Panayides *et al.*
Evolution: Education and Outreach (2024) 17:11
https://doi.org/10.1186/s12052-024-00203-2

Evolution: Education and Outreach

RESEARCH

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Evolution content in school textbooks: data from eight European countries

Andreas Panayides[1†], Xana Sá-Pinto[2*†], Evangelia Mavrikaki[3], Duur K. Aanen[4], Sara Aboim[5,6], Bento Cavadas[7,8], Radka Marta Dvorakova[9], Marcel Eens[10], Eliska Filova[11], Tanja Gregorčič[12], Nausica Kapsala[13], Mathijs Nieuwenhuis[4], Lino Ometto[14], Penelope Papadopoulou[15], Rianne Pinxten[16], Giulia Realdon[17], Nuno Ribeiro[18,19], José Luis Coelho da Silva[20], Bruno Sousa[21], Gregor Torkar[12] and Konstantinos Korfiatis[1*]

Abstract

Background Evolution is a unifying theme in biology and its understanding is essential to address sustainability problems. However, many people across the world do not understand evolution. Textbooks are among the most widely used educational resources and the way they depict evolution may greatly impact students' scientific literacy in evolution. In this paper we investigate which evolution concepts are addressed in European science textbooks, from the 1st to the 9th grade. A content analysis using the 'Framework for the Assessment of school Curricula on the presence of Evolutionary concepts", was performed on textbooks from eight European countries: Belgium, Cyprus, Czech Republic, Greece, Italy, Netherlands, Portugal and Slovenia. At least two experienced coders per country independently analysed the texts, images and activities, discussed the results and reached a final consensus.

Results Our results show that textbooks lack or rarely address concepts considered important for evolution understanding, notably the processes driving evolution and their daily life implications, limiting opportunities for education for sustainability.

Conclusions We recommend that science textbooks emphasize evolution and its processes since the first school years. This recommendation is particularly relevant for the analysed textbooks from Cyprus and Belgium, that cover less than 45% of the concepts important to evolution literacy.

Keywords Textbook analysis, Scientific literacy, Evolution education, Education for sustainability

Background

Evolution is a central and unifying theme in biology that provides a foundational framework for addressing a broad range of biological questions. An effective teaching of evolution is essential for students to understand and appreciate the explanatory and predictive power of this underlying framework (Alles 2001; Lloyd-Strovas and Bernal, 2012). Evolution is related to many current life experiences and problems, as diverse as resistance to drugs by microorganisms, to insecticide by mosquitos, and to herbicide by weeds, or the existence of allergies or food intolerances (Corbett et al. 2018). Furthermore, a basic understanding of evolutionary processes is fundamental to address a number of key socioscientific issues such as biodiversity loss, climate change, health, food security or pandemics (Carroll et al. 2014; Sá-Pinto et al. 2022).

†Andreas Panayides and Xana Sá-Pinto have contributed equally to this work.

*Correspondence:
Xana Sá-Pinto
xanasapinto@gmail.com
Konstantinos Korfiatis
korfiati@ucy.ac.cy
Full list of author information is available at the end of the article

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However, research shows that the theory of evolution is not sufficiently understood, or even accepted, by many people in different countries across the world (Athanasiou and Papadopoulou 2012; Lloyd-Strovas and Bernal, 2012; Miller et al. 2006; Miller et al. 2022; Sieckel and Friedrichsen, 2013). Many students do not fully understand evolution and hold remarkably high levels of alternative conceptions about basic evolutionary principles (see Gregory, 2009; Kuschmierz et al. 2021; Nehm and Schonfeld 2008).

To improve public scientific literacy in evolution, teaching evolution during compulsory education is of significant importance, not only for promoting the understanding of evolution but also for learning about scientific practices and the Nature of Science (NoS) (NRC, 2007; NRC, 2012). However, many studies indicate that the teaching at this level is unsatisfactory (Alters and Nelson 2002; German National Academy of Sciences Leopoldina, 2017; Glaze and Goldston 2015; Mead et al. 2017; Nehm et al. 2009) and continues to be surrounded by social controversies in many societies, including in European countries (Allgaier 2010; Asghar et al. 2014; Beniermann, 2019; Blancke et al. 2013; Cleaves and Toplis 2007; Graf 2011; Kutschera, 2008; McCrory and Murphy, 2009; Village and Baker 2013; Williams 2008; Williams 2009). Furthermore, evolution misconceptions are frequently spread through media, schools, textbooks and teachers (Dvořáková and Schierová, 2019; Prinou et al. 2011). Educators in formal education have the difficult task to overcome the usually misleading effect of media and other information sources on the correct understanding of evolution by youngsters (Alters and Nelson 2002; Hartelt et al. 2022).

The low level of public understanding of evolution has been attributed to many reasons, including curricula and textbooks inadequacies (Mavrikaki et al. 2024; Miller 2010; Sanders and Makosta, 2016). In some European countries and regions, curricula do not sufficiently explore evolution key concepts (Mavrikaki et al. 2024), which may result in students completing their formal education without having the necessary level of scientific literacy in evolution needed to understand and address some societal problems. In some countries, students are exposed to the Biblical myths of Creation in kindergarten and in elementary school, while science education starts years later and evolutionary biology is taught only briefly in high school classes (Kutschera, 2008). In some cases, science teachers and textbooks themselves reinforce misconceptions and unscientific ideas (Novitasari et al. 2019; Prinou et al. 2011; Rees 2007; Tshuma and Sanders 2015).

Textbooks as educational resources and how they represent evolution

In this paper we focus on how the science and biology textbooks depict and communicate knowledge about evolution. Textbooks play a significant role in education (Weiss et al. 2003) and their content and structure are very important for the promotion of a specific vision of a curriculum (Okeeffe 2013). In fact, science textbooks have a significant role on how science is taught and assessed and on the science classroom learning environments (Valanides et al. 2013). Science textbooks are often used as the primary organizer and source of the subject matter that students are expected to master. They provide detailed explanations of the topics to be taught and act as the main authority and a source of legitimacy that supports teachers while exploring evolution (Chiappetta and Fillman 2007; Goldston and Kyzer 2009; Miller 2010). In many cases, the textbook constitutes the 'delivered' curriculum, determining what teachers teach and what students are expected to learn (Chiappetta et al. 2002). As emphasized by DiGiuseppe (2014), in terms of science education, science textbooks continue to make an important contribution (Stern and Roseman 2004), purportedly accounting for 75–90% of instruction and 90% of all teacher-assigned homework (Chiappetta et al. 2006). Because of their central role in education, many nations invest heavily in creating and revising textbooks (Miller 2010; Stern and Roseman 2004; Swarts et al. 1994). Detailed analyses of biology textbooks across nations may be useful to enhance evolution education at both the national and global levels by providing: (i) concrete comparative data for guiding the development and revision of new textbooks, (ii) a summary of major themes, organizing principles, thoroughness of coverage, scientific accuracy, and degree of up-to-dateness of information, (iii) an assessment of the current level of biology education and baselines data on the biology curricula currently presented to students, and (iv) guidelines for policy on textbook design and reform (Swarts et al. 1994).

