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The CEPS Journal is an open-access, peer-reviewed journal devoted to publishing research papers in different fields of education, including scientific.

Aims & Scope

The CEPS Journal is an international peer-reviewed journal with an international board. It publishes original empirical and theoretical studies from a wide variety of academic disciplines related to the field of Teacher Education and Educational Sciences; in particular, it will support comparative studies in the field. Regional context is stressed but the journal remains open to researchers and contributors across all European countries and worldwide. There are four issues per year. Issues are focused on specific areas but there is also space for non-focused articles and book reviews.

About the Publisher

The University of Ljubljana is one of the largest universities in the region (see www.uni-lj.si) and its Faculty of Education (see www.pef.uni-lj.si), established in 1947, has the leading role in teacher education and education sciences in Slovenia. It is well positioned in regional and European cooperation programmes in teaching and research. A publishing unit oversees the dissemination of research results and informs the interested public about new trends in the broad area of teacher education and education sciences; to date, numerous monographs and publications have been published, not just in Slovenian but also in English.

In 2001, the Centre for Educational Policy Studies (CEPS; see http://ceps.pef.uni-lj.si) was established within the Faculty of Education to build upon experience acquired in the broad reform of the national educational system during the period of social transition in the 1990s, to upgrade expertise and to strengthen international cooperation. CEPS has established a number of fruitful contacts, both in the region – particularly with similar institutions in the countries of the Western Balkans – and with interested partners in EU member states and worldwide.

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Revija Centra za študij edukacijskih strategij je mednarodno recenzirana revija z mednarodnim uredniškim odborom in s prostim dostopom. Namenjena je objavljanju člankov s področja izobraževanja učiteljev in edukacijskih ved.

Cilji in namen

Revija je namenjena obravnavanju naslednjih področij: poučevanje, učenje, vzgoja in izobraževanje, socialna pedagogika, specialna in rehabilitacijska pedagogika, predšolska pedagogika, edukacijske politike, supervizija, poučevanje slovenskega jezika in književnosti, poučevanje matematike, računalništva, naravoslovja in tehnike, poučevanje družboslovja in humanistike, poučevanje na področju umetnosti, visokošolsko izobraževanje in izobraževanje odraslih. Poseben poudarek bo namenjen izobraževanju učiteljev in spodbujanju njihovega profesionalnega razvoja.

V reviji so objavljeni znanstveni prispevki, in sicer teoretični prispevki in prispevki, v katerih so predstavljeni rezultati kvantitativnih in kvalitativnih empiričnih raziskav. Še posebej poudarjen je pomen komparativnih raziskav.

Revija izide štirikrat letno. Številke so tematsko opredeljene, v njih pa je prostor tudi za netematske prispevke in predstavitve ter recenzije novih publikacij.

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Varia

Reviews

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Evolution Education in Europe

Evolution by natural selection is one of the most powerful and significant theories in the history of science (Dawkins, 2009), representing a unifying paradigm within which everything in biology makes sense (Dobzhansky, 1973). For this reason, research on the acceptance and understanding of evolution is a central topic in science education research (Sa Pinto et al., 2021). A wide range of variables impact the learning of evolution, including beliefs, religiosity, educational backgrounds, curricular emphasis on evolution, and knowledge and understanding of the nature of science (Kuschmierz et al., 2021). Without knowledge of evolution by natural selection, it is impossible for students to understand how or why organisms have come to exhibit their diversity and complexity, and for them to develop acceptance of evolution as valid within science.

Science classrooms remain one of the arenas where evolution education can take place. The question of how a teacher can effectively teach evolutionary ideas and deal with the controversial aspects of evolution is relevant to evolution education. There is an ongoing need to pursue this area of research in Europe, in order to properly address the diversity of Europe's socio-cultural contexts. The lack of understanding of evolution and the consequent deficit in the ability to effectively teach and learn the topic and address problems concerning the acceptance of evolution as the main unifying paradigm in biology, as well as the fact that many people believe evolution contradicts their beliefs, are the main triggers for this focus issue. The idea for the issue was inspired by the framework of the COST Action Euroscitizen (CA17127) project, which aimed to identify targeted strategies to raise the level of scientific literacy in Europe using evolution as a model (EuroScitizen building in Scientific Literacy in Evolution in Europe; euroscitizen.eu).

In the thematic part of this issue, six papers discuss the aforementioned challenges of evolution education in Europe. In the first article, entitled *Not by Design Alone! Modelling Practices to Identify Students' Frameworks of Evolution in Real-Life Contexts,* the authors focus on engaging students in modelling evolution in real-life contexts by modelling the resistance developed by a population of mosquitoes in a lagoon when an insecticide is introduced. After modelling the process of natural selection, the explanations appeared to improve (from Lamarckian to Neo-Darwinian views) and most of the groups of students provided accurate explanations regarding adaptation. In conclusion, the authors highlight the fact that the relationships between genetics and evolution in modelling experiences may help students to develop more accurate explanations of natural selection as a form of retroactive rather than linear causality.

In the second article, entitled *The Role of Wonder in Students' Conception of and Learning About Evolution,* the authors investigate the role of wonder in seventh-grade students' learning about evolution. Lessons and workshops were carried out to elicit a sense of wonder in relation to concepts that are known to impact the learning of evolution: aesthetic experiences, defiance of expectations, agency and awareness of a mystery within the ordinary. A qualitative analysis of the role of wonder in the students' meaning-making about, learning of and engagement in evolution showed that it is possible to design science teaching that triggers students' wonder in relation to an intended learning object. However, the authors also highlighted the fact that the students still struggled to make sense of the concept of evolution after six weeks of teaching, which once again emphasises the difficulty of teaching and learning about the theory.

In the third article, entitled *Relationships between Epistemological Beliefs and Conceptual Understanding of Evolution by Natural Selection*, the authors explore Cypriot twelfth-grade students' epistemological beliefs and conceptual understanding of evolution before and after an inquiry-based intervention on evolution. The intervention involved students' collaborative work in inquiry teaching and learning activities to investigate specific concepts and problems related to evolution. The aim of the intervention was to help the participants obtain a deep conceptual understanding of the related mechanisms and processes of evolution, as well as facilitating discussion, interaction and reflection on the tasks. In conclusion, the authors report that engagement in an inquiry-based intervention might be a promising way to acquire content knowledge and develop more sophisticated epistemological beliefs.

The following two articles focus on conceptions of prospective teachers and primary school students in Portugal. In the first article, entitled *Conceptions of Portuguese Prospective Teachers about Real-Life Evolution Situations*, the authors explore the ability of Portuguese prospective teachers to apply evolution to two real-life situations. Specifically, they examine the students' ability to identify evolution misconceptions in online newspaper articles, their misconceptions expressed when explaining real-life evolution situations, and the evolution key concepts they apply to make sense of real-life evolution situations. The findings show that half of the prospective teachers struggled to identify teleological misconceptions in the newspaper articles, and some of them revealed their own misconceptions in their explanations. The students also found it difficult to explain how evolution is related to the real-life situation described. The results remind us how important it is to devote particular attention to evolution education in teacher education.

In the second article from Portugal, entitled *The Impact of Exploring Sexual Selection on Primary School Students' Understanding of Evolution*, the authors explore primary school students' level of understanding of evolution by sexual selection and their ability to employ differential reproduction to propose and justify evolutionary predictions. To promote students' learning about evolution by sexual selection, the authors planned and implemented an educational programme that included four sessions, introducing different practical activities to explore the variation principle, the transmission and expression of these features, and sexual selection. The authors report a significant increase in the students' justifications employing the concept of differential reproduction, and therefore conclude that activities that model and simulate biological evolution through sexual selection can contribute to students' understanding of evolutionary processes.

The final article of the thematic part, entitled *Evolution in the Spanish Primary Education Autonomic Curricula and Textbooks. A Geographic Analysis*, brings a different but equally important methodological approach to the analysis of the quality of evolution education, which enriches this issue. The authors conducted a detailed analysis of selected evolution concepts in the autonomic curricula of Spain and in the activities of eighteen Spanish primary education textbooks, and concluded that curricula and textbooks have important gaps when addressing evolution. The article therefore has an important message and recommendation for curriculum developers and textbook authors.

The thematic part of the issue is completed by a review of a book entitled *Learning Evolution Through Socioscientific Issues*, which sheds light on the connections between the Socioscientific Issues (SSI) approach and evolution education, as described by the author Bento Cavadas. The book is useful reading for anyone interested in evolution education.

