that people, including high school and university students, fail to understand fitness (Kuschmierz et al., 2021), tend to believe that fitness is determined by the individuals' ability to survive, and fail to understand that these traits will be evolutionarily irrelevant if they do not result in a higher number of offspring (Gregory, 2009). As our results indicate, the low number of curricula exploring sexual selection is worrying, as learning about this process emphasizes the most important trait determining the fitness of an individual: its reproductive output (Sá-Pinto et al., 2017; Sá-Pinto et al., 2023). A recent study highlighting the importance of learning goals related to evolutionary fitness showed that after exploring educational activities that model sexual selection processes, elementary schools use the concept of differential reproduction significantly more often to reason about evolutionary processes (Sá-Pinto et al., 2023).

The paucity of learning goals relating to mechanisms of frequency change across generations in the curricula under analysis, does not account for the recent studies, which show that students can learn about these processes from an early age (Campos & Sá-Pinto, 2013; Kelemen et al., 2014; Emmons et al., 2017; Brown et al., 2020; Sá-Pinto, Pinto et al., 2021 , Sá-Pinto et al., 2023). These studies also show that introducing young students to natural selection may prevent the development and strengthening of evolution misconceptions (Brown et al., 2020) that are difficult to overcome at older ages (Bishop & Anderson, 1986; Nehm & Reilly, 2007).

### ***Learning about Studying Evolution***

Although many of today's problems affecting our species at the individual, local or global scales are due to evolutionary processes and require evolution knowledge-based solutions (Jørgensen et al., 2019), only seven out of the 19 curricula include learning goals related to daily life applications of evolutionary biology. Research suggests that many students do not use evolutionary principles to argue about complex social problems (Sadler et al., 2005) even though evolution is fundamental to predicting the outcomes of different solutions in future biological systems and to evaluating their potential strengths and limitations. Evolutionary understanding is essential for students' anticipatory competency and systems thinking that UNESCO (2018) and the European sustainability framework (Bianchi et al., 2022) identify as a key competency in education for sustainability. Therefore, exploring evolution within the scope of daily life examples and problems is advised by many science education organisations and movements (Fowler & Zeidler, 2016), and educators have developed resources to facilitate this exploration (see examples at Sá-Pinto et al., 2022) .

***Learning about the Nature of Science***

Understanding the NoS is fundamental for a person to be scientifically literate (Lederman, 2019; OECD, 2019). The understanding of the NoS has been shown to be positively correlated with people's acceptance of evolution (Cofré et al., 2018; Irez & Bakanay, 2011; Sieckel & Friedricksen, 2013; but see Coleman et al., 2015 for conflicting results), and evolution has been proposed as a topic with great potential to teach about NoS (National Academy of Sciences, 1998). NoS is one of the categories with the highest frequency and diversity of learning goals across the analysed curricula, although, in the majority of the curricula, less than half of the subcategories related to NoS are covered. However, NoS learning goals may also be present in the curricula of other science disciplines that we did not analyse (such as physics or chemistry for example) as this is a transversal topic in science education.

***Learning about the Scientific Practices***

Our results show that, except for Cyprus, all the curricula included learning goals related with scientific practices, which are important to foster the public's ability to evaluate scientific evidence and claims and distinguish these from non-science-based claims (NRC, 2012; OECD, 2019).

One important limitation of our study is related to the fact that analysed curricula vary greatly in extent and flexibility. While some curricula are very extensive, describing in detail the concepts to be taught and the goals that the students should achieve, others allow teachers and/or schools a much more flexibility (Thijs & Van Den Akker, 2009; Scholl et al., 2012). In some countries and regions, the national/regional learning goals are considered as minimum learning goals to which teachers and schools are expected to add more. In Flanders, for example, there are various educational networks, each developing their own specific, and much more detailed, learning plan, based on the minimum learning goals set by the Flemish curriculum. Trying to compare two curricula that vary in the degree of flexibility provided to teachers/school systems may be misleading, if the differences are narrowly interpreted. However, the existence or lack of concepts and goals in a curriculum not only reflects the importance given an the educational system to these concepts and goals (Roldão & Almeida, 2018), but also provides the reference framework for school textbook authors. A good example is the case of Turkey, where the most recent curriculum came into effect in 2018 and involved significant changes. The unit that could potentially cover mechanisms of evolution and fundamental concepts formerly named ‘The Beginning of Life and Evolution’, was renamed to ‘Living Beings and the Environment’. It covers essential evolutionary concepts like variation, adaptation, mutation, natural and artificial selection, and biodiversity. However, the term ‘evolution’ was removed from the curriculum and was not reintroduced, neither was the concept of evolutionary theory or Darwin. In the new curriculum, topics like the origin of life, the evolution of species, and the extinction of species have been entirely removed. The absence of the term ‘evolution’ poses a significant problem, as it is unclear how the mechanisms of the evolutionary process can be connected without the use of the term ‘evolution’. Whether teachers will use the term ‘evolution’, or not, will depend on their worldview and their understanding of biology. Along with other changes, the absence of the term ‘evolution’ anywhere in the curriculum indicates an intention, which is that evolution is not addressed.

Furthermore, as the curricula often clarify the schools’ and teachers’ legal obligations in terms of what they need to teach, teachers use the curricula to identify what they are allowed or not allowed to teach (Scholl et al., 2012). In this sense, adding particular learning goals to the curricula is expected to increase the chance of these being included in the content taught by teachers, and provide teachers a legal protection that may be particularly important in societies where the teaching of evolution is socially controversial.