To date, few studies focused on the evolutionary content of biology textbooks. Asghar et al. (2014) found that, with the exception of Pakistani's textbooks, religion does not seriously compromise the evolutionary content in the textbooks of five muslim countries. However, they also noticed that human evolution was absent from all the analysed textbooks. The same result was found by Quessada et al. (2008) for six countries (Algeria, Malta, Morocco, Mozambique, Portugal and Tunisia). From the remaining 12 countries (a total of 28 books), the analysis of the textbooks' images revealed that they mostly represented human evolution depicting a white male dressed in occidental clothing,

with very few depicting human diversity in terms of gender or culture and/or children. Hanisch and Eirdosh (2022) studied German high school biology textbooks showing that these do not sufficiently integrate concepts such as cooperation and social learning, which were important for human evolution. Tshuma and Sanders (2015) highlighted the important misconceptions on evolution in two popular series of science textbooks in South Africa. Rees (2007) identified and discussed the historical accuracy about Charles Darwin's life and its contributions to evolution in 12 UK A-level textbooks. Cavadas (2017) showed that, even when the Portuguese state standards did not make that prescription, the majority of textbooks published between 1859 and 1959 addressed the mechanisms of Darwinian evolution. Laille (2010) analysed the presentation of Evolutionism in nineteenth century secondary school textbooks from Spain and England and concluded that textbooks where creationism was prevalent were frequent in Spain before 1874, with Darwin being increasingly cited in the textbooks after that. In the USA, Skoog (1979) concluded that the textbooks published between 1900 and 1919 eclipsed evolution, with only three, from the eight textbooks analysed, having chapters teaching this subject. Later, after the 1960s' curricular reconstruction stopped neglecting evolution, this theory came to have a significant expression in USA textbooks (Skoog 1979). Nehm et al. (2009) analysed the three best-selling introductory biology textbooks for majors in the USA and found that most of the evolutionary terms and concepts were isolated in the sections about evolution, thus precluding students to understand the central role played by evolution in biology. Finally, Miller (2010) described the controversy in Texas (USA) for excluding unscientific ideas, such as creationism, from school textbooks, and argued for the importance of providing scientifically correct and comprehensive textbooks to students and educators.

These studies mostly focus on the historical presence of evolution in textbooks and the conflicts generated by this presence (Cavadas, 2017; Laille 2010; Miller, 2006; Skoog 1979), the presence or absence of particular topics related with evolution (human evolution, nature of science, Gaia theory and the representation of Darwin's life; Asghar et al. 2014; Hanisch and Eirdosh 2022; Quessada et al. 2008; Rees et al. 2007; Vojir and Rusek, 2019); evolution misconceptions or biased representation (Prinou et al. 2011; Tshuma and Sander, 2015) and evolution integration across the curriculum (Nehm et al. 2009). However, up to our knowledge, no study compared, in a standardized way, how the different dimensions of evolution knowledge are present in textbooks of different countries. Here, we address this lack of information by analysing what dimensions of evolution knowledge are present in the context of the school textbooks that are used for biology teaching in eight European countries (Belgium, Cyprus, Czech Republic, Greece, Italy, the Netherlands, Portugal, Slovenia) and how these are addressed and integrated into the diverse biology concepts.

Methods

Sample

We analysed the science and/or biology school textbooks in use during the school year 2020–2021 in Belgium (the Dutch speaking Flanders region), Cyprus, Czech Republic, Greece, Italy, Netherlands, Portugal and Slovenia. These countries were members of the EuroScitizen COST Action (https://www.euroscitizen.eu/wg2-formal-education/), and their representatives voluntarily declared their interest to participate in the present research. EuroScitizen COST Action is an international network that aims to promote evolution literacy in Europe that was funded by COST Association and is now transitioning to the International Association EvoKE (https://evokeproject.org/) that aims to contribute to a world where people understand and use evolutionary principles to make informed decisions and address sustainability problems.

We selected the school textbooks used from the 1st until the 9th grade of each participating country. These school grades were chosen to meet 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). Furthermore, 9th grade is the end of the shared compulsory curricula in most of the analysed countries, with the exception of Italy (where the curriculum includes 9th and 10th grades in a single segment) and Belgium (here: 8th grade). After this year students can choose among several options, some of which do not include biology education. Therefore, we aimed at studying which characteristics of evolution education all children participating in each country's education system are potentially exposed to through their school textbooks. As for Italy, the same textbook is used for 9th and 10th grades, the results for this country include the evolution concepts that are explored in the textbooks during these two years which are clustered as a single segment in the Italian curricula.

The European education system is far from unified. For example, in some countries (e.g. Greece, Cyprus) there is only one textbook available that teachers can use, while in others (like Portugal) multiple different textbooks are available and teachers might choose among these. In our research we studied 67 school textbooks in total. A list and a short description of these textbooks

together with the criteria that led us to their choice, can be found at Additional File 1. For each country and grade we analysed the most commonly used book, except for Greece and Cyprus where there is only one official school textbook per grade that teachers can use. The number of books and volumes analysed differs from country to country because (i) in Italy the same textbook is used for several grades, as Italian curricula are divided by cycle and not by grade, so fewer textbooks were analysed for this country; (ii) in other countries, the same textbook is divided into more than one volume for some grades, but all volumes are mandatory for the respective grade, so we analysed all volumes. It should be noted, however, that the total number of references to a concept in the textbooks analysed, regardless of the number of books or even the number of pages of these books, represents the number of times a particular concept is used by a student up to grade 9.

Data analysis

A deductive content analysis was used to analyse textbooks, as it is appropriate to examine the messages derived from the artefacts (written, verbal or iconic) of a social communication (Weninger 2018).

Unit of analysis

The unit of analysis can vary from a word to an entire edition or volume, as discussed by Milne and Adler (1999) and Roller and Lavrakas (2015). Textbooks use various modes to present biological information and to foster students' learning. To analyse these diverse ways of presenting information, we employed different units of analysis based on definitions from Holsti (1969) and Krippendorff (2004) (see Table 1). This approach mirrors that used by Chiappetta and Fillman (2007) for textbook analysis. Below we define the distinct types of units of analysis.