The Varia part of the issue offers three interesting articles and one additional book review, thus creating very rich issue of the CEPS Journal. We hope that the issue will resonate with those interested in evolution education.

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Gregor Torkar and Kostas Korfiatis

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Not by Design Alone! Modelling Practices to Identify Students' Frameworks of Evolution in Real-Life Contexts

Noa Ageitos*[1], Laura Colucci-Gray[2] and Blanca Puig[3]

Despite being a fundamental concept in biology, evolution continues to be one of the most challenging topics to teach in science education. Ideas of evolution emphasising anatomical or behavioural features of individuals, as opposed to the interplay between genetics and the environment, are reinforced through language and culture, making them robust and persistent in the student population at all educational levels. Model-based reasoning has been reported to be useful for students to make sense of process-based science content, combining epistemological with linguistic and value dimensions. However, there is a dearth of evidence in biology education showing how modelling can instigate epistemological maturity, specifically about issues of agency and design in evolution by natural selection. Drawing on this perspective, this study focuses on describing the nature of students' ideas while modelling the resistance developed by a population of mosquitoes in a lagoon after an insecticide is introduced. Data collection includes students' written reports and drawings, which were analysed with content and discourse analysis. The findings show that, at first, students believed adaptation to feature at will was a behavioural characteristic instigated by a pre-existing design. After modelling the process of natural selection, the explanations appeared to improve (from Lamarckian to Neo-Darwinian views), and most groups showed accurate explanations about adaptation.

Keywords: modelling, evolution, adaptation, natural selection, evolution frameworks

1 *Corresponding Author. Universidade de Santiago de Compostela, Spain; noa.ageitos@edu.xunta.es.
2 Moray House School of Education and Sport, University of Edinburgh, UK.
3 Faculty of Education, Universidade de Santiago de Compostela, Spain.

Ne samo po zasnovi – prakse modeliranja za prepoznavanje učenčevega razumevanja evolucije v okviru resničnega življenja

Noa Ageitos, Laura Colucci-Gray in Blanca Puig

Čeprav je evolucija temeljni koncept v biologiji, je še vedno ena najzahtevnejših tematik pri poučevanju v naravoslovnem izobraževanju. Ideje o evoluciji, osredinjene na anatomske ali vedenjske prvine osebka, so v primerjavi z vzajemnim učinkovanjem genetike in okolja, okrepljene prek jezika in kulture, kar jih napravlja robustne in vztrajnostne med učenci na vseh stopnjah izobraževanja. Na modelu koncipirano razmišljanje naj bi bilo uporabno za učence, da osmislijo procesno temelječe znanstvene vsebine, ki združujejo epistemološke razsežnosti z jezikovnimi in vrednostnimi. V biološkem izobraževanju pa se kaže primanjkljaj tistih raziskav, ki bi prikazale, kako lahko modeliranje spodbudi epistemološko zrelost, zlasti glede vprašanj delovanja in oblikovanja v evoluciji z naravno selekcijo. Na podlagi te perspektive se ta študija osredinja na opisovanje narave idej učencev, medtem ko modelira odpornost, ki jo razvije populacija komarjev v laguni po uvedbi insekticida. Zbrani podatki obsegajo pisna poročila učencev in risbe, za katere je bila storjena vsebinska in diskurzivna analiza. Ugotovitve kažejo, da so učenci sprva verjeli, da je prilagoditev na poljubno lastnost vedenjska značilnost, ki jo je sprožila obstoječa zasnova. Po modeliranju procesa naravne selekcije se zdi, da so se razlage izboljšale (od Lamarckovih do neodarvinističnih pogledov), pri čemer je večina skupin ponudila natančne razlage o prilagajanju.

Ključne besede: modeliranje, evolucija, prilagoditev, naravna selekcija, evolucijski okviri

Introduction

A large body of research on evolution in biology education exists, since evolution is a central concept in biology and one of the most challenging to learn as well as to teach (Andrews et al., 2017). Students often hold alternative conceptions about the main mechanisms of evolutionary changes and what the theory of evolution explains (Siani & Yarden, 2021). Typically, natural selection is framed as a direct and causal process (Ferrari & Chi, 1998), which might be related to intentional, instrumental, or teleological thinking. For instance, when explaining the evolution of pesticide resistance in a population of insects, students may explain the phenomenon in terms of linear causality, suggesting that the occurrence of a mutation resulted in resistance (Cooper, 2016). With the goal of understanding how to improve students' ideas on evolution, diverse instructional models have been proposed; modelling-based instruction has proved to be useful in identifying students' ideas and promoting reasoning about evolution. In line with d'Apollonia et al. (2004), this study focuses on students' development of models and/or explanatory frameworks to organise knowledge and to make explanations and predictions about natural phenomena related to the process of natural selection. It is through the iterative nature of model-based reasoning that students build knowledge about the phenomenon under study but, most importantly, so that they can think and reason with their own ideas (Passmore et al., 2014). Vattam et al. (2011) view student-constructed models as tools for facilitating students' thinking about the causal and mechanistic relationships that are inherent in biological systems. In a similar vein, this research adopted the notion of modelling as a process that may not only reveal students' reasoning but may also enable the construction of thinking frameworks on evolutionary theory, supporting epistemic maturity about the key questions of linear causality and agency in evolutionary processes. We suggest that this is an important role of biology education to prepare students to understand and grapple with future thinking about change, survival, and variability on a planet in flux (Colucci-Gray & Gray, 2022).

Building on current research on alternative frameworks, this paper advances understanding of the value of modelling in surfacing the fluidity of such frameworks vis-à-vis the ongoing debates and dynamic thinking in evolutionary theory seeking to grapple with environmental change.

Focus of the study

Despite extensive research in evolutionary biology focussing on adaptive and selective explanations for evolutionary change, less is known about the processes supporting students' reasoning while seeking to explain the same phenomena. This study is part of this line of research (Beggrow & Nehm 2012), and it assumes that modelling, as a process of embodied thinking through doing, can play a central role in evolution learning. We consider modelling, both as a scientific and educational practice, that combines conceptual and practical dimensions of thinking and doing (Nathan, 2022); the making of a model engages 'the how' as well as 'the why' of a process and is proposed here as being particularly helpful in engaging with thinking about evolutionary processes, as they occur through a variety of linear and non-linear mechanisms (Colucci-Gray & Gray, 2022). Specifically, we look at the ways in which modelling through drawing can support students' articulation of the role of natural selection and how this process can support epistemological maturity on issues of agency and design within a systemic perspective. The research questions are:

1) In what way and to what extent do students' models of evolution differ?
2) What evolution frameworks underpin students' explanations when building and evaluating a model of evolution? And how do these frameworks change?

Background

Key debates in evolutionary thinking in biology

A lively debate characterises evolutionary biology both on the question of agency and of inheritance, that is, the process through which so-called 'adaptive traits' are 'passed on' to the next generation. In these debates, the process of linear causality as the main mechanism for explanation is discussed according to two main alternative positions.

One idea rests on genetic programming, which is quite pre-formationist; while gaining traction in some research fields, such as genetic engineering, it remains a contested idea in evolutionary biology and genetics of populations. For example, simple random changes in the proportion of genes, caused by the fact that different families have different numbers of offspring, may account for differential patterns of inheritance; equally, genetic drift may play some evolutionary role in small populations.

However, if we exclude this approach, the other route to explaining evolutionary change rests on the notion of 'developmental dualism' whereby some features might develop under the aegis of the genes (Konner, 2022), while others are shaped by the environment. This second aspect points to a dual developmental process that reflects the old and tangled nature-nurture dilemma, leading to ongoing difficulties in synthesising knowledge of genetic development with an understanding of evolutionary processes (Beggrow & Nehm, 2012; Oyama, 2000;).

In *Evolution in Four Dimensions,* Eva Jablonka and Marion J. Lamb (2005) point to new knowledge on genes and genomes and challenge dualist assumptions. They argue that the concept of inheritance currently used in evolutionary thinking is far too narrow and must be widened to integrate results from molecular biology as well as behavioural sciences. This approach to evolution calls for a systemic view, whereby the development of individual organisms is part of a set of nested systems and their changes over time.

Despite the ongoing debates, evolution instruction often focuses on more simplistic approaches, presented as mutually exclusive, as a succession of linear explanations provided by singular scientists over time (Brigandt, 2020). Considering this gap, this paper focuses on the characteristic of biological thinking, which is to offer a multiplicity of theories and frameworks *with which to think*.