Differences in the way school systems and/or teachers interpret and operationalise the learning goals in the curricula may either create opportunities for new learning goals to be set (Roldão & Almeida, 2018), or diminish the importance of some of the learning goals found in the curricula. This problem is further exacerbated by learning goals that are vaguely phrased, allowing multiple interpretations by teachers and authors of educational resources. Considering these caveats, curricula analyses provide a simplistic view of the content knowledge, skills and attitudes that students actually develop in the classrooms. Studies of classroom practices or educational resources used by teachers (such as textbooks and other educational materials) could potentially shed a brighter light on the ground reality. In this context, textbook analysis can be quite informative, as textbooks are the most often used educational resource, serving as primary organisers of the subject matter that students are expected to master, and, when it comes to evolution teaching, as the main authority to legitimise the topic (Chiappetta & Fillman, 2007; Yager, 1983; Goldston & Kyzer, 2009). It would also be important to explore teachers' trainings and practices. The latter are deeply influenced by the teachers' pedagogical content knowledge and several studies have shown that many teachers do not understand and are not prepared to teach evolution (Gresch & Martens, 2019; Muğaloğlu, 2018; Prinou et al., 2011; Sickel & Friedrichsen , 2013; Stasinakis & Athanasiou, 2016; Venetis & Mavrikaki 2017; Ziadie & Andrews, 2018). It is also important to stress that our results refer to the minimum knowledge about evolution that a student can gain in a country. In many countries, students may choose to pursue further optional studies in biology-related disciplines, and thus might achieve additional evolution-related learning goals. These optional pathways are not included in this analysis as we focused on what the general population of a country is expected to learn about evolution in school.

Our results provide the first description of how evolution is expected to be addressed in the early grades of education across multiple European countries and regions. This study creates the possibility of new research lines focusing on the impacts of curricula on students' scientific literacy, teachers' practices and educational resources contents. Furthermore, our results have implications for education policy and should foster discussions about curricular changes needed for long-term enhancement of public evolutionary literacy across Europe.

**Competing interests**

The authors report there are no competing interests to declare.

**Ethics statement**

No research based on human subjects was necessary for the development of this paper, therefore no ethics statement is needed.

**References**


Andrews, T. M., Price, R. M., Mead, L. S., McElhinny, T. L., Thanukos, A., Perez, K. E., Herreid, C. F., Terry, D. R., & Lemons, P. P. (2012). Biology Undergraduates' Misconceptions about Genetic Drift. *CBE—Life Sciences Education, 11*(3), 248-259. https://doi.org/10.1187/cbe.11-12-0107

Asghar, A., Bean, S., O'Neil, W., & Alters, B. (2015). Biological evolution in Canadian science curricula. *Reports of the National Center for Science Education*, *35*(5), 1.1–1.21.

Asghar, A., Wiles, J., & Alters, B. (2007). Discovering international perspectives on biological evolution across religions and cultures. *International Journal of Diversity in Organizations, Communities, and Nations*, *6*(4), 81–88. https://doi.org/10.18848/1447-9532/CGP/v06i04/39200.

Asghar, A., Wiles, J., & Alters B. (2010). The origin and evolution of life in Pakistani High School Biology. *Journal of Biological Education*, *44*(2), 65–71. https://doi.org/10.1080/00219266.2010.9656196

Athanasiou, K., & Mavrikaki, E. (2014). Conceptual inventory of natural selection as a tool for measuring Greek University Students' evolution knowledge: differences between novice and advanced students. *International Journal of Science Education, 36*(8), 1262-1285. https://doi.org/10.1080/09500693.2013.856529

Bakanay, Ç. D., & Durmuş, Z. Ö. (2013). Lise Biyoloji Öğretim Programında Evrim Eğitiminin Kapsamı ve İçeriğinin Değerlendirilmesi [Evaluation Scope and Content of Teaching Evolution in High School Biology Education]. *Trakya University Journal of Education, 3*(2), 92-103.

Barberá, O., Zanon, B., & Perez-Pla, J. F. (1999). Biology curriculum in twentieth-century Spain. *Science Education, 83*, 97–111. https://doi.org/10.1002/(SICI)1098-237X(199901)83:1<97::AID-SCE5>3.0.CO;2-8

Beggrow, E. P., & Nehm, R. H. (2012). Students' mental modes of evolutionary causation: natural selection and genetic drift. *Evolution: Education and Outreach, 5*, 429–444. https://doi.org/10.1007/s12052-012-0432-z

Beniermann, A. (2019). *Evolution—von Akzeptanz und Zweifeln. Empirische Studien über Einstellungen zu Evolution und Bewusstsein* [Evolution—about acceptance and concerns. Empirical studies on attitudes towards evolution and consciousness]. Springer Spektrum. https://doi.org/10.1007/978-3-658-24105-6

Beniermann, A., Moormann, A., & Fiedler, D. (2022). Validity aspects in measuring evolution acceptance: Evidence from surveys of preservice biology teachers and creationists. *Journal of Research in Science Teaching*, 1-43. https://doi.org/10.1002/tea.21830

Bianchi, G., Pisiotis, U., Cabrera Giraldez, M. (2022). *GreenComp – The European sustainability competence framework*. (M. Bacigalupo & Y. Punie, Eds). Publications Office of the European Union. doi:10.2760/13286, JRC128040.