Paragraphs

Paragraphs were used as the unit of analysis in the cases of plain texts. A paragraph is defined as 'a group of sentences or a single sentence that forms a unit' (Lunsford and Connors 1995, p.116), and a 'self-contained unit of discourse in writing dealing with a particular point or idea', constituting thus 'the building blocks of texts'.

Images

Images (including photos, drawings, tables, figures) are very common elements of school textbooks. In cases where an image contained essential information, it was included in the analysis, and each individual image/graph was considered as a unit of analysis. However, when a group of images were presented together, serving the same purpose (e.g. a group of photos of specimens of the same species aiming to show intra-specific variability), we considered the whole group of images/graphs as one unit.

Text/images

In some cases, text and image were complementary and inseparable to each other. In these cases, we considered the combination of text and image as one unit, rather than considering each one as a separate unit.

Activities

A common way for many textbooks to deploy their content is by proposing various kinds of activities, most of which combine practical exercises, tests, graph interpretation, images and worksheets. However, all activities are part of a task that has to be accomplished by the student. Therefore, we did not count each element of an activity as a separate unit, but rather considered each whole activity as one unit.

Framework of analysis

We used the Framework for the Assessment of school Curricula on the presence of Evolutionary concepts (FACE; Sá-Pinto et al. 2021b) to perform our analysis. FACE was developed as a framework for content analysis of school curricula. As school textbooks are used to facilitate the application of the curriculum, we considered it appropriate to be used as the framework of analysis. The FACE is divided into six categories and 35 sub-categories, capturing all the important aspects of evolution education (subcategories described at Additional File 2). Following the categories of FACE, our categories of analysis were: (1) History of Life, (2) Evidence for Evolution, (3) Mechanisms of Evolution, (4) Studying Evolution; (5) Nature of Science and (6) Scientific Practices (Sá-Pinto et al. 2021b). The two last categories are not specific to evolution education, but these were included in FACE as several studies suggest a significant correlation between understanding of the Nature of Science (NoS) and evolution acceptance and understanding (see for example Scharmann 2018; Nelson et al. 2019). Scientific practices are also an essential component of scientific literacy and its inclusion in the FACE framework was considered essential to ensure its validity and reliability (Sá-Pinto, 2021b). The category "studying evolution" includes only the concepts that help students understand how and why we study evolution, as this has been proven fundamental for people to accept evolution (Cooper, 2002). More information about this framework can be found in its original description (Sá-Pinto et al. 2021b).

Table 1 Examples of coding including sources, unit of analysis type and FACE subcategory

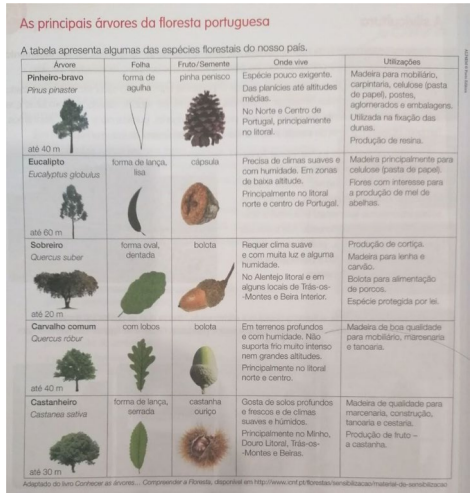
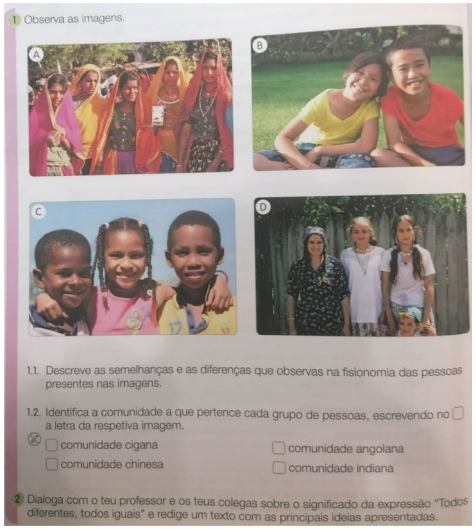
Example	Source (country, subject, grade, page)	Type of unit of analysis	FACE subcategory
Our body is similar to and different from other people's bodies. It is similar, as we have bones, muscles, joints, skin, etc. It differs because of our height, our weight, our color	Greece, Study of the environment, grade 4, p. 104	Paragraph	There is variation within a population (3.2)
Antibiotics, which are substances with antimicrobial activity, over time and their reckless use have become less effective against germs. In fact, penicillin, discovered by Fleming in 1920, has little effect today. How does this relate to Natural Selection?	Greece, Biology—grade 9, p. 140	Activity	Evolution can be directly observed (2.2)
 In some plants the seeds have a suitable construction that allows them to be carried away by the wind	Greece, Biology—grade 7, p. 31	Image	Organisms' features, when analysed in relation to their environment provide evidence for evolution (2.6)
	Portugal, Study of the Environment, grade 4, p.128	Text with Image	Similarities and/or differences among existing organisms (2.1)

Table 1 (continued)

Example	Source (country, subject, grade, page)	Type of unit of analysis	FACE subcategory
	Portugal, Study of the Environment, grade 3, p.54	Exercise	There is variation within a population (3.2)
At-home experiments: 1. Fill the plastic cup halfway with water. Carefully place it with your parents in the freezer. What will you see when you and your parents take it out of the freezer in the morning?	Czech Republic, Freshman 2, grade 2, p. 53	Practical exercise	Development of scientific practices (6)
What traits distinguish mammals from reptiles?	Czech Republic, Natural History 8, grade 8, p. 9	Exercise	Similarities and/or differences among existing organisms (2.1)
Cephalopods lived on Earth in very ancient times. Evidence of this are the fossils of their bodies in layers of limestone that formed at the bottom of prehistoric seas	Czech Republic, Natural History 6, grade 6, p. 61	Text	The fossil record provides evidence for evolution (2.3)
 *Stopy dinosaurů (západ Portugalska)* Dinosaur tracks (west of Portugal)	Czech Republic, Natural History 9, grade 9, p. 99	Figure	The fossil record provides evidence for evolution (2.3)

Coding

Coders familiarized themselves with the content of the selected textbooks, selected the units to be included into our analysis framework, and attributed a code to each unit, classifying it into the corresponding categories and subcategories. Coders were the 20 authors of this paper and were already familiar with the coding process or were trained either as a group or in face-to-face sessions. According to Krippendorff (2004), this, together with the extended information given about FACE in the paper by Sá-Pinto et al. (2021b) and the examples provided therein, that make the meaning of the categories and subcategories easily understood, satisfies the first requirement to generate reliable data using observed agreement. The other two requirements to generate reliable data according to Krippendorff (2004) were also satisfied, as (a) coders were familiar with the material (either teachers who would teach using these textbooks, textbook authors, textbook reviewers, biologists or biology education researchers), and (b) at least two coders independently analysed the textbooks of each country. Consensus was reached through discussion of conflicts and disagreements between coders for the units and their coding (Lombard et al. 2004). The consensus reached through these discussions also ensures the reliability of our results (Harris et al. 2006). Given the expertise of the coders, interrater reliability was estimated as the percentage of the initial agreement between coders (McHugh, 2012).