Alternative frameworks about evolution commonly used in the classroom

Three alternative and distinct frameworks of evolution are common and commonly found when addressing the topic of evolution in the classroom.

The first one, the Darwinist framework, is presented as the most up-to-date and accepted theory, which is centred upon the concept of natural selection. However, as reported by Depew (2020), while Charles Darwin emphasised the correspondence between organisms and the environment that results from natural selection and adaptation (e.g., in the formation of specific ecological niches), he was never concerned with the interpretive power of language. In this view, natural selection is often understood to be akin to a mechanism of cause and effect, of the likes of Newtonian physics, as a force shaping a passive organism.

These assumptions about agency and passivity, linearity, and interactivity make understanding of selection problematic in two important ways. Firstly, Nature is discursively positioned as being *outside* the organisms and acting upon them. This view translates the concept of natural selection as an external force discriminating the fit from the unfit; but it is also at the root of a second, common conception, which is often associated with Lamarckian ideas.

To this regard, a second frame of Neo-Darwinist ideas has gathered force around the notion of a selfish gene, according to which any action is a supremely self-serving one on the part of the actor, devoid of motivation to serve the larger group to which the actor belongs. The Neo-Darwinist framework has gained traction in popular culture, and it is frequently introduced in Biology instruction, for instance, in Spanish textbooks in higher education, even though it is not the most recent interpretation in biological thinking. Consensus among the scientific community exists regarding the epigenetic contributions to evolutionary theory, as reported by Jablonka and Lamb (2005), yet these ideas have not acquired visibility in school teaching.

This points to a third frame, suggesting that the inheritance of developmentally acquired variation and the transmission of induced or accidental epigenetic modification might be adaptive. As opposed to seeing evolution as the display of properties residing either in the individual or in the environment, evolutionary features of organisms may thus be more powerfully seen as produced and emergent in interaction (Oyama, 2000).

With the goal of understanding students' frameworks on evolution, we look at models as epistemic and dynamic tools that may be useful to support the elaboration of different explanations and predictions for creating new knowledge and to generate potentially new frameworks (Gouvea & Passmore, 2017).

Modelling practices in learning and teaching about evolution

Several approaches to models and modelling exist in science education. In this study, models are considered to be abstractions or simplified representations of a phenomenon used to create explanations and/or predictions (Gericke et al., 2013). Scientific models have different functions (Mendonça & Justi, 2013), such as to simplify complex phenomena in order to identify key variables and dimensions (Gilbert, 2008), support explanations of natural phenomena and construct theories (Passmore & Stewart, 2002), make predictions (Clement, 2008) and provide the basis for experimental proposals and interpretations (Morrison & Morgan, 1999); communicate scientific knowledge (Nersessian, 1999), or assist in the visualisation of abstract entities (Gilbert, 2008). Sometimes, more than one model is used because no single model can capture all the relevant features; or, more interestingly, the possibility to *think with* different models can generate different insights into the problem under study, especially when studying complex phenomena, such as global climate change, involving a multiplicity of interacting factors (Lloyd, 2015). Hence, models are not intended to describe or represent the natural world with perfect fidelity but to offer a version much like it, though less complicated and amenable to change (Gilbert, 2008).

Parke and Plutinski (2022) remind us that it is common in biology to use the terms 'theory' and 'model' almost interchangeably as a key aspect of how biologists go about producing their theories and explanations is literally by building and manipulating their own models. The thinking and the making are intertwined, in the same way models and theories become almost interchangeable (Nathan, 2020). Moreover, biological models, more than any other domain, capture a wide range of metaphorical expressions, a rich imagery that becomes associated with concrete phenomena, and are culturally transferred in everyday language (Brigandt, 2020). Such models may be rendered as physical artefacts but also as diagrammatic representations, a visual grammar, in which arrows may always be used to associate signifiers with signified, within a rich ecology of signs, a multiplicity of nested logics, which are recursively pursued and identified. In this study, we focus on models as external representations, considered as dynamic forms of knowing (Pérez Echevarría & Scheuer, 2009) connected to mental processes and amenable to being communicated and manipulated over the course of instruction.

Method

Context

This study adopts a qualitative case-study approach and draws upon discourse analysis as a method for analysing the discursive and rhetorical functions of modelling, understood as a repertoire of students' biological thinking (Ageitos et al., 2019; Brigandt, 2020). The study runs as a longitudinal project over two school years (2014–2016), focussing on learning genetics and evolution through modelling and argumentation practices.

The project took place in a state high school located in Galicia (Northwest of Spain). The participants were 16–17-year-old students (N=20) and their biology teachers. The school was set in a semi-rural location with a medium level of socio-economic advantage. The students (7 male, 13 female) had chosen a scientific itinerary and had previously participated in modelling and argumentation tasks.

The students worked in groups (n=5) over the entire course of the project, with minor changes between the first and second year due to new students enrolling in and dis-enrolling from the school. The teacher had more than 15 years of experience and had previously participated in research on modelling. While engaging in this project, he participated in two workshops with the researchers on argumentation and modelling. His role consisted of guiding the lessons and supporting students to participate in the tasks, providing help when needed.

The design of the activities was led by the authors and negotiated with the teacher. In the first year, the project consisted of four tasks: 1) students modelling gene expression, 2) application of the model to a different context, 3) students' engagement in argumentation about genetic testing, and 4) students' application of their knowledge of evolution to explain the evolutionary relationship between sickle cell disease and malaria. The analysis of the first-year tasks revealed difficulties and misconceptions about genetics and evolution (Authors, 2019); thus, in the second year, the design was modified to help students overcome them.

The second-year project consisted of three tasks. The first focused on the metaknowledge of modelling. The second required students to apply the model of gene expression to explain the development of an animal disease with a genetic component triggered by stress, as it has been suggested that specific emphasis on genetics during instruction may enhance conceptual change in evolution (Kampourakis & Zogza, 2009). The last activity, *Can a mosquito population change when insecticide appears in a lagoon?*, involved students in argumentation as well as modelling, which is the focus of this study.

Description of the task

The task analysed corresponds to the last activity of the project. It contained three phases: 1) using knowledge about evolution to assess a case, 2) simulating natural selection and building a model about evolution, and 3) evaluating the model considering Lamarck and Darwin's theories of evolution. This structure was derived from considering that modelling-based activities involve the construction, communication, and evaluation of knowledge (Schwartz, 2009); therefore, in this case, the focus was the explanation of an evolutionary phenomenon.

Phase 1: the case of DDT (insecticide) to eradicate mosquitoes causing malaria in a lagoon was presented to students. While the case was presented as historical and hypothetical, students were informed of current research showing that, with climate change, malaria is, in fact, a recurring problem in particular regions of the world (Sainz-Elipe et al., 2010) and even extending to new regions where it had been previously eradicated. The case was presented as follows: 'A farmer on the east coast grows rice in a lagoon and wants to use an insecticide to protect his crops. However, his neighbour is concerned that the use of DDT may create a resistant population of mosquitoes, and, therefore, increase the cases of malaria'. This ecosystem corresponds to a Mediterranean area in which malaria was present. Students were asked to reason in small groups (N=5) about the possibility of mosquitoes developing resistance against the insecticide and decide with whom they would agree more and justify it.

This initial phase was designed to elicit students' prior knowledge and understanding of evolutionary processes and the elaboration of explanations according to their own personal frameworks (Gilbert, 2008).

Phase 2: The above situation was later simulated by students using pieces of foam representing the mosquitoes (brown ones (the non-resistant mosquitoes) and black ones (the resistant) ones). A few mosquitoes were added to the area, and in each generation, each mosquito created another mosquito. When the insecticide appeared, each resistant mosquito created another mosquito, and the non-resistant mosquitoes disappeared. This simulation was repeated twice, once with and once without insecticide in the environment. The results were represented in graphs. Each group explained what happened in each situation and the differences between the two simulations. Afterwards, they were asked to build a model explaining how evolution was affecting the different responses in each context. Students were not provided with instructions on how to build the model, they were invited to use any material they wanted, and they were invited to then report their model in writing by creating a representation. This second phase was designed to provide students with tools for thinking in action, each time introducing new variables and modifying their connections to craft new structural knowledge (Mayer, 2015). The analysis considered such representations alongside students' evaluations (Phase 3) to explore the discursive shifts from a singularity to a multiplicity of pathways and from linear to systemic configurations.