Bishop, B. A., & Anderson, C. W. (1986). Student conceptions of natural selection and its roles in evolution. *Journal of Research in Science Teaching, 27*(5), 415-427. https://doi.org/10.1002/tea.3660270503

Brown, S.A., Ronfard, S., & Kelemen, D. (2020). Teaching natural selection in early elementary classrooms: Can a storybook intervention reduce teleological misunderstandings? *Evolution: Education and Outreach*, *13*, 12. https://doi.org/10.1186/s12052-020-00127-7

Brenan, M. (2019, July 26). 40% of Americans believe in creationism. Gallup. https://news.gallup.com/poll/261680/americans-believe-creationism.aspx

Campos, R., & Sá-Pinto, X. (2013). Early evolution of evolutionary thinking: Teaching biological evolution in elementary schools. *Evolution: Education and Outreach*, *6*(25), 1–13. https://doi.org/10.1186/1936-6434-6-25

Cavadas, B. (2017). On the Origin of Species: Didactic transposition to the curriculum and Portuguese science textbooks (1859-1959). *Espacio, Tiempo y Educación, 4*(2), 143-143. https://doi.org/10.14516/ete.149.

Cavadas, B., & Sá-Pinto, X. (2021). Conceções de Estudantes Portugueses em Formação Inicial de Professores sobre a Evolução e a Origem da Vida. *Revista Brasileira De Pesquisa Em Educação Em Ciências, 20*(u), 1339–1362. https://doi.org/10.28976/1984-2686rbpec2020u13391362

Cervato, C., & Frodeman, R. (2012). The significance of geologic time: Cultural, educational, and economic frameworks. In K. A. Kastens, & C. A. Manduca, (eds.), *Earth and Mind II: A Synthesis of Research on Thinking and Learning in the Geosciences - Geological Society of America Special Paper, 486,* (pp.19–27). Doi: 10.1130/2012.2486(03)

Chasteen, S., Perkins, K., Beale, P., Pollock, S., & Wieman, C. (2011). A thoughtful approach to instruction: Course transformation for the rest of us. https://www.researchgate.net/publication/228530662_A_Thoughtful_Approach_to_Instruction_Course_transformation_for_the_rest_of_us

Chiappetta, E. L., & Fillman, D. A. (2007). Analysis of five high school biology textbooks used in the United States for inclusion of the nature of science. *International Journal of Science Education*, *29*(15), 1847-1868.

Cofré, H. L., Santibáñez, D. P., Jiménez, J. P., Spotorno, A., Carmona, F., Navarrete, K., & Vergara, C. A. (2018). The effect of teaching the nature of science on students' acceptance and understanding of evolution: myth or reality? *Journal of Biological Education*, *52*(3), 248-261. DOI: 10.1080/00219266.2017.1326968

Coleman, J., Stears, M., & Dempster, E. (2015). Student teachers' understanding and acceptance of evolution and the nature of science. *South African Journal of Education*, *35*(2), 01-09. doi: 10.15700/saje.v35n2a1079

Cotner, S., Brooks, D. C., & Moore, R. (2010). Is the age of the earth one of our 'sorest troubles?' Students' perceptions about deep time affect their acceptance of evolutionary theory. *Evolution, 64*, 858-864. https://doi.org/10.1111/j.1558-5646.2009.00911.x

Dodick, J., & Orion N. (2003). Measuring student understanding of geological time. *Science Education*, *87*(5), 708-731.

Emmons, N., Lees, K., & Kelemen, D. (2017). Young children's near and far transfer of the basic theory of natural selection: An analogical storybook intervention. *Journal of Research in Science Teaching*, *55*(3), 321-347. https://doi.org/10.1002/tea.21421

Eurydice (2019). *The education system in the Republic of Slovenia*. (Ed. T. Taštanoska). Ministry of Education, Science and Sport of the Republic of Slovenia.

Fortus, D., & Krajcik, J. (2012). Curriculum Coherence and Learning Progressions. In B. Fraser, K., Tobin, & C., McRobbie (eds), *Second International Handbook of Science Education*.

*Springer International Handbooks of Education*, vol 24. Springer. https://doi.org/10.1007/978-1-4020-9041-7_52

Fowler, S. R., & Zeidler, D. L. (2016). Lack of evolution acceptance inhibits students' negotiation of biology-based socioscientific issues. *Journal of Biological Education, 50*(4), 407–424.

German National Academy of Sciences Leopoldina (2017). *Teaching evolutionary biology at schools and universities*. Deutsche Akademie der Naturforscher Leopoldina e.V. Nationale Akademie der Wissenschaften, Halle (Saale).

Glaze, A., & Goldston, J. (2019). Acceptance, Understanding & Experience: Exploring Obstacles to Evolution Education among Advanced Placement Teachers. *American Biology Teacher, 81*(2), 71-76. https://doi.org/10.1525/abt.2019.81.2.71

Goldston, M. J., & Kyzer, P. (2009). Teaching evolution: Narratives with a view from three southern biology teachers in the USA. *Journal of Research in Science Teaching*, *46*, 762-790. https://doi.org/10.1002/tea.20289

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today, 24*(2), 105–112. https://doi.org/10.1016/j.nedt.2003.10.001

Gregory, T. R. (2009). Understanding natural selection: Essential concepts and common misconceptions. *Evolution: Education and Outreach, 2*(2), 156–175. https://doi.org/10.1007/s12052-009-0128-1

Gresch, H., & Martens, M. (2019). Teleology as a tacit dimension of teaching and learning evolution: A sociological approach to classroom interaction in science education. *Journal of Research in Science Teaching, 56*(3), 243–69. https://doi.org/10.1002/tea.21518.

Hannah, M. (2021). *Extinction - Living and Dying in the Margin of Error.* Cambridge University Press.

Harlen, W. (2001). The assessment of scientific literacy in the OECD/PISA project. *Studies in Science Education, 36*(1), 79-103. doi: 10.1080/03057260108560168

Hartelt, T., Martens, H., & Minkley, N. (2022). Teachers' ability to diagnose and deal with alternative student conceptions of evolution. *Science Education*, *106*(3), 706-738. https://doi.org/10.1002/sce.21705

Harris, J., Pryor, J., & Adams, S. (2006). The challenge of intercoder agreement in qualitative inquiry. Retrieved April 17, 2023, from https://www.researchgate.net/publication/228490436_The_challenge_of_intercoder_agreement_in_qualitative_inquiry

Irez, O. S., & Bakanay, Ç. D. Ö. (2011). An assessment into pre-service biology teachers' approaches to the theory of evolution and nature of science. *Education and Science, 36*(162), 39-55.