Validity and statistical analysis

To ensure the validity of our content analysis we followed the validation efforts proposed by Krippendorff (2004) as:

- *Face validity* was ensured by using the FACE (Sá-Pinto et al. 2021b) as the coding scheme. FACE has been proven to be a valid instrument to measure the coverage of evolution in the curricula.
- *Sampling validity* was ensured as the textbooks we chose accurately represent the textbooks that are used in each country (in some countries these are the only ones used, in the remaining countries we have chosen the most used textbook).
- *Semantic validity* was ensured as the categories and subcategories of FACE accurately describe the concepts that a student should know to understand the theory of evolution (Sá-Pinto et al. 2021b).
- The *internal structure validity* has also been ensured by Sá-Pinto et al. (2021b) in the development and validation of FACE.
- Finally, as similar research has not been carried out yet, *correlate validity* and *predictive validity* are not expected to be established.

Chi-square test was used to test for the differences in the distribution of the FACE categories and subcategories among the textbooks of each country.

Comparison between curricula and textbooks

To understand how the textbooks contents are related with the curricula guidelines when it comes to evolution key concepts, we used the data obtained by Mavrikaki et al. (2024) for the total number of times each FACE subcategory is found in the curricula of Flanders, Cyprus, Czech Republic, Greece, Italy, Portugal and Slovenia up to the 9th grade, with the total number of times that these categories appeared in the textbooks of these countries up to the same grade. The Netherlands was not included in this analysis as data for the curricula of this country was not available. We used a Shapiro–Wilk test for testing the normality of the data. As the data did not fit the normal distribution we performed a Spearman's rank correlation coefficient and estimated Spearman rho and the statistical significance of this test. All these analyses were done with SPSS.

Results

Interrater reliability was higher than 83% in all countries' analysis (97% for Belgium, 92% for Cyprus, 91% for Czech Republic, 96% for Greece, 86% for Italy, 95% for the Netherlands, 83% for Portugal, 96% for Slovenia). These values are higher than 70%, the threshold considered as acceptable for reliable data in the literature (Stemler, 2004, p.2).

Figure 1 shows the total number units of analysis attributed to FACE categories, in the school textbooks

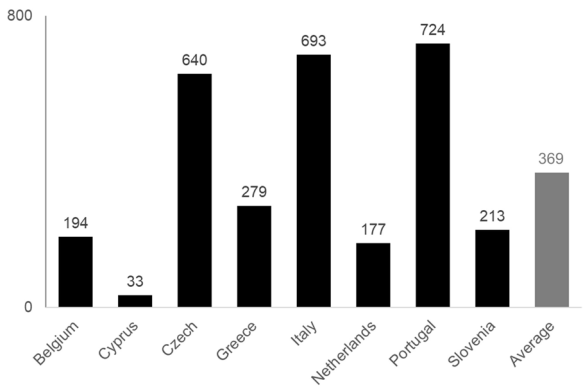


Fig. 1 Total references to FACE categories in school textbooks (grades 1–9) per country

studied per country. While the textbooks from Czech Republic, Italy and Portugal have more than 500 units of analysis related to evolution, those from Belgium, Cyprus, Greece, Netherlands and Slovenia have less than 280 references. Cyprus is the country with the least number of units of analysis related to evolution in its textbooks.

In all countries, except the Netherlands, concepts from Category 2 –'Evidence for Evolution'—were the most frequently addressed, but significant differences were found between these countries' textbooks regarding the frequency of the six FACE categories when all grades are considered ($\chi^2 = 588.55$, df = 35, $p < 0.001$, Fig. 2).

When all the countries are averaged, all FACE categories have less than 75% of their subcategories covered in the textbooks until 9th grade, with the exception of 'Scientific practices', which includes only one subcategory (Fig. 3). The most extreme situation is observed for the category 'Mechanisms of evolution'.

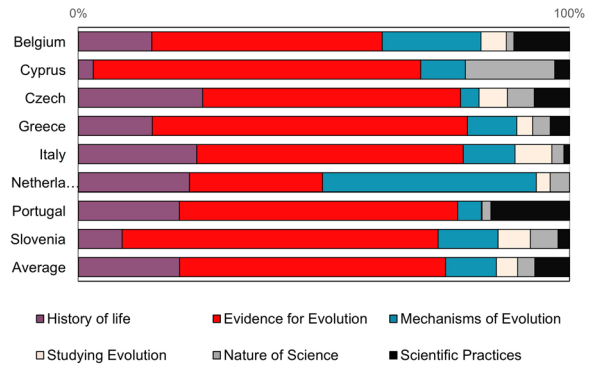


Fig. 2 Relative frequency of FACE categories in the countries' textbooks considering all grades

For this category, in 4 countries (Belgium, Cyprus, Czech Republic and Portugal), the most commonly used textbooks until 9th grade do not cover even half of the subcategories of this category (Fig. 3). The textbooks from Cyprus and Belgium address the lowest percentage of subcategories from the categories of 'History of Life' and 'Evidence from Evolution'. For 'Studying Evolution' the textbooks from Cyprus, Portugal and the Netherlands address the lowest percentage of subcategories, while the textbooks from Greece and Belgium address the lowest percentage of subcategories related with 'Nature of Science'. Evidence of the only subcategory of 'Scientific Practices' were found in the textbooks of all countries except those from the Netherlands.

When we analyse the absolute frequencies of each subcategory in the textbooks, additional patterns emerge (Fig. 4).

For the 'History of Life', the most striking pattern is the almost complete absence of subcategories in Cyprus. In this country, only one subcategory is present and found only once in the textbooks from all the nine grades. Overall, large differences in the frequencies of subcategories are found across countries.