Phase 3: Students evaluated their models by referring to Darwinian, Lamarckian, and Neo-Darwinian theories and offered evidence and justification for which model they felt most closely aligned. This phase was designed to elicit awareness of students' own thinking, specifically in relation to the nature of causality and agency of natural selection (Vattam, 2011), and to reflect on the role of Nature and the environment as external or as part of the evolutionary destiny of the organisms, thus integrating ideas from a range of disciplinary perspectives in biology (Oyama, 2000).

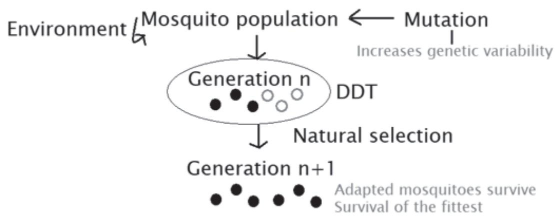
Data collection and analysis

All sessions were attended by Authors 1 and 3, who took field notes and collected the models and written reports elaborated by the five groups.

For the examination of both research questions, a reference model of evolution was elaborated by the authors from the two most alternative frameworks presented in Spanish classrooms (i.e., Neo-Darwinian and Lamarckian), which provided a dialectics between the idea of direct transmission from parental adaptations (Lamarck) and that of adaptation because of selection operated through the organisms' interactions within a particular environment (Darwin) as well as variability in the genetic pool (Neo-Darwinism).

Figure 1

Neo-Darwinian reference model.

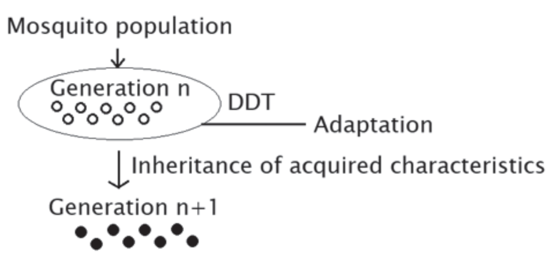


In the model above (Figure 1), a population of mosquitoes with genetic variation is represented throughout several generations. It encounters an insecticide (DDT) in the environment, which leads to the natural selection of the fittest individuals (the ones who are resistant to the insecticide), resulting in a resistant population against the insecticide and surviving. The survival of the individuals is thus understood as adaptation.

In the model below (Figure 2), a population of mosquitoes is represented throughout several generations. It encounters an insecticide (DDT) in the environment and develops resistance features, which leads to the population becoming resistant to the insecticide and surviving. The passing on of specific abilities is thus understood as adaptation.

Figure 2

Lamarckian reference model



The examination of RQ1, *How far and to what extent do students' models of evolution differ?*, is based on qualitative content analysis of students' models.

They were compared against one of the two models of reference (Figures 1 and 2), and attention was placed on these four aspects:

a) *Type of representation*: It could be a concept map, flow chart, drawing or any other type of visual representation used to explain evolution.

b) *Complexity*: Number of scenarios, elements and relationships built between them, taking into consideration how they were included and how they were related.

c) *Starting point*: first element included in the model. Specifically, the presence of the environment as the external factor or the organism as a predesigned factor offered particular points of attention.

d) *Scientific words*: concepts and phenomena included in each model, especially those related to genetics and evolution concepts (Table 1).

Regarding RQ2, what evolution frameworks underpin students' explanations when building and evaluating a model of evolution? How do these frameworks change over the course of modelling? Qualitative content analysis was carried out, focusing on students' models and the written evaluation of their models. For the identification of the evolution frameworks, we drew upon key notions included in the Lamarckian and Darwinian reference models (Figures 1 and 2). Due to the co-existence of alternative frameworks in students' ideas and confronted with the appearance of mixed models in the data, we located students' models on a spectrum of ideas between Lamarckian and Darwinian views regarding evolution theory, each model bringing particular features, as summarised in Table 1.

Table 1

Key ideas on each evolution framework

Key ideas of each evolution framework	
Lamarckism	**Neo-Darwinism**
Adaptation (after change) Inheritance of acquired characteristics	Adaptation (before change) Natural selection Mutation Genetic variability Survival of fittest

Results

Students' models of evolution in the context of explaining a real-life problem

Student's models and explanations were analysed by attending to the four aspects (a, b, c, and d) described above. They constructed models similar to diagrams and concept maps (semantic network of concepts represented in boxes, interconnected by arrows indicating the relationships among them). Table 2 summarises the results.

Table 2
Analysis of students' models

Group	a. Type of representation	b. Complexity	c. Starting point	d. Scientific words
1	Concept map	Two routes	Mutation in a population	Environment (change) Natural selection Adapt (population)
2	Flow chart	Four routes	Change in environment	Ecosystem (change) Natural selection Genetic variability Adaptation
3	Flow chart	One route	Ecosystem with living things	Change in the ecosystem Natural selection Evolution
4	Concept map	Three routes	Change in environment	Environment Natural selection Evolution Adaptation
5	Flow chart	One route	Population	Change environment Natural selection

The analysis of the type of representations points to two main approaches:

a) **Concept maps**, representation that depicts relationships between concepts (Groups 1–4)
Cause & effect relations: Group 1.
Explanatory: Group 4.

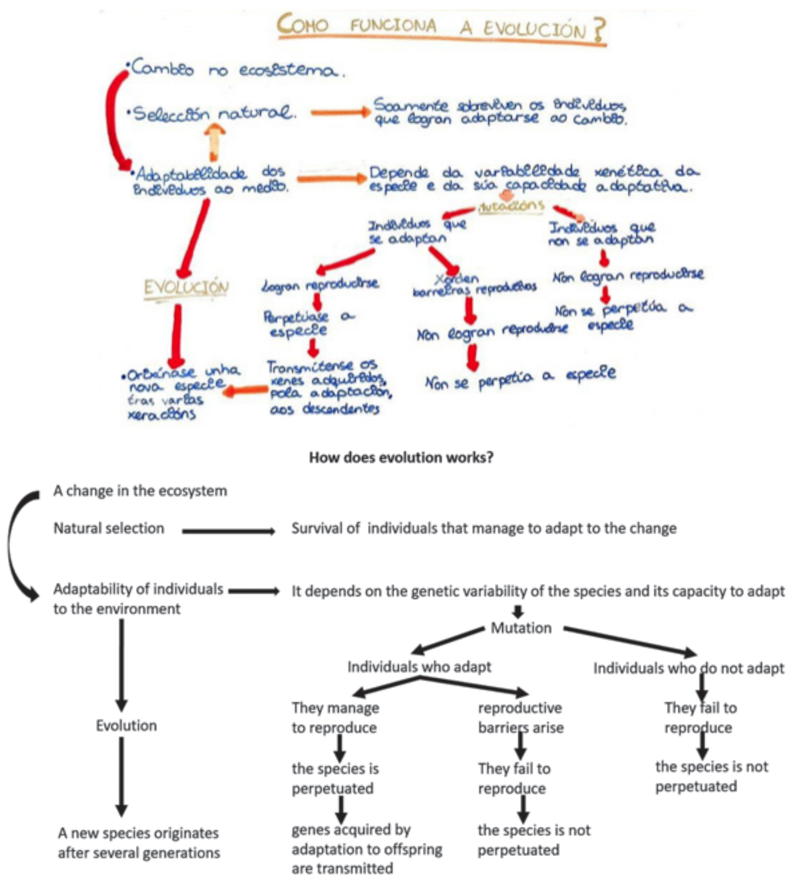
b) **Flowcharts**, representation that shows the sequence of action in a process (Groups 2, 3, and 5).

Complexity

The most frequent element is change in the environment, appearing a total of four times. In all models, a reference to the population, species, or individual appears. Across all groups, regardless of whether they had chosen a concept map or a flowchart, the layout of the models is linear (Figure 3, a & b). All groups represented the process of evolution with arrows or lines leading to one or several scenarios. For example, Figure 3a shows the representation elaborated by Group 2, in which there is a path that goes in one direction, while none of the groups considered the possibility of relating the elements backwards (as retroactive feedback) nor including relations within the environment. However, some of them included several possible routes (from Group 2 to Group 4) departing from different points in the model (e.g., in Figure 3, a & b, mutation may or may not be perpetuated across the species).