Jaimes, P., Libarkin, J. C., & Conrad, D. (2020). College Student Conceptions about Changes to Earth and Life over Time. *CBE—Life Sciences Education*, *19(*3), ar35. https://doi.org/10.1187/cbe.19-01-0008.

Jørgensen, P. S., Folke, C., & Carroll, S. P. (2019). Evolution in the Anthropocene: Informing governance and policy. *Annual Review of Ecology, Evolution, and Systematics, 50*(1), 527–546. https://doi.org/10.1146/annurev-ecolsys-110218-024621

Kampourakis, K. (2020). Students' "teleological misconceptions" in evolution education: why the underlying design stance, not teleology per se, is the problem. *Evolution: Education and Outreach, 13*(1). https://doi.org/10.1186/s12052-019-0116-z

Kelemen, D. (1999). Why are rocks pointy? Children's preference for teleological explanations of the natural world. *Developmental Psychology*, *35*(6), 1440–1452. Doi: 10.1037//0012-1649.35.6.1440

Kelemen, D. (2012). Teleological minds: How natural intuitions about agency and purpose influence learning about evolution. In K. S., Rosengren, S. K., Brem E. M., Evans & G. M. Sinatra (eds), *Evolution Challenges: Integrating Research and Practice in Teaching and Learning about Evolution* (pp. 66–92). Oxford University Press.

Kelemen, D., Emmons, N.A., Schillaci, R. S., & Ganea, P. A. (2014). Young children can be taught basic natural selection using a picture storybook intervention. *Psychological Science*, *25*(4), 893-902. https://doi.org/10.1177/0956797613516009

Krippendorff, K. (2004). Reliability in Content Analysis: Some Common Misconceptions and Recommendations. Human Communication Research, *30*(3), 411–433. https://doi.org/10.1111/j.1468-2958.2004.tb00738.x

Kuschmierz, P., Beniermann, A., Bergmann, A., Pinxten, R., Aivelo, T., Berniak-Woźny, J., ... & Graf, D. (2021). European first-year university students accept evolution but lack substantial knowledge about it: a standardized European cross-country assessment. *Evolution: Education and Outreach*, *14*(1), 1-22. https://doi.org/10.1186/s12052-021-00158-8

Kuschmierz, P., Beniermann, A., & Graf, D. (2020). Development and evaluation of the knowledge about evolution 2.0 instrument (KAEVO 2.0). *International Journal of Science Education*, *42*, 2601–2629. https://doi.org/10.1080/09500693.2020.1822561

Kuschmierz, P., Meneganzin, A., Pinxten, R., Pievani, T., Cvetković, D., Mavrikaki, E., ... & Beniermann, A. (2020). Towards common ground in measuring acceptance of evolution and knowledge about evolution across Europe: a systematic review of the state of research. *Evolution: Education and Outreach*, *13*(1), 1-24. https://doi.org/10.1186/s12052-020-00132-w

Lederman, N. G. (2019). Contextualizing the relationship between nature of scientific knowledge and scientific inquiry implications for curriculum and classroom practice. *Science Education, 28*, 249–67. Doi: 10.1007/s11191-019-00030-8

Morgan, H. (2022). Understanding Thematic Analysis and the Debates Involving Its Use. *The Qualitative Report*, *27*(10), 2079-2091. https://doi.org/10.46743/2160-3715/2022.5912

Muğaloğlu, E. Z. (2018). An insight into evolution education in Turkey. In H. Deniz & L. Borgerding (Eds), *Evolution education around the globe* (pp. 263-279). Springer, Cham. https://doi.org/10.1007/978-3-319-90939-4_14

National Academy of Sciences (1998). *Teaching About Evolution and the NoS*. The National Academies Press. https://doi.org/10.17226/5787.

Nehm, R. H., Kim, S. Y., & Sheppard, K. (2009). Academic preparation in biology and advocacy for teaching evolution: Biology versus non-biology teachers. *Science Education*, *93*(6), 1122–1146. https://doi.org/10.1002/sce.20340

Nehm, R. H., Poole, T. M., Lyford, M. E., Hoskins, S. G., Carruth, L., Ewers, B. E., & Colberg, P. J. S. (2009). Does the Segregation of Evolution in Biology Textbooks and Introductory Courses Reinforce Students' Faulty Mental Models of Biology and Evolution? *Evolution: Education and Outreach, 2*, 527–532. https://doi.org/10.1007/s12052-008-0100-5

Nehm, R.H., & Reilly, L. (2007). Biology major's knowledge and misconceptions of natural selection. *BioScience*, *57*, 263–272. https://doi.org/10.1641/B570311

NRC (National Research Council) (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

OECD (2019). *PISA 2018 Assessment and Analytical Framework*. OECD Publishing. https://doi.org/10.1787/b25efab8-en.

Patrick, P., & Matteson, S. (2018). Elementary and middle level biology topics: a content analysis of Science and Children and Science Scope from 1990 to 2014, *Journal of Biological Education, 52*(2), 174-183. doi:10.1080/00219266.2017.1293556

Pinxten, R., Vandervieren, E., & Janssenswillen, P. (2020). Does integrating natural selection throughout upper secondary biology education result in a better understanding: a cross-national comparison between Flanders, Belgium and the Netherlands. *International Journal of Science Education*, *42*(10), 1609–1634. https://doi.org/10.1080/09500693.2020.1773005

Prinou, L., Halkia, L., & Skordoulis, C. (2008). What Conceptions do Greek School Students Form about Biological Evolution? *Evolution: Education and Outreach*, *1*(3), 312–317. https://doi.org/10.1007/s12052-008-0051-x.