For the 'Evidence of Evolution', the subcategories 2.1 ('Similarities and/or differences among existing organisms provide evidence for evolution') and 2.6 ('Organisms' features, when analysed in relation to their environment provide evidence for evolution') are frequently found in the textbooks of all countries. The subcategory 2.3 ('The fossil record provides evidence for evolution') is found in the textbooks of all countries except in those from Cyprus and Belgium. The remaining three subcategories (2.2, 2.4 and 2.5, see

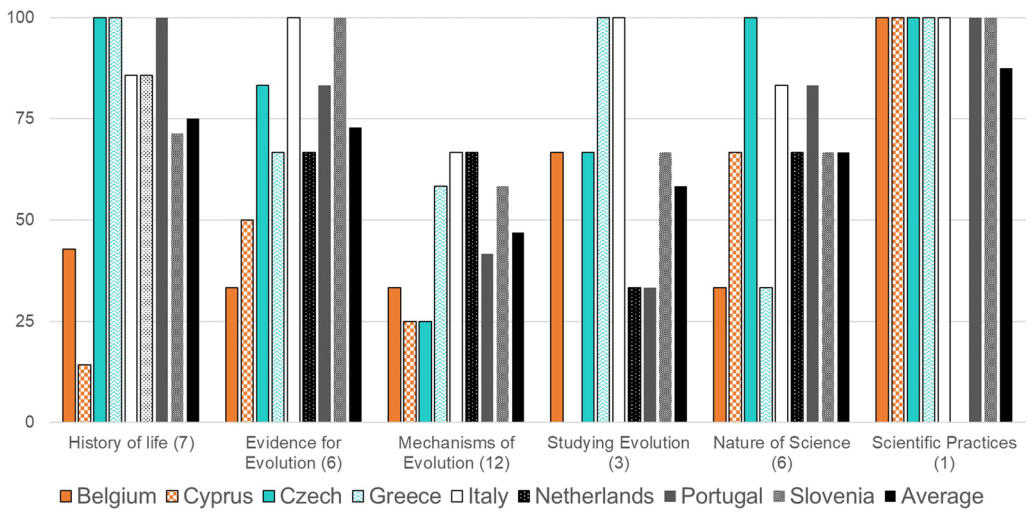


Fig. 3 Percentage of subcategories of each FACE category in countries' textbooks considering all grades



Fig. 4 Absolute frequencies of the subcategories in countries' textbooks considering all grades. **A** 'History of life', **B** 'Evidence for Evolution', **C** 'Mechanisms of Evolution', **D** 'Studying Evolution', **E** 'Nature of Science' and **F** 'Development of Scientific Practices' (Subcategories' codes in Additional File 2)

Additional File 2) are very infrequent and most often absent from the textbooks of all the countries.

Considering the 12 subcategories for 'Mechanisms of Evolution', except for Belgium, 3.2 ('There is variation within a population') and 3.3 ('Living things have offspring that inherit many traits from their parents but are not exactly identical to their parents') are the most frequently found in the textbooks of the countries, while subcategory 3.8 ('Genetic drift acts on the variation that exists in a population') is not addressed in any of the textbooks from the 1st to the 9th grade in all eight countries. Subcategories 3.4 ('Evolution occurs through multiple mechanisms') and 3.9 ('Fitness is reproductive success') occur very infrequently and in only one country each (Greece and Slovenia respectively).

For 'Studying Evolution', subcategory 4.3 ('Classification is based on evolutionary relationships') is the most frequently addressed in all countries, except in Greece, where subcategory 4.1 ('Scientists study multiple lines of evidence about evolution') is the most frequent instead.

For 'Nature of Science' there is strong variation between the countries' textbooks. The two most frequently addressed subcategories are 5.1 ('Science is a human endeavor') and 5.3 ('Science is based on empirical evidence'), while, on average, subcategory 5.5 ('Scientific theories are built through a transparent collective endeavor') is the least frequently mentioned.

Finally, for 'Scientific Practices', there is strong variation in the absolute frequencies between countries' textbooks. While in Portuguese textbooks 'Scientific Practices' are addressed more than 100 times, in the Netherlands these do not appear and, in textbooks of Cyprus, Italy and Slovenia these are addressed less than 10 times.

Comparison between curricula and textbooks

Our results show that the frequency of times that a given FACE subcategory appears in the textbooks of the countries is significantly correlated with the number of times it appears in the curricula of these countries (Spearman rho = 0,506; $p < 0.001$). Despite this, in each of these countries, the textbooks present a higher number of FACE subcategories than those observed in the curricula of the countries (approximately 62% of the subcategories are present at least once in the textbooks until the 9th grade, against 36% present in the curricula until this grade in the countries included in this analysis).

Discussion

Despite the importance of evolution as a central unifying principle required to understand biology (NRC, 2007; NRC, 2012) and to make informed decisions about globally important sustainability issues (Carrol et al. 2014), our results highlight that the textbooks most widely used from the 1st to the 9th grade in eight European countries exhibit important deficits in the way they cover evolution:

(1) For most countries, 30% or more of the concepts important for evolution understanding are not addressed.
(2) The concepts most frequently addressed are mostly promoting the basic ability to recognise the existence of biodiversity and, although essential, these are not sufficient for people to support and/or understand evolution.
(3) Concepts addressing the mechanisms of evolution are often not included (as it is the case for genetic drift and sexual selection (subcategories 3.8 and 3.7, respectively)) or, when included, they are not emphasized (as it is the case of natural selection (subcategory 3.5)) nor used as unifying key concepts;
(4) Half of the countries do not address the implications of evolution in our daily life.