Figures 3a & 3b

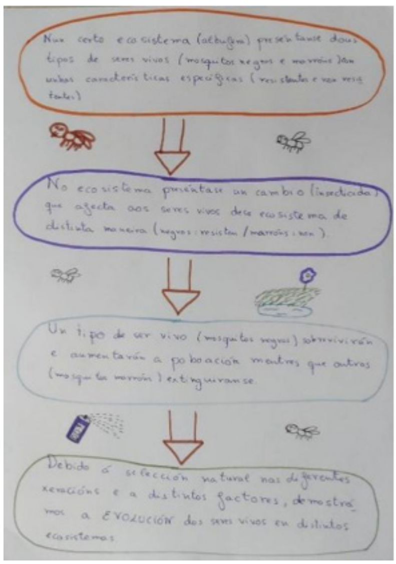
Figure 3a: Model from Group 2 (linear with 3 paths); Figure 3b: English translation.



Conversely, the model produced by Group 3 is a flowchart presenting a linear explanation of evolution (Figure 4 a & b). Their design followed four consecutive steps. The first describes the population, the second introduces the change in the environment (insecticide), the third argues which mosquitoes survive, and the fourth step is the result. In contrast, as shown in Figure 3 above, Group 2's model differentiates between the individuals that can adapt and the ones that are not able and also separates those who can adapt but do not survive.

Figures 4a & 4b

Figure 4a: Original Model from Group 3 (linear with 1 path); Figure 4b: English translation.



in a certain ecosystem (lagoon) two types of living beings appear (black and brown mosquitoes) with specific characteristics (resistant and nonresistant)

↓

A change (insecticide) appears in the ecosystem that affects living things in that ecosystem in different ways (black: resist / brown: don´t)

↓

One type of living thing (black mosquitoes) will survive and increase in population while others (brown mosquitoes) will become extinct

↓

Due to natural selection in different generations and different factors, we have shown the evolution of living things in different ecosystems

Starting point

Most groups started their model at a different point. As seen in Table 1, two groups identified the 'change in the environment' as the starting point; the other two focused on the living things/population and the last group on the mutations.

Scientific words

Natural selection appeared in three of the models, and adaptation also appeared in three models but not in the same ones. This may be relevant, as adaptation is a notion that can be used both from a Darwinian or a Lamarckian perspective. In the Lamarckian framework, adaptation occurs because of a change and the willingness to survive. However, in light of Darwin's ideas, adaptation may be present before any other change.

Evolution frameworks that emerge when building and assessing the models

The models and the written assessments of students' models were analysed to identify the frameworks on evolution that appeared in the two stages of the modelling process: first, while they were building the models and then when evaluating the models considering their newly acquired learning. Two main frameworks were identified: Neo-Darwinism and Lamarckian. Students' responses varied along a continuum between both frameworks as their explanations moved back and forth, drawing in explanations and ideas from either a Neo-Darwinian or Lamarckian explanation. Table 3 shows the position of students' responses on the continuum and the results of each group according to this analysis. To locate students' positions along the continuum, the number of keywords was considered. The starting point is in between frameworks, and each word/expression moves along a position on the continuum.

Table 3 summarises the results.

Table 3

Analysis of RQ2: Students' models (building and evaluating) perspective

Group	Building and explaining the model		Evaluating the model	
	Lamarckism	Neo-Darwinism	Lamarckism	Neo-Darwinism
1	– Adapt	– Mutation – Natural selection		– Mutation – Natural selection – Adapt
				
2	– Adapt – Acquired genes	– Natural selection – Genetic variability	– Inheritance of acquired characteristics)	– Darwinian
				
3		– Survival of the fittest – Natural selection		– Natural selection – Survival of the fittest
				
4		– Survival adapted		– Adapted before birth – Natural selection – Survival fittest
				
5		– Survival of the fittest		– Adapted before birth – Natural selection – Survival of the fittest
				

Building and explaining the model

From Table 3, the results show that almost all groups were closer to the Neo-Darwinism explanation rather than the Lamarckian one. In fact, none of the models showed a complete Lamarckian explanation, while one group showed mixed ideas and was neither close to Neo-Darwinian nor the Lamarckian one.

Four out of the five groups were closer to Neo-Darwinian perspectives. Moreover, they did not use many key ideas related to Neo-Darwinism; they emphasised mutation appearing prior to the change in the environment (e.g., see Group 1) and referred to mutation and natural selection as external forces acting upon the population.

For instance, for the group with mixed explanations, Group 2 included in their model: 'only surviving individuals that are able to adapt to the change', suggesting the presence of needs-based misconceptions. They identified adaptation as the result of the willingness or need to survive and change to overcome an obstacle (in this case, mosquitoes obtaining resistance against the insecticide).

Groups 4 and 5 included the survival of the fittest in their models. In their model, Group 4 wrote that the adapted are the ones that survive, while Group 5 identified the resistant to the insecticide as the ones that survive.

Group 3 is the one that included more Darwinian notions. Their last explanation said, 'Due to natural selection in different generations and different factors, we have shown the evolution of living things in different ecosystems'.

Some groups included references to a framework but showed misconceptions. Such is the case of Group 1, which included natural selection occurring before adaptation.

Evaluating the model

After instruction and the simulation activity, most of the groups moved closer to the Neo-Darwinism perspective when comparing their models to Lamarckian and Darwinist ideas.

Regarding the evaluation, we can see a shift in the ideas presented in three groups (1, 4 and 5), scoring higher in the Darwinian perspective. It is noteworthy that Group 2 is the only one that included ideas from both perspectives in their model.

> Group 2:
> 'Our model is primarily Darwinian. However, it is true that there are certain Lamarckist aspects that we add (such as the inheritance of new characters to offspring).'

This group acknowledged that in their model, there was a mixture of characteristics from the two frameworks. In the explanation, we can see that they highlighted the Lamarckian perspective, which may lead us to think that evaluating their model is more Lamarckian. However, they mentioned that they have more Darwinian characteristics, even though they did not reference them explicitly. This group showed no change between the phase of building the model and the evaluation one.

Group 4:
'Natural selection makes the best adapted to the environment individuals survive, as they are genetically adapted before birth and the fittest survive.'

This group started mentioning the survival of the ones adapted when building the model and advanced to include more ideas related to the Neo-Darwinian perspective. In the evaluation, they enriched their explanation of adaptation and included natural selection in their explanation (see example below).

Group 1:
'Individuals carry a genetic feature that results from a mutation that allows them to adapt to the environment.'

Natural selection and adaptation were the most common notions used by most groups. As seen in Group 1, there was a shift in how it is used 'adapt' towards a Darwinian point of view when making an evaluation. As shown in Table 3, in three out of the five groups, more key notions were mobilised when evaluating the model compared to when building it. The remaining two groups showed no change.

Discussion

Despite being one of the fundamental concepts in biology, evolution continues to be one of the most challenging and numerous difficulties have been reported (Andrews et al., 2017). This study has revealed difficulties while modelling the appearance of resistance in mosquitoes when an insecticide is present in the environment. Students' models were linear, presenting different steps to explain evolution that coincided with the original simulation in which they were engaged. Two of the models can be considered conceptual maps, one showing cause-effect relationships and the other being more discursive and explanatory. It needs to be highlighted that students were not explicitly instructed in making models, although they have previously engaged in modelling tasks. The fact that they have elaborated more descriptive than explanatory models can be affected by this, but it may also be down to their prior experience of doing schemas to summarise the contents of a unit with the teacher.

Two of the five groups presented as a starting point the change in the environment, highlighting the importance of this factor for them. Regarding the most frequent notions used in the models, adaptation and natural selection are used three times each. The analysis of these notions in students' explanations reveals that they understood the appearance of adaptation at will, which is coherent with previous results (Gregory, 2009). Aligned with Kampourakis (2013), the origin of adaptations is a commonly misunderstood process by secondary students and is related to the teleological view of evolution. Following this author, we understand that in teleological explanations, a phenomenon is framed in terms of the ultimate purpose to which it contributes. However, as recently reiterated by Kampourakis (2020), the educational problem we need to address may not be teleology per se but the underlying 'design stance', that is, whether a trait may be originally designed to perform a purpose or whether it is selected as advantageous for the organism in a particular environment. In the case of this study, students' models pointed to the possibility of shifting between and across different theories, enabling students to grapple with important questions of purpose. For example, in evaluating the model, Group 1 talked about a mutation that allows one to adapt to the environment. It has been proposed that to overcome teleological explanations and promote conceptual change, it is helpful to introduce a new conceptual framework that is more scientifically consistent with current thinking in biology (Kampourakis & Zogza, 2009).