Prinou, L., Halkia, L., & Skordoulis, C. (2011). The Inability of Primary School to Introduce Children to the Theory of Biological Evolution. *Evolution: Education and Outreach*, *4*(2), 275–285. https://doi.org/10.1007/s12052-011-0323-8.

Quessada, M. P., & Clément, P. (2011). The origin of humankind: a survey of school textbooks and teachers' conceptions in 14 countries. In A. Yarden & G. S. Carvalho (Eds), *Authenticity in Biology Education. Benefits and Challenges*, (pp. 295-305). ERIDOB & CIEC, Minho University.

Reiser, B., Duschl, R. A. (Ed.), Schweingruber, H. A. (Ed.), & Shouse, A. W. (Ed.) (2007). Taking science to school: Learning and teaching science in grades K-8. Committee on Science Learning, Kindergarten through 8th grade. National Research Council, Board on Science Education, Division of Behavioral and Social Sciences and Education. The National Academies Press.

Roldão, M. C., & Almeida, S. (2018). *Gestão curricular para a autonomia das escolas e professores.* Direção-Geral da Educação.

Sadler, T. D. (2005). Evolutionary theory as a guide to socioscientific decision-making. *Journal of Biological Education*, *39*(2), 68–72. https://doi.org/10.1080/00219266.2005.9655964

Sá-Pinto, X., Cardia, P., & Campos, R. (2017). Sexual selection: a short review on its causes and outcomes and activities to teach evolution and the nature of science. *American Biology Teacher*, *79*(2), 135-143. https://doi.org/10.1525/abt.2017.79.2.135

Sá-Pinto, X., Pinto, A., Ribeiro, J., Sarmento, I., Pessoa, P., Rodrigues, L., Vázquez-Bem, L., Mavrikaki, E., & Lopes, J. B. (2021). Following Darwin's footsteps: Evaluating the impact of an activity designed for elementary school students to link historically important evolution key concepts on their understanding of natural selection. *Ecology and Evolution*, *11*(18), 12236-12250. https://doi.org/10.1002/ece3.7849

Sá-Pinto, X., Realdon, G., Torkar, G., Sousa, B., Georgiou, M., Jeffries, A., ... & Mavrikaki, E. (2021). Development and validation of a framework for the assessment of school curricula on the presence of evolutionary concepts (FACE). *Evolution: Education and Outreach*, *14*(1), 1-27. https://doi.org/10.1186/s12052-021-00142-2

Sá-Pinto, X., Beniermann, A., Børsen, T., Georgiou, M., Jeffries, A., Pessoa, P., Sousa, B., & Zeidler, D.L. (Eds.) (2022). *Learning Evolution Through Socioscientific Issues*. UA Editora. https://doi.org/10.48528/4sjc-kj23

Sá-Pinto, X, Pessoa, P., Pinto, A., Cardia, P., Lopes, J.B. (2023). The Impact of Exploring Sexual Selection on Primary School Students' Understanding of Evolution. *Center for Educational Policy Studies Journal*, *13*(1), 121-141. https://doi.org/10.26529/cepsj.1508

Sanders, M. & Makotsa, D. (2016). The possible influence of curriculum statements and textbooks on misconceptions: The case of evolution. *Education as Change*, *20*(1), 216-238. https://doi.org/10.17159/1947-9417/2015/555

Scholl, D. (2012). Are the Traditional Curricula Dispensable? A Feature Pattern to Compare Different Types of Curriculum and a Critical View of Educational Standards and Essential Curricula in Germany. *European Educational Research Journal*, *11*(3), 328-341. https://doi.org/10.2304/eerj.2012.11.3.32

Siani, M., & Yarden, A. (2020). Evolution? I don't believe in it. *Science & Education, 29*, 411–441. https://doi.org/10.1007/s11191-020-00109-7

Sickel, A. J., & Friedrichsen, P. (2013). Examining the evolution education literature with a focus on teachers: major findings, goals for teacher preparation, and directions for future research. *Evolution: Education and Outreach*, *6*, 23. https://doi.org/10.1186/1936-6434-6-23

Skoog, G., & Bilica, K. (2002). The emphasis given to evolution in state standards: a lever for change in evolution? *Science Education*, *86*, 445–62. https://doi.org/10.1002/sce.10014

Stasinakis, P. K., & Athanasiou, K. (2016). Investigating greek biology teachers' attitudes towards evolution teaching with respect to their pedagogical content knowledge:

Suggestions for their professional development. *Eurasia Journal of Mathematics, Science and Technology Education*, *12*(6), 1605-1617. doi: 10.12973/eurasia.2016.1249a

Thijs, A. & Van Den Akker, J. (Eds.) (2009). *Curriculum in development*. Netherlands Institute for Curriculum Development (SLO).

Tibell, L. A. E., & Harms, U. (2017). Biological principles and threshold concepts for understanding natural selection Implications for the developing and visualization as a pedagogic tool. *Science Education*, *26*, 953–73. https://doi.org/10.1007/s11191-017-9935-x

Tidon, R., & Lewontin, R. C. (2004). Teaching evolutionary biology. *Genetics & Molecular Biology*, *27*(1), 124–31. https://doi.org/10.1590/S1415-47572004000100021.