Our results are aligned with those found by Kim and Chang (2003) that showed that the Korean textbooks lacked some fundamental concepts related to evolution, suggesting that the detected problems are universal, rather than strictly European. The textbook is the resource that teachers mostly use in the classroom, serving as a source of information, knowledge, program and scientific authority (Chiappetta et al. 2006, 2002; Chiappetta and Fillman 2007; Goldston and Kyzer 2009; Miller 2010). Given this, the lack of important evolution concepts up to the 9th grade, suggests that many students may leave mandatory education without ever addressing them. These results mirror those obtained in a curricula analysis that included the same countries (except the Netherlands; Mavrikaki et al. 2024). Our results show that the textbooks reflect the learning goals included in the official curricula and the number of times a given FACE subcategory is included in the textbooks until the 9th grade are correlated with the number of times it appears in the countries' curricula. However, the textbooks include additional contents and concepts, enriching evolution education. This is probably due to the examples provided and/or the conceptual links highlighted by the book authors. Despite this, textbooks show the same patterns and problems found in the curricula mostly focusing on basic evolution learning goals, not sufficiently addressing evolutionary mechanisms and not addressing the implications of evolution in our daily lives. This further reinforces the need to change the official curricula of the countries, to allow students to explore evolution and evolutionary processes since primary schools, and how these are linked to daily life problems and situations. A deep exploration of these key ideas is fundamental for students to develop their scientific and evolutionary literacy (Mavrikaki et al. 2024; Kampourakis, 2022). With the exception of the Netherlands, more than 45% of the references to evolution found in the textbooks were related with 'Evidence for Evolution', and from these, most, are related with identifying differences and similarities between organisms (category 2.1). Although this is a fundamental concept in biology, it is, per se, not sufficient for people to support and/or understand evolution. The second most frequently mentioned concept (subcategory 2.6 'Organisms' features, when analysed in relation to their environment provide evidence for evolution') is also problematic if not explored in the light of natural, sexual and artificial selection, as it may result in or reinforce existing teleological misconceptions (Kampourakis, 2020). This is particularly worrying as this concept

appears on average almost six times more often in the textbooks than the FACE subcategories related with natural and sexual selection, thus providing many opportunities to reinforce misconceptions that are frequent in European students (Kuschmierz et al. 2021).

The mechanisms of evolution are poorly explored in the textbooks until the 9th grade in most of the countries analysed. In almost all countries the textbooks address evolution by natural selection in at least one unit of analysis (subcategories 3.5 and 3.6). However, in the textbooks from Cyprus, Czech Republic, Greece, Portugal and Slovenia, only nine or less references were found. This shows that in the textbooks of these countries natural selection is mentioned, on average, only one time or less per grade. This pattern strongly contrasts with the central unifying role of evolutionary processes in biology and clearly shows that these processes are barely used to link concepts from the diverse biology subdisciplines and/or to make sense of these as it would be expected, a pattern also found by Nehm et al. (2009) when analysing three American best seller textbooks. In some countries, like Belgium, evolutionary processes are explored mainly at higher school grades (Pinxten et al. 2020), likely assuming these concepts may be understood only by older students. However, several recent studies show that students can learn about natural selection since elementary school and that teaching this process at these young ages may allow students to more easily overcome misconceptions, than doing it at older stages (Brown et al. 2020; Campos and Sá-Pinto, 2013; Emmons et al. 2017; Kelemen et al. 2014; Pinxten et al. 2020; Sá-Pinto et al. 2021a). Other concepts that explicitly address evolution as allele frequency change across generations, are even less present in the analysed textbooks. Genetic drift is not covered in any of the textbooks from any of the countries analysed and the idea that evolution occurs through multiple mechanisms is only explored once in Greece. Sexual selection, as a mode of natural selection, is only addressed in the textbooks of half of the countries analysed (Belgium, Greece, Italy and the Netherlands) and even in these countries only three times or less. This observation is aligned with those from previous studies that show that educators, education researchers and curricula give stronger emphasis to natural selection than to genetic drift and sexual selection (Mavrikaki et al. 2024; also see review at Andrews et al. 2012). However, it also shows that sexual selection and drift are barely covered in the analysed textbooks until the 9th grade. This observation is not in alignment with recent studies that show that students can learn about sexual selection from elementary schools (Sá-Pinto et al. 2023). These studies also suggest that exploring sexual selection may contribute for students to better understand natural selection, by promoting understanding of differential reproduction (Sá-Pinto et al. 2023), the key concept that tends to be less frequently mentioned by elementary school students when they explore natural selection (Sá-Pinto et al. 2021a). Many people hold misconceptions related to fitness, believing that it is determined by individuals' ability to survive and not relating fitness with individuals' reproductive output (Gregory, 2009). This highlights the need to further explore sexual selection and its outcomes in textbooks since elementary schools (Sá-Pinto et al. 2023; Sá-Pinto et al. 2017). The complete absence of references to genetic drift in all textbooks from all the countries we analysed until the 9th grade mirrors the results found when analysing the official curricula of most of the analysed countries (Mavrikaki et al. 2024). But genetic drift is a pervasive process that strongly impacts population divergence, genetic diversity and consequently species' adaptive potential. Understanding genetic drift may also contribute for students to understand the role and significance of chance and randomness in evolution, a threshold concept for evolution understanding according to Tibell and Harms (2017) and to address important socioscientific issues. Despite the importance of genetic drift, many students hold important misconceptions about this process (Andrews, 2012) and many teachers fail to understand it, or even recognise its existence and importance (Hartelt et al. 2022; Venetis and Mavrikaki, 2017). The study of Campos and Sá-Pinto (2013) suggests that genetic drift can be explored with elementary school students with some success, although a deeper analysis and more studies focusing students' learning outcomes about this process would be needed. If confirmed, these results would support the importance of introducing key concepts essential to understanding genetic drift (as those proposed by Price et al. 2014) in the shared curricula. This is expected to result in the introduction of these concepts in textbooks, supporting teachers' in their teaching practices and students in their learning processes.

In half of the countries, the most used textbooks do not provide examples of applications of evolution in our everyday life (subcategory 4.2) while in the other half, this is explored at maximum 2 times across the nine grades. The same trend is observed in education research: a recent literature review shows that very few studies addressed evolution education to promote education for sustainability (Pessoa et al. 2022). These findings contradict the recommendations of several education institutions, researchers and movements (Fowler and Zeidler 2016; NRC, 2012; Sadler 2005; Sá-Pinto et al. 2022 and chapters there in) and is particularly worrying, as some of the most pressing sustainability problems

we face require solutions and decisions informed by evolutionary biology (Carrol et al. 2014; Jeffries, 2022; Jørgensen et al. 2019). The fact that sustainability problems are not explored in the light of evolution may preclude students to understand how evolutionary processes can be used to develop and evaluate solutions. In fact, a study done in the USA shows that many students do not apply evolution concepts to reason about complex problems (Sadler et al. 2005).