The students seemed to encounter challenges in understanding the process of evolution due to its complexity (Mead & Scott, 2010), as well as holding needs-based misconceptions (i.e., the individual organism changes to survive), which is a common obstacle when learning about natural selection (Peel at al., 2019). This study uncovers notions from alternative frameworks on evolution (Lamarckian, Darwinism and Neo-Darwinism) that varied when building and evaluating the model, moving from Lamarckian to Darwinian explanations. After modelling, students managed to enrich their explanations on adaptation when evaluating their models in a way that is consistent with previous research (Peel et al., 2019). Three groups used the notion of adaptation more accurately, showing that this concept is a key component in their models, as well as being evidence of the theoretical frameworks behind students' explanations.

Conclusions, educational implications, and limitations

This study engaged students in the process of modelling to explain evolution of an issue in real-life contexts. The analysis shows that building models and evaluating them do not have the same cognitive requirements. We are aligned with Schwarz et al. (2009) in their suggestion that modelling activities should engage students in the process of building, explaining, assessing, and comparing models, involving them in the application of scientific knowledge as well as in the metaknowledge of the practice. Encouraging students to participate in modelling-based tasks in the classrooms may help them to overcome misconceptions about evolution; therefore, we suggest promoting modelling tasks that involve building and evaluating models to help students understand evolution.

Furthermore, engaging students in modelling evolution in real-life contexts can help us to identify students' evolutionary frameworks. As this study shows, alternative frameworks emerged when building and assessing the models. This relates to previous research, as Nehm and Schonfeld (2008) pointed out, showing that students' evolutionary explanations consisted of a mix of key notions. Attention to how these notions were applied in accordance with alternative frameworks is required. Biology instruction should attend to alternative and multiple frameworks when designing activities for evolution learning. For example, Darwin's theory of natural selection is a very general theory that is not tied to any mechanism of inheritance or cause of variation (Jablonka & Lamb, 2014), which means that evolution instruction should consider it.

Despite a growing consensus that interdisciplinary connections between disciplines are needed to better enhance students learning and understanding of evolution (Tibell & Harms, 2017), students' written explanations of natural selection did not include details or relationships to account for the genetic basis of evolution (e.g., Kalinowski et al., 2010; Bray-Speth et al., 2009). Emphasis on the relationships between genetics and evolution in modelling experiences may help students to develop more accurate explanations of natural selection as a form of retroactive rather than linear causality. It may be helpful to make explicit connections in the classroom relating the disciplines needed to enrich students' understanding of evolution, such as genetics and bio-geography, geology and history. This leads to a second implication: for biology education to embrace a plurality of interpretational frameworks, including recent calls for the active use of open-ended concepts (Brigandt, 2020) to support understanding of complex processes, which are dynamic and multi-levelled, such as evolution; and for genetics and evolution to be taught together, through processes that engage students in connecting both domains (Ageitos et al., 2019).

Some limitations need to be acknowledged. The evolution frameworks were difficult to distinguish, and the same applies to the continuum between Lamarckism and Neo-Darwinian ideas. The nature of the data analysed in this study does not allow us to have a deeper understanding of how students move back and forth between two different evolution frameworks and to what extent the process of modelling could help unravel the evolution frameworks. Further research will focus on the analysis of audio-recording to pick up on the detail of students' explanations and grapple with the methodological challenge of analysing thinking through doing to deepen our response to the research questions.

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Biographical note

Noa Ageitos is a science high school teacher in Spain and collaborates with the USC (Universidade de Santiago de Compostela) research group RODA. Her research interests include argumentation and modelling practices in evolution and genetics learning and critical thinking in socio-scientific issues.

Laura Colucci-Gray is a Senior Lecturer in Science and Sustainability Education at Moray House School of Education and Sport, University of Edinburgh (UK). Her research interests include participatory methodologies to deal with complex, socio-environmental issues; citizen science, STEAM eduation, transdisciplinarity, and creative teaching and learning for future-making.

Blanca Puig is an assistant professor in science education at the Faculty of Education, at University of Santiago de Compostela (USC). Her main areas of research are critical thinking in socio-scientific learning and instruction, argumentation and modelling practices in evolution and genetics learning. She is currently involved in an emergent line of investigation about ocean literacy for blue sustainability at secondary and high education.

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The Role of Wonder in Students' Conception of and Learning About Evolution

Bodil Sundberg*[1] and Magdalena Andersson[2]

Learning about evolution can be challenging for students, as a full understanding may require them to see the world in new ways, to master a disciplinary language and to understand complex processes. Drawing on a long line of theoretically grounded arguments of philosophers and researchers for including wonder in science teaching, we report on the results of an empirical study with the primary aim of investigating the role of wonder in students' learning about evolution. The study was carried out through a formative intervention in which two researchers in science education collaborated with a seventh-grade teacher. Over a period of six weeks, 45 students participated in lessons and workshops aimed at eliciting a sense of wonder in relation to concepts that are known to impact the learning of evolution. We incorporated four 'triggers' to elicit students' wonder in the science class: *aesthetic experiences, defiance of expectations, agency and awareness of a mystery within the ordinary*. Logbook entries and interviews with student pairs provided empirical material for a qualitative analysis of the role of wonder in the students' meaning-making about, learning of and engagement in evolution. The results show that it is possible to design science teaching that triggers students' wonder in relation to an intended learning object. The results also reveal that the participating students described their sense of wonder in qualitatively different ways and that they still struggled to make sense of the concept of evolution after six weeks of teaching.

Keywords: evolution, formative intervention, lower secondary school, threshold concepts, wonder

1 *Corresponding Author. Science Education at the School of Science and Technology, Örebro University, Sweden; bodil.sundberg@oru.se.

2 School of Science and Technology, Örebro University, Sweden.

Vloga čudenja pri učencih glede pojmovanja evolucije in učenja o njej

Bodil Sundberg in Magdalena Andersson

Učenje o evoluciji utegne učencem predstavljati izziv, saj lahko od njih terja, da morajo za popolno razumevanje uvideti svet na nove načine, da obvladajo strokovni jezik in razumejo kompleksne procese. Na podlagi dolge vrste teoretično utemeljenih argumentov filozofov in raziskovalcev za vključevanje čudenja v poučevanje naravoslovja poročamo o izsledkih empirične študije, ki je bila osredinjena na vlogo čudenja pri učenju evolucije učencev. Raziskava je bila izvedena s formativno intervencijo, v kateri sta dva raziskovalca naravoslovnega izobraževanja sodelovala z učiteljico sedmega razreda. V obdobju šestih tednov je 45 učencev sodelovalo pri pouku in na delavnicah, katerih cilj je bil vzbuditi občutek čudenja v povezavi s koncepti, za katere je znano, da vplivajo na učenje evolucije. Vključili smo štiri »sprožilce«, s čimer smo med poukom naravoslovja pri učencih izvali čudenje: estetska doživetja, kljubovanje pričakovanjem, posredništvo in zavest o skrivnosti v običajnem. Dnevniški vnosi so skupaj s tandemskimi intervjuji učencev zagotovili empirično gradivo za kvalitativno analizo vloge čudenja pri oblikovanju pomenov, ki jih imajo učenci o evoluciji, učenju in o sodelovanju pri njej. Izsledki kažejo, da je mogoče poučevanje naravoslovja zasnovati tako, da bi pri učencih sprožilo čudenje v kontekstu zamišljenega učnega cilja. Prav tako izsledki nakazujejo, da so sodelujoči učenci to opisali na kvalitativno različne načine, pri čemer so stežka osmislili koncept evolucije tudi po šestih tednih poučevanja.