UNESCO. (2018). *Issues and Trends in Education for Sustainable Development*. UNESCO Publishing. https://www.bic.moe.go.th/images/stories/ESD1.pdf

University of California, Museum of Paleontology (2020). *Understanding Evolution*. https://evolution.berkeley.edu/teach-evolution/conceptual-framework/

Vázquez-Bem, L., & Bugallo-Rodríguez, A. (2018). El modelo de evolución en el curriculum de Educación Primaria: Un análisis comparativo en distintos países. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 15*(3), 3101. doi:10.25267/Rev_Eureka_ensen_divulg_cienc.2018.v15.i3.310

Venetis, K., & Mavrikaki, E. (2017). Οι γνώσεις των εκπαιδευτικών θετικών επιστημών σχετικά με τους εξελικτικούς μηχανισμούς των ζωντανών οργανισμών. Στο Α. Πολύζος, & Λ. Ανθης, (Επιμ.), *Πρακτικά εργασιών* $4^{ου}$ *Πανελλήνιου Συνεδρίου «Βιολογία στην Εκπαίδευση»,* (σσ. 143–151). Πανελλήνια Ένωση Βιοεπιστημόνων [Knowledge of secondary education science teachers regarding the evolutionary mechanisms of living organisms. In A. Polyzos, L. Anthis (Eds.), *Proceedings of the 4th Panhellenic Conference "Biology in Education,* (pp. 143-151). Panhellenic Association of Bioscientists].

Weisberg, D. S., Landrum, A. R., Metz, S. E., & Weisberg, M. (2018). No missing link: Knowledge predicts acceptance of evolution in the United States. *BioScience*, *68*(3), 212-222. https://doi.org/10.1093/biosci/bix161

Wyner, Y., & Desalle, R. (2020). Distinguishing Extinction and Natural Selection in the Anthropocene: Preventing the Panda Paradox through Practical Education Measures. *BioEssays*, *42*(2), 1900206. https://doi.org/10.1002/bies.201900206

Yager, R. E. (1983). The importance of terminology in teaching K-12 science. *Journal of Research in Science Teaching, 20*(6), 577-588. https://doi.org/10.1002/tea.3660200610

Yasri, P., & Mancy, R. (2016). Student positions on the relationship between evolution and creation: what kinds of changes occur and for what reasons? *Journal of Research in Science Teaching*, *53*(3), 384–399. https://doi.org/10.1002/tea.21302

Ziadie, M. A., & Andrews, T. C. (2018). Moving evolution education forward: a systematic analysis of literature to identify gaps in collective knowledge for teaching. *CBE—Life Sciences Education*, *17*(1), ar11. Doi:10.1187/cbe.17-08-0190

## APPENDIX A

Short description of the educational systems that the analysed school curricula were derived from.

### ***Albania***

In Albania, according to the amended Law no. 69/2021 compulsory education comprises primary and middle school. It starts at the age of 6 (1st grade) and extends until the age of 15 (9th grade). Biology is taught within the ‘natural sciences’ curriculum from preschool and along primary and middle school (grades 1-9), under five major topics. Evolution is included in the Diversity topic. In middle school (grades 6-9), biology is taught separately, 2 hours per week. In primary school (grades 1-5), a teacher can teach all subject areas. In middle school, biology is taught by a science or natural science teacher, who has a bachelor’s in Biology or Biochemistry.

### ***Cyprus***

Cyprus has a centralised, public education system but also some private schools. The latter have their own curriculum, syllabus and tuition fees. In this study we focus on the public education system of the country, since it concerns the vast majority of school-aged children. Secondary Education is provided for students aged 12 to 18. For the public schools, it is offered through two three-year cycles - Gymnasium and Lyceum. The attendance is free of charge for all classes and compulsory until the age of 15 or the completion of the first cycle, whichever comes first. Biology in the public schools is taught as part of the ‘science’ subject during elementary school, while it is an independent subject during the high school years.

***Czech Republic***

Compulsory education starts at the age of 5 (one year in kindergarten) and lasts for 10 years . At school, first 5 years are primary education, after which there are two distinct educational pathways of secondary education: 1) the second grade of primary school (no entrance exam ), 2) ‘gymnasium’ (entrance exam ). Each school in the Czech Republic creates its own curriculum based on the National Curriculum issued by the Ministry of Education. In primary education, an integrated science program conveying general topics from biology and other sciences is taught, during lower secondary education, biology is a compulsory subject taught in every grade, usually twice a week.

***England, United Kingdom***

The 4 nations of the United Kingdom have different governmental education departments. In England, compulsory education begins in the academic year in which children become 5 years old (Reception/Year R), followed by 13 years, leading to GCSE in year 11 and culminating in A-Levels in Year 13. Science education is a compulsory part of the National Curriculum and includes education about evolution in years 5 and/or 6 (the last 2 years of primary school) and throughout secondary school years 7-9, with the greatest depth of concepts delivered in years 10 and 11 during GCSE teaching. After Year 11, Science is no longer compulsory, and A-Levels may include no science at all.

***Finland***

During the time of the study, there was a compulsory education up until 16 years (currently, 18 years). There is a single national core curriculum for grades 1 to 9 in Finland and it is to be used as a basis for the local curricula done by the organisers of the education, which can be, for example, municipality, private organisation or central government. Finnish students start school during the year that they reach 7 years. In primary education (grades 1-6), biology is part of the ‘environmental studies’ and in lower secondary school (grades 7-9), it is a separate subject. During lower secondary school, there are 7 courses of biology and geography in total, of which usually half is biology. Thus, biology is approximately 1,2 lessons per week. Some students might be enrolled in specific study lines, where there are more, for example, science classes, but these are usually only a course or two. Those who continue to upper secondary school have 2 mandatory and 3 optional courses of biology.