We would like to highlight here that this is not a comparative study, in the sense that we do not aim to evaluate which country has the 'best' textbooks. We rather try to present the situation from different European countries with different cultural traditions and education systems, in order to create an idea of the current situation of evolution education in Europe. In fact, in some of the countries included in this study there are many textbooks available for each grade from which the teachers can choose from. Although we analysed the most widely used textbooks for these countries, many students may be using other textbooks that cover a different set of evolutionary concepts, which is an important limitation of our study. We should also highlight that, although textbooks are among the most widely used resources in the classrooms, teachers can complement these with additional resources and activities. This precludes us to make strong inferences relative to what is actually explored in the classrooms. Future studies may focus on teachers' practices relative to evolution education. Furthermore, the results here reported do not allow us to understand when a given concept is first introduced across the school grades analysed, nor how this concept is explored. This information is however important to understand how evolution is approached in the textbooks of the different countries and to provide more detailed recommendations. This highlights the need for further studies focused on how and when the different evolution concepts are explored in the textbooks across the different grades. These analyses are particularly important as several studies support the importance of evolution education since the first school years (Brown et al. 2020; Campos and Sá-Pinto, 2013; Emmons et al. 2017; Kelemen et al. 2014; Pinxten et al. 2020; Sá-Pinto et al. 2021a). It is also important to understand how evolution education in higher grades (including upper secondary education not addressed in this study) builts on the learning goals explored in the first school years. Finally, additional studies that perform a more detailed comparison between our results and those of the recently published curricula analyses in the same countries (Mavrikaki et al. 2024) are important to better understand how textbook authors implement curricular recommendations and whether and how textbooks allow us to overcome the limitations observed in the curriculum.

Conclusions and recommendations for textbook authors

Our results show that textbooks from the 1st to the 9th grade from Belgium (Flanders), Cyprus, Czech Republic, Greece, Italy, Netherlands, Portugal and Slovenia display several problems in the way they cover evolution. Based on our results, we recommend textbook authors to more deeply explore evolution and evolutionary processes starting from the first school years, avoiding reinforcing students' misconceptions (NRC, 2007, 2012). This should be done by integrating evolution in other biology topics as an unifying concept throughout students' learning progressions (as emphasized by Nehm et al. 2009 and Pinxten et al. 2020) and highlighting its relationship with sustainability complex problems (Sá-Pinto et al. 2022 and references therein). Although this recommendation is important for most countries, the need to increase book contents related to evolution is particularly relevant for countries such as Cyprus and Belgium (Flanders), where the coverage of evolution from the 1st till the 9th grade is particularly scarce. For teachers, we would recommend to complement the textbook information and activities with additional educational resources and practices that allow students to explore the evolution learning goals absent from textbooks.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12052-024-00203-2.

Additional file 1. Information about the educational systems and list of analysed textbooks from each country.

Additional file 2. Absolute frequencies of the learning goals attributed to a FACE subcategory per country and average frequency of learning goals assigned to a subcategory.

Acknowledgements

This article is based on work from the project COST Action EuroScitizen: Building on Scientific Literacy in Evolution Towards Scientifically Responsible Europeans (CA17127), supported by COST (European Cooperation in Science and Technology). This work is funded by national funds through FCT—Fundação para a Ciência e a Tecnologia, I.P., under the Scientific Employment Stimulus—Individual Call—2022.06070.CEECIND/CP1720/CT0041 (https://doi.org/10.54499/2022.06070.CEECIND/CP1720/CT0041) and the CIDTFF Research Centre (projects UIDB/00194/2020 and UIDP/00194/2020). Nuno Ribeiro is supported by the FCT/Portuguese Foundation for Science and Technology under grant CEECIND/00506/2018 (https://doi.org/10.54499/CEECIND/00506/2018/CP1557/CT0002). Gregor Torkar and Tanja Gregorčič are supported by the project "Za kakovost slovenskih učbenikov" (For the Quality of Slovenian Textbooks, https://kauc.splet.arnes.si), which is co-funded by the Republic of Slovenia and the European Union from the European Social Fund.

Author contributions

Kostas Korfiatis, Duur K. Aanen, Xana Sá-Pinto and Evangelia Mavrikaki were involved in the conception of this research project. Kostas Korfiatis led

the project ensuring the communication with all national teams. Andreas Panayides and Xana Sá-Pinto analysed the data, prepared the figures and led the writing of the paper. Bruno Sousa, Rianne Pinxten, Giulia Realdon, Gregor Torkar, Evangelia Mavrikaki, Kostas Korfiatis and Duur K. Aanen were the national team leaders, ensuring the communication with the project leader as well as the collection, comparison of the individual analysis, the discussion and the agreement on a final coding for all the units of analysis. All the authors of this paper were involved in the textbook analysis, reviewed the manuscript and approved its final version.

Funding
This article is based on work from the project COST Action EuroScitizen: Building on Scientific Literacy in Evolution Towards Scientifically Responsible Europeans (CA17127), supported by COST (European Cooperation in Science and Technology). Xana Sá-Pinto is funded by FCT—Fundação para a Ciência e a Tecnologia, I.P., under the Scientific Employment Stimulus—Individual Call—2022.06070.CEECIND/CP1720/CT0041 (https://doi.org/10.54499/2022.06070.CEECIND/CP1720/CT0041). Nuno Ribeiro is supported by the FCT/Portuguese Foundation for Science and Technology under grant CEECIND/00506/2018 (https://doi.org/10.54499/CEECIND/00506/2018/CP1557/CT0002). Gregor Torkar was supported by the project Za kakovost slovenskih učbenikov [For the Quality of Slovene Textboks], which is co-funded by the Republic of Slovenia and the European Union from the European Social Fund, and by the project Developing the Twenty-first Century skills needed for sustainable development and quality education in the era of rapid technology-enhanced changes in the economic, social and natural environment, no. J5-4573, funded by Slovenian Research And Innovation Agency.

Availability of data and materials
Data provided in Appendix File 2.

Declarations

Competing interests
Bento Cavadas, Bruno Sousa, and Nuno Ribeiro authored natural sciences textbooks from 2020 onwards. None of the textbooks analyzed in this paper are authored by any of them and these are published by a different editorial house. José Luis Coelho da Silva authored an unrelated natural sciences textbook, also not analysed in this paper, published by the same house editing the majority of the Portuguese textbooks in this analysis. Evangelia Mavrikaki authored Biology textbooks that were analyzed in this paper, however she was not among the coders of these books and neither did she intervene in their results. The remaining authors declare that they have no competing interests.