Ključne besede: evolucija, formativna intervencija, nižja srednja šola, pragovni koncepti, čudenje

Introduction

The theory of evolution is one of the key explanatory models in biology. An accurate understanding of evolution is therefore essential for understanding other areas of life sciences. However, decades of research has found that both teaching and learning about evolution can be very challenging, while numerous misconceptions and alternative beliefs have been documented among students (Gregory, 2009; Groß et al., 2019; Nicholl & Davies, 2019; Pobiner et al., 2019; Sinatra et al., 2008). A number of causes have been suggested to explain students' difficulties in accurately understanding evolution, including both cognitive and emotional barriers. Cognitive barriers include conceptual difficulties, whereby evolution can be perceived as difficult because it describes complex phenomena and involves invisible and counterintuitive objects and processes (Barnes et al., 2017; Göransson, 2021). Emotional barriers, on the other hand, can arise from the human tendency to find it easier to accept things one wants to be true and more difficult to accept things one does not want to be true (Thagard & Findlay, 2010). Several studies have shown that students commonly construct teleological explanations, i.e., that changes are purpose driven, rather than using scientific explanations of evolutionary change (Gresch & Martens, 2019). In the literature, a number of sources for emotional barriers to learning about evolution have been described: students' prior beliefs that conflict with the scientific perspective of biological change, religious orientation, biological worldviews and difficulties in accepting evolutionary theory (Demastes et al., 1995; Evans, 2001). Much of the research that addresses students' difficulties in understanding evolution relies on a conceptual framework that emphasises the importance of students' meaning-making of key and threshold concepts (Meyer & Land, 2003; Tibell & Harms, 2017). Key concepts are discipline-specific theoretical descriptions that together can be used to describe scientific principles such as *origin of variation*, *differential fitness* and *inheritance*. Threshold concepts, on the other hand, describe general concepts such as *randomness*, *probability*, *spatial scales*, *adaption* and *temporal scales* (Tibell & Harms, 2017, p. 958). From an educational point of view, threshold concepts are important, as they are difficult to grasp. Once understanding is achieved, however, it represents a radical and permanent change in the way the student makes meaning about a subject (Meyer & Land, 2003). In a recent study aimed at measuring students' 'threshold crossings', Walck-Shannon et al. (2019, p. 2) describe how students »can take multiple paths oscillating in and out of a liminal state of uncertainty as they approach, learn, and master a threshold concept«.

To summarise, helping students to understand evolution is not simply a matter of supporting the cognitive aspects of learning. Teaching about evolution also needs to encompass thoughtful teaching that helps students to see the world in new and different ways. In the present study, we draw on literature that theoretically argues that wonder can make students open to this kind of transformative teaching and learning. Wonder is a so-called epistemic emotion, i.e., an affective phenomenon that is defined by a direct relation to (not) knowing and understanding (Candiotto, 2019; Valdesolo et al., 2017). Wonder is triggered by objects and events that, in a profound way, make us aware of what we do not know and cannot explain. The trigger can be various sorts of objects: the sight of a star-filled night sky, a sound, an idea or a work of art. Regardless of what triggers the sense of wonder, this emotion is defined by how it makes us aware of the fact that there is more to be learned, of the beauty or complexity of a natural phenomenon, thus forcing us to question our worldviews and stretch our minds (Candiotto, 2019; Paulson et al., 2021). In the present article, we hypothesise that making room for wonder may be one way for teachers to support students to work through the complex process of understanding evolution. We present the results from a formative classroom intervention in which a seventh-grade teacher, in collaboration with researchers in science education, developed, implemented and analysed the role of wonder as a pedagogical tool for students' engagement in meaning-making of and learning about evolution.

The aim of the study presented in this article was twofold. First, we wanted to empirically explore ways for teachers to make room for wonder in ordinary school science. Second, we wanted to investigate the ways in which such teaching might affect students' engagement in learning about evolution. The following two questions were used to guide our study:

1. In what ways can teachers make room for wonder in their science classroom?
2. In what ways, if any, does making room for wonder impact students' meaning-making, engagement in and learning about biological principles and threshold concepts that are known to be important when learning about evolution?

Wonder – A scientific emotion?

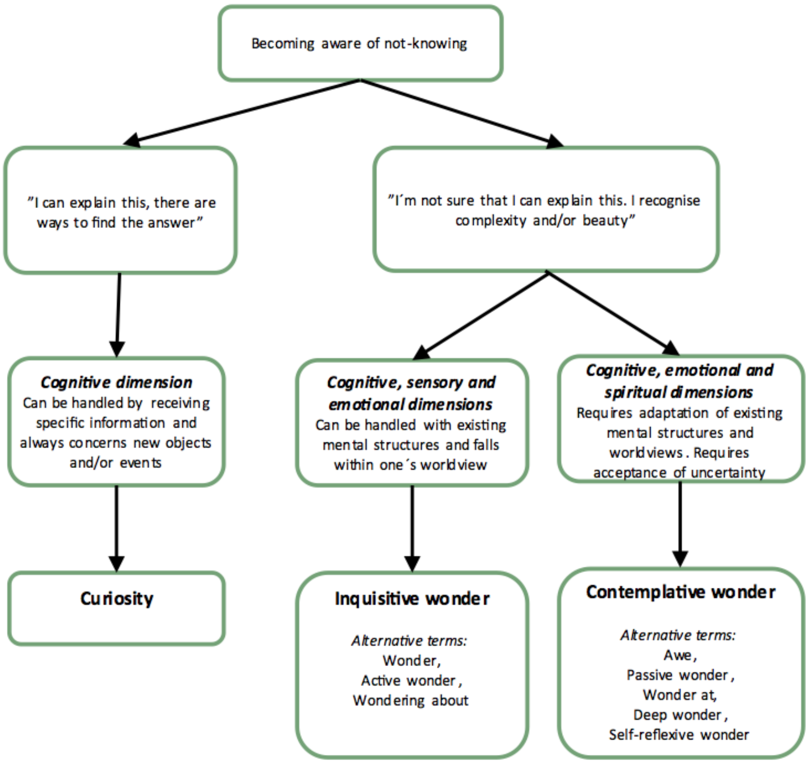
The idea of wonder being integral to learning about and understanding the world around us was suggested as early as by the ancient Greek philosophers. Plato stated that »wonder is the beginning of philosophy« and Socrates consistently urged his fellow citizens and students to consider strange new ways of looking at the world. Within the natural sciences, modern scientists such as

Richard Dawkins and Donna Strickland still highlight wonder as an indispensable dimension of the scientific endeavour (Dawkins, 2000; Strickland, 2020). In a recent study, Cuzzolino (2021) showed that epistemic emotions served as an important motivator to the »quest for understanding«, as well as a source of new perspectives on learners' work and worldview.

In general, researchers use the term wonder to address a whole range of emotions that describe not-knowing in relation to learning. For example, educational researchers refer to dichotomies such as inquisitive wonder vs. contemplative wonder, active wonder vs. passive wonder, childish wonder vs. self-reflexive wonder, and wondering about vs. wondering at (Egan et al., 2014; Hadzigeorgiou, 2011). In psychology research, where the interest in epistemic emotion has increased in the past two decades, the term *awe* is generally used (Keltner & Haidt, 2003; Valdesolo et al., 2017) to describe emotions that overlap with the term *wonder* as more commonly used in educational research. In relation to art/aesthetics, three dimensions of wonder have been described: the sensory dimension, the cognitive dimension and the spiritual dimension (Gess, 2019). Thus, in the literature referred to above, the definitions of different types of wonder sometimes overlap, but are sometimes described as distinctively different. It is beyond the scope of the present article to engage in a detailed discussion of the overlapping features and distinctions of these terms; however, to help the reader, we have summarised the main characteristics of and relationships between the common terms used to describe wonder in science education contexts (Figure 1).

Figure 1

Model of the main characteristics of and relationships between the most common terms applied to describe emotions related to not-knowing in educational research.



Note: Terms in bold are those used in the present article. Adapted from Valdesolo (2017), Wolbert and Schinkel (2021), Schinkel (2017), Egan et al. (2014) and Hadzigeorgiou (2011).

In the present article, we use the terms *curiosity*, *inquisitive wonder* and *contemplative wonder* to make distinctions between the three main types of affective response to not-knowing described in educational research. In short, curiosity covers terms that relate to a cognitive explanation-seeking response to not-knowing. The trigger for curiosity always involves a dimension of novelty, that is, it is triggered by an object or process that the person has never encountered before. Inquisitive wonder covers terms that describe experiences that are related to curiosity in that they are inquisitive, but in these cases the experience involves a cognitive as well as a sensory and emotional dimension. The trigger for inquisitive wonder may involve the dimension of novelty, but it can also involve something familiar that is seen from a new perspective (Schinkel, 2017). Contemplative wonder encompasses terms describing cognitive, emotional and spiritual experiences, i.e., when »we sense the utter mysteriousness of whatever we are contemplating« (Schinkel, 2017). The definitions of both inquisitive and contemplative wonder overlap with how the term *awe* is used within the literature. Contemplative wonder may appear to be less important for educational purposes, as it may just leave us lost for words; nevertheless, in relation to teaching and learning evolution, contemplative wonder may be of particular importance, as this type of wonder is supposed to make us stretch our minds and question our worldviews.