### *Flanders, Belgium*

Education is compulsory in Belgium from 5 till 18 years . Belgium is a federal state that is divided into three autonomous regions: the Flemish Region (or Flanders), the Brussels-Capital Region, and the Walloon Region. Flanders has a separate education curriculum and separate central education goals for primary and secondary education. . In Flanders, there are also various educational networks, such as the Catholic Schools, which each develop their own specific learning plans, based on the central education goals, but which are much more detailed. . We therefore only analysed the central education goals for K1-K10, set by the Flemish Ministry of Education.

During primary education (K1-K6), biology is taught as part of ‘World Orientation’. Since 2019-2020, the Flemish curriculum for secondary education is being modernized, implying that there are no specific courses defined but only education goals. The first cycle of two years (K7-8) is common for all students. For upper secondary education (K9–12), students have to choose between three types of secondary education, either preparing for the labour market, for higher education or for both, which each have their own specific education goals. We analysed the ‘Mathematics, Natural Sciences, Technology and STEM’ education goals . for the type of secondary education aiming for higher education for the second cycle (K9-10). It should be noted that evolution is specifically addressed in the education goals of the third cycle (K11-K12), which were not analysed in the present study.

***Germany***

In Germany, compulsory education starts at the age of 6 and goes up, depending on the degree, until the age of 14, 15 or 19, comprising 9, 10 or 13 years of education. It includes 9 or 10 years of basic education split into two parts (4 years of primary education, 5 or 6 years of lower secondary education). Those who are eligible after the 10 years of education have the option of receiving 3 years of higher secondary education.

During lower secondary education , Biology is a compulsory subject , in most German federal states as part of the subject ‘Science’ in Grades 5–6 . Also, Biology is not taught in every grade. During upper secondary education , Biology is an elective subject. If students choose Biology, they can attend either a basic course (typically 2–4 hours per week) or an advanced course (usually 5 hours per week).

***Greece***

In Greece, compulsory education starts at the age of 4 and goes up to 15 years old and it includes a total of 11 years of education. More specifically, 2 years of kindergarten, 6 years of primary school and 3 years of lower secondary education. During primary education biology is taught through concepts integrated in the unified curriculum of science, but in lower secondary education (7th to 9th grade) biology is taught as a separate subject, 1 hour per week.

***Hungary***

Compulsory education starts at the age of 3 in Hungary, with kindergarten. Children start elementary school at the age of 6-7 years and must stay within the system at least until 16 years of age. Secondary education is diverse, and children can choose from multiple secondary education types. The most common combination is 8 years of elementary school followed by 4 years of high-school (gymnasium) or 3-4 years of vocational education (8+4). It is also possible to enter a high school at 5th grade (4+8) or after 6th grade (6+6). Some high schools also offer a mandatory extra 'language year' in their educational program (8+5 and 6+7). During early elementary education biology is integrated into a unified science curriculum and becomes a separate subject only in the latter years of elementary school. In secondary education, biology is taught as a separate subject in 9-10th grades and then students can choose either to continue biology as an elective course or to enroll in a general science course. In the latter case, the contribution of biology to the general science curriculum may vary among schools.

***Israel***

In Israel education is compulsory from the age of 3 till 18 years. In primary school (1st to 6th grade) and in middle school (7th to 9th grade), science and technology are taught as one subject, including biology, chemistry, physics and technology. Science is studied 2-4 hours per week in primary school and 5 hours per week in middle school. In high school (10th to 12th grade), biology is an elective topic studied 5 hours per week.

***Italy***

In Italy, compulsory education starts at the age of 6 and extends for 10 years. The school system comprises primary school (grades 1-5), middle school (grades 6-8) and high school (grades 9-13). Until 8th grade the curriculum is unique for all students, then diverges for different school specialisations. Biology is taught within the ‘science’ curriculum from 3rd grade up to 8th grade and, for higher grades, within ‘natural sciences’. Curricula are issued by the Ministry of Education and are the same across the country, but teachers are free to choose textbooks and teaching methods.

***Kosovo***[2]

In Kosovo, basic or compulsory education comprises primary and middle school. Compulsory education is 9 years, from age 6 to 14 years old. It starts at the age of 6 (1st grade) and extends until the age of 14 (9th grade). The Kosovo school system in Albanian consists of preschool system (non-mandatory), primary school (grades 1-5; age 6-10), middle school (grades 6-9; age 11-14) and high school (grade 10-12; age 15-18).

***Lithuania***

In Lithuania, compulsory education starts from the age of 6 or 7 and extends until 16 years. It covers primary level and basic level of education. The school system in Lithuania consists of pre-primary education (not compulsory, lasts for 1 year, for children aged 5 to 7), primary education (compulsory, lasts for 4 years, for children aged 6 to 11), lower secondary education or basic education (compulsory, lasts for 6 years, for children aged 10 to 17), upper secondary education (non-compulsory, lasts for 2 years, for children aged 16 to 19).

***Poland***

[2] Within the COST programme, Kosovo is considered a Near Neighbor Country (NNC) by the Committee of Senior Officials of COST. This designation is without prejudice to positions on status and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

The Polish educational system consists of 8-year compulsory primary school and non-compulsory upper secondary education (4 or 5 years) or post-primary vocational schools (3-5 years). In primary education, lower grades of primary school (grades 1-3) are taught an integrated science program conveying general topics from biology and other sciences. In the 4th grade, biology is taught as part of an integrated ‘Natural Sciences’ subject – and it lacks any reference to evolution or its importance in biology. From the 5th grade, biology becomes a compulsory subject and its curriculum contains a clear reference to biological evolution. In the majority of cases, biological evolution is taught close to the end of primary school. In secondary school students select one of two options of further science education – either science subjects in an extended scope or an interdisciplinary supplementary subject (basic level).