Author details
[1]Department of Education, University of Cyprus, Nicosia, Cyprus. [2]Research Centre on Didactics and Technology in the Education of Trainers, Department of Education and Psychology, University of Aveiro, Aveiro, Portugal. [3]Department of Pedagogy and Primary Education, National and Kapodistrian University of Athens, Athens, Greece. [4]Department of Plant Sciences, Laboratory of Genetics, Wageningen University, Wageningen, The Netherlands. [5]Polytechnic of Porto: School of Education, Porto, Portugal. [6]inED - Centre for Research and Innovation in Education, Porto, Portugal. [7]Polytechnic University of Santarém/School of Education, Santarém, Portugal. [8]CeiED - Interdisciplinary Research Centre for Education and Development, Lusófona University, Lisboa, Portugal. [9]Department of Biology Education, Faculty of Science, Charles University, Prague, Czech Republic. [10]Department of Biology, Behavioural Ecology and Ecophysiology Group, University of Antwerp, Antwerp, Belgium. [11]Department of Biology and Environmental Studies, Faculty of Education, Charles University, Staré Město, Czech Republic. [12]Department of Biology, Chemistry and Home Economics, Faculty of Education, University of Ljubljana, Ljubljana, Slovenia. [13]Faculty of Pedagogy and Primary Education, National and Kapodistrian University of Athens, Athens, Greece. [14]Department of Biology and Biotechnology, University of Pavia, Pavia, Italy. [15]Faculty of Social Sciences and Humanities, University of Western Macedonia, Kozani, Greece. [16]Antwerp School of Education, Didactica Research Group, University of Antwerp, Antwerp, Belgium. [17]UNICAMearth Group, Geology Section, University of Camerino, Camerino, Italy. [18]Ipatimup - Instituto de Patologia e Imunologia Molecular da Universidade do Porto, Porto, Portugal. [19]i3S - Instituto de Investigação e Inovação em Saúde, Universidade do Porto, Porto, Portugal. [20]Centre for Research in Education, University of Minho - Institute of Education, Braga, Portugal. [21]Albufeira Poente School Group, Albufeira, Portugal.

Received: 14 January 2024 Accepted: 5 June 2024
Published online: 09 July 2024

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Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Andreas Panayides is a PhD student in the University of Cyprus in "Learning in Natural Sciences and Environment", where he explores how science education can help destabilise conspiracy theories and pseudoscience.

Xana Sá-Pinto is an assistant researcher at CIDTFF, University of Aveiro, Department of Education and Psychology where she conducts research in sustainability and evolution education. She is a founding member of EvoKE and was the co-leader of WG2 (formal education) in EuroScitizen COST Action.

Evangelia Mavrikaki is a Professor of Biology and Health Education and the director of the Postgraduate Diploma "Didactics and Public Understanding of Science and Digital Technology" in the Department of Pedagogy and Primary Education of the National and Kapodistrian University of Athens (NKUA), Greece and director of the Research Institute "Environment, Climate Change and Quality of Life: Research and Education" (NKUA).

Duur K. Aanen is professor in Evolutionary Biology at Wageningen University, The Netherlands. He teaches courses in genetics, population genetics, and evolution and studies the origin and evolution of cooperation and conflict.

Sara Aboim is a science education teacher at the School of Education of Polytechnic of Porto (Portugal). Researcher at the Centre for Research and Innovation in Education, her research focuses on science teaching (experimental teaching and STEAM education).

Bento Cavadas is a Portuguese science education teacher at the Polytechnic Institute of Santarém/School of Education (Portugal). Had an active participation in EuroScitizen COST Action, assuming a coordination role in Deliverable 5—Teacher Training Actions of the WG2.

Radka Marta Dvorakova has a Master's in Theoretical and Evolutionary Biology, and a PhD in Biology education. She works at the Department of Biology Education at the Faculty of Science at Charles University Prague (Czechia), she is also a part-time biology teacher at Archbishop's High School in Prague.

Marcel Eens is professor in Behavioural Ecology at the University of Antwerp, Belgium. He studies the causes and consequences of variation in behavioural traits among individuals and teaches behavioural biology, behavioural ecology, behavioural physiology, applied and conservation behaviour, and ornithology.

Eliska Filova is a graduate of the Master's program Education in Biology at the Faculty of Science at Charles University in Prague, currently a doctoral student at the Faculty of Education at the same university.

Tanja Gregorčič a teaching assistant for biology education at the University of Ljubljana Faculty of Education. Her current research interests are biology education, e-learning and eye-tracking technology in science teaching.

Nausica Kapsala is a biologist, she holds a M.Ed. and a Ph.D. in Biology Teaching. She teaches at secondary schools and at

the Faculty of Pedagogy and Primary Education of the NKUA as a teaching and research fellow.

Mathijs Nieuwenhuis is an education developer and student tutor at the Education Institute for Biology at Utrecht University. He completed his PhD in 2021 at Wageningen University on the evolution of mutualisms in a genus of symbiotic fungi.

Lino Ometto is a professor of Zoology at the University of Pavia (Italy), where he studies the genetic basis of biodiversity and adaptation using a combination of computational and experimental approaches.

Penelope Papadopoulou is a vice-president of the Italian Society for Evolutionary Biology. He has a bachelor's degree in Biology and a PhD in Biology Education and he is a professor in Biological Education. His research interests focuses on teaching basic biological concepts in preschool and compulsory education, on theory and practice of Environmental Education/Education for Sustainability, on in-service teachers' training in science and on issues of teaching and learning evolution theory.

Rianne Pinxten is professor in Didactics of Biology at the University of Antwerp, Belgium, where she conducts research in evolution education. She was the co-leader of WG 1 (Assessment) in the EuroScitizen COST Action.

Giulia Realdon is a retired high school teacher, and teacher trainer working in education research at the University of Camerino, Italy and within EMSEA (European Marine Science Educators Association). Her research interests include geoscience education, Ocean Literacy and the teaching of evolution. She was a member of WG 2 (formal education) in EuroScitizen COST Action.

Nuno Ribeiro is currently a Researcher at Ipatimup's Cancer Prevention Unit and a Research Collaborator at DigiMedia (University of Aveiro). His research focuses on the implementation of cancer prevention strategies in young populations with an emphasis on digital and interactive media.

José Luis Coelho da Silva is an assistant professor at the Institute of Education at the University of Minho (Portugal) and member of the Research Centre in Education at the same University. He participates in projects and publishes in the areas of science education, pedagogy for autonomy, teacher education and supervision and pedagogy at the university.

Bruno Sousa is a Portuguese science teacher and school book author. School, teaching, strategic partnerships, coconstruction, science communication and sustainability are some of his research interests.

Gregor Torkar associate professor for biology education at the University of Ljubljana Faculty of Education. His current research interests are biology education, sustainability education, outdoor education, m-learning, eye-tracking technology in science teaching and learning, and nature conservation.

Konstantinos Korfiatis is Professor of Environmental Education in the University of Cyprus. His research focuses mainly on children's development through participation in environmental projects and on systems approaches in biology education.