***Portugal***

In Portugal, compulsory education starts at the age of 6 and goes up until the age of 18, comprising 12 years of education. It includes 9 years of basic education split into 3 cycles (4 years of first cycle, 2 years of second cycle and 3 years of third cycle) and 3 years of secondary education. In the first cycle of basic education, biology content is included in a multidisciplinary subject named 'Study of the Environment. In the second and third cycles of basic education biology is taught with geology in a subject called ‘Natural Sciences’. In secondary education students can opt, in the first two years, for the subject ‘Biology and Geology’ and in the last year for the subject Biology.

***Republic of Serbia***

Compulsory education in the Republic of Serbia commences at the age of 6, during the final year of kindergarten, providing essential preparation for the first grade of primary school. This six-month preparatory period ensures a smooth transition into formal education. Subsequently, primary school education begins with the 1st grade and continues for eight years, or until age 15. The primary school system is structured into two stages: lower grades ($1^{st}$-$4^{th}$) and higher grades ($5^{th}$-$8^{th}$). In the lower grades, biological topics are thoughtfully integrated into two subjects—The World Around Us (grades $1^{st}$-$2^{nd}$) and Nature and Society (grades $3^{th}$-$4^{th}$). Upon reaching the higher grades ($5^{th}$-$8^{th}$), students explore biology more deeply as a standalone subject, and Biology classes are conducted for 2 hours per week. Compulsory education ends with primary school.

***Slovenia***

C ompulsory school is divided into three three-year cycles (for students from 6 to 14 years old). The first six years can be recognised as the primary level. Grades 7–9 are internationally recognised as the lower secondary school (Eurydice, 2019). Upon completion of compulsory basic education, students – typically aged 15 – may choose to continue their education at the upper secondary level at a school and a programme of their own choice . Upper secondary education programmes are either general or vocational. The upper secondary educational qualification is awarded only after passing the final examination (mature, leaving examination) that grants also the right to enroll in higher levels (Eurydice, 2019).Biology learning objectives are included in four compulsory school subjects in nine-year compulsory school: Learning about the environment (1st, 2nd and 3rd grade), Science and Technology (4th and 5th grade), Science (6th and 7th grade), and Biology (8th and 9th grade). Biology education is also a part of upper secondary education in subjects of Biology, Science or Science and Society, depending on the study program in upper secondary school.

***Spain***

In Spain, compulsory education starts at the age of 6 and goes up until the age of 16, comprising 10 years of education. It is divided into primary education (6-12 years old) and secondary education (12-16 years old). For each stage, the Ministry of Education produces a general curriculum, with basic guidelines, that must be observed throughout the whole country. The different 'Autonomous Communities' may later adapt this document to make it more appropriate to their needs and context. In this paper, we present the analysis of the curricula produced by the Ministry of Education in 2014 (for primary education) & 2015 (for secondary education), still applicable at the moment of developing our project and writing down this paper.

During primary education , the science curriculum is common for all students and it is essentially covered in a subject called 'Natural Sciences', although some topics, e.g. the Solar System, or climate, might be addressed also/only in another subject called 'Social Sciences' .

In secondary education , all students attend Biology and Geology in 7th and 9th grade (in 8th grade, instead of Biology and Geology, students learn only about Physics and Chemistry; in 9th grade they have both). In 10th grade though, when evolution and genetics are specifically addressed, Biology and Geology becomes an optional subject.

***Turkey***

In Turkey, compulsory education comprises 12 years, and begins at 66 months in a 4+4+4 model (4-year elementary, 4-year middle school and 4-year high school). Children aged 60-66 months attend school voluntarily (with the permission of their parents). Science education continues under the name of the 'General Science lesson' from the 3rd to the 9th grade. While science lessons are conducted by the classroom teacher in the 3rd and 4th grades of primary school, science teachers guide students in science lessons from the 5th grade. In the 3rd grade, students who are introduced to science with the subject called 'the Layers of the Earth', enter biology with the subject of 'the

World of Living things' which focuses on the concepts of living and non-living things. In the 9th grade, the general science lesson is divided into physics, chemistry and biology branches. After this grade, biology lessons are taught by biology teachers. Physics, chemistry and biology courses are common in 9th and 10th grades and are available as elective courses in 11th and 12th grades. The intensity of the subject knowledge of physics, chemistry and biology courses in the program and the course hours vary according to the type of high school (in descending order: Science High school, General High School, Fine Arts High School, Social Science High School and Sports High School). In all school types, science lessons in 9th and 10th grades are two hours. At the beginning of the 11th grade, students in general high schools determine which class type (science or social) they want to choose and proceed in this direction. Students studying in other high schools (Science high school or Fine arts ext.) continue their education in this direction, since they have already chosen their field when starting the 9th grade.

## APPENDIX B

Number of coders per analysed school curricula and the school grades they covered along with the educational system they are part of. In countries where only a regional curriculum was analysed, this region is described in Table 3.

[Table 3 around here]

**Appendix C**

Absolute frequencies of the learning goals attributed to a FACE subcategory (see the definition of FACE subcategories in Table 2) per school curriculum and average frequency of learning goals assigned to a subcategory (Ave) (Table 4). Curricula of the distinct countries/regions are identified as following: Albania (AL), Belgium (BE), Cyprus (CY), Czechia (CZ), Germany (DE), England (EN), Finland (FI), Greece (GR), Hungary (HU), Israel (IL), Italy (IT), Kosovo (KO), Lithuania (LT), Poland (PL), Portugal (PT), Republic of Serbia (RS), Slovenia (SI), Spain (ES), Turkey (TR) (the abbreviations listed are for this table exclusively).

[Table 4 here]