Wonder in school science

In line with the literature described above, arguments have been put forward to acknowledge wonder as an important dimension of school science, as well. Wonder is hypothesised to motivate students to explain and explore the physical world (Dewey, 1910; Valdesolo et al., 2017; Wolbert & Schinkel, 2021), to open an emotional relationship with nature and science content knowledge (Hadzigeorgiou & Schulz, 2014), and to predict a more accurate understanding of how science works, as well as a rejection of creationism and teleological explanations (Gottlieb et al., 2018).

Despite the fact that wonder has repeatedly been hypothesised to be beneficial to science teaching and learning, there are very few empirically based studies informing teachers how to shape their science teaching to make room for wonder. Science curricula today lack both guiding instructions and motivation for science teachers to make room for emotions (Fortus et al., 2022; Gilbert & Byers, 2017; Hadzigeorgiou, 2011; Wolbert & Schinkel, 2021). One explanation for the lack of empirical studies may be the complex and challenging demands that 'teaching for uncertainty' and making room for emotions imposes on teachers (Hadzigeorgiou, 2011; Gilbert & Byers, 2017; Wolbert & Schinkel, 2021). In making space for wonder, and therefore uncertainty, teachers need to abandon routine practices that place students' ability to articulate correct answers in the foreground. Moreover, it may be difficult to inspire teachers to make room for wonder in the classroom because they doubt the place of such emotions in science education in the first place. In a study by Stolberg (2008), pre-service teachers expressed views on wonder as something that is part of being irrational, or connected wonder to spirituality, thus positioning it as unscientific. Another reason for the lack of empirically based studies is the methodological difficulties in identifying and describing students' experiences of wonder in the ongoing reality of the science classroom.

The results of two of the few classroom-based studies of wonder are of interest for the present research. The first study, performed by Hadzigeorgiou (2011), describes a classroom intervention in which a ninth-grade physics teacher and Hadzigeorgiou together designed teaching that could foster a sense of wonder. The results showed a positive effect on students' learning of the scientific phenomena, and an increased understanding consistent with the principles of scientific methods. In the second study, Gilbert and Byers (2017) used wonder as a pedagogical tool to help primary student teachers overcome the negative associations with science that they had acquired from their own school science experiences. The results showed that the explicit use of the concept of wonder provided important insights, created a context for the students' interest in science and gave them the courage to take on science teaching. These two classroom-based studies indicate that the pedagogical potential of wonder argued for in theory may be translated into classroom practice and demonstrated how this may affect students' learning and appreciation of science. However, there is a need for more empirical studies that thoroughly study the educational potential and limitations of wonder in specific school science subjects, which is why, in our opinion, the present study is important.

Theoretical framework for wonder as a pedagogical tool in science education

In designing our strategy for the present study together with a lower secondary teacher, we were inspired by the works of Trotman (2014) and Wolbert and Shinkel (2021). Trotman (2014, pp. 36–38) draws on four biographical vignettes and some examples of educational practices to theoretically discuss the educational possibilities of and barriers to wonder in school-based education. He suggests six prerequisites for the development of wonder-full teaching: 1) an environment where exploration, chance and serendipity are valued as necessary features of education, 2) a curriculum that generates vivid imaginative and emotional connection within and across subjects, 3) empathic teaching that includes imagination, emotion and affect, 4) reception and generation of moments beyond the initial 'wow' of novelty, 5) education that is driven by neither pre-specified nor instrumental outcomes, and 6) education that includes opportunities for projects of personal interests.

The work of Wolbert and Schinkel (2021) builds on Trotman's reasoning, but is adjusted to fit the restraints of school-based teaching. Like Trotman, they recommend teaching that makes room for improvisation, imagination and the students' own interests. However, their suggestions emphasise the importance of the capacity of the teacher herself/himself to wonder, to recognise students' wonder and to see wonder in the ordinary.

The Swedish context

The education system in Sweden is based on a nine-year comprehensive school (*grundskola*), with mandatory attendance for students between seven and sixteen years of age. Secondary schooling is separated into the compulsory lower secondary (grades 7–9) and voluntary higher secondary (grades 10–12). The sample for this study comprised 45 students in one seventh-grade class (13–14 years of age).

The national curriculum that was valid when the study was carried out, Lgr 11 (National Agency for Education, 2011), regulates the aims and guidelines for all aspects of education in the comprehensive school. With regard to teaching evolution, the curriculum states: »Through teaching, pupils should get an insight into the worldview of science with the theory of evolution as a foundation, and also get perspectives on how evolution as a scientific field has developed and what cultural impact it has had« (National Agency for Education, 2011, p. 166). The core content to cover in relation to evolution is described in Table 1.

Table 1

Core content related to evolution that biology teaching should cover in grades 7–9

Section	Content to cover
Body and health	The body's cells, organs and organ systems, and their structure, function and interaction. Comparisons between man and other organisms from an evolutionary perspective. Evolutionary mechanisms and their outcomes, as well as heredity and the relationship between heredity and the environment.
Biology and worldviews	Scientific theories about the origins of life. The development of life and diversity from evolutionary theory perspectives.
Biology, its methods and ways of working	How organisms are identified, categorised and grouped, based on relationships between species and their evolution.

Note. Adapted from National Agency for Education, 2011, pp. 169–170.

Method

The study setup

The study was carried out through formative interventions. The main goal of formative interventions is to enable collaborative work between researchers and stakeholders of a specific profession in order to develop practice (Penuel, 2014). In our case, two researchers (the authors) and one teacher collaborated over a period of six weeks to design and evaluate models for introducing wonder into teaching evolution. The role of the researchers was to articulate, support and sustain the expansive transformation process within the project team (Engeström & Sannino, 2010), and to document and analyse the empirical material. The role of the teacher was to contribute professional knowledge to the planning and evaluation process and to decide on the overall setup of the six weeks of teaching so that the implementation would fit her specific class and the frame factors of the school. Prior to the intervention, the teacher and the guardians of the students received written information about the project and were informed that participation was voluntary and could be cancelled. All of the guardians were asked for written consent for their children's participation in the documented activities.

The study was preceded by a pilot study in which researchers and teachers (including the teacher in the present study) met in workshops to discuss the concept of wonder and how it might be related to teaching and learning science. During these workshops, four 'triggers' that might elicit students' wonder in the science class were jointly agreed on, drawing on theoretical frameworks suggested for teaching for wonder by Trotman (2014, pp. 37–38) and Wolbert and Schinkel (2021), as well as the participating teachers' own experiences of students' expressions of wonder in the classroom. The four triggers were: *aesthetic experiences*, *defiance of expectations, students' agency* and *awareness of a mystery within the ordinary* (Table 2).

Table 2
Descriptions of the four 'triggers' that guided the design of the workshop

Triggers	Description	Examples
Aesthetic experiences	Sensory experiences and opportunities for students to express themselves through different modes. Experiences in which mind and body are used to increase one's understanding of an object or process.	*Touch a petal to sense its softness* *Watch the glistering body of an earthworm for a long time* *Draw a detailed picture of an earthworm*
Defiance of expectations	Experiences of surprise when confronted with new aspects of something familiar, or new objects or processes in familiar settings.	*Discover that a small seed can grow into a huge sunflower* *Observing that insects have feet*
Agency	Experiences of being able to achieve something on their own or in cooperation with others.	*Design a scientific experiment on your own*
Awareness of a mystery within the ordinary	Experiencing a spiritual dimension. A feeling that 'there is more to this than what I can observe and understand'.	*Appreciate a rainbow beyond the scientific explanation of it* *A feeling of being part of something greater*

Note. Adapted from Trotman (2014, pp. 37–38), Wolbert and Schinkel (2021) and teachers' experiences of students' expressions of wonder in the classroom.

During the six-week period of the study, two lessons per week were planned covering evolution. Three of these twelve occasions were used for various workshops in which making room for wonder was explicitly planned for. In the present article, we describe the setup and results of the first workshop, which was entitled *Three Things*, and how the students responded to this intervention. The other two workshops focused on the concepts *variety, competition and natural selection* and *evolutionary time*. In the first workshop, the students were instructed to »'play' finches by using different types of 'bird beaks' (pliers) to pick food (seeds, nuts) of varying sizes and shapes«. In the next workshop, the students made a »deep time walk« along a 46 meter long string as a visual metaphor for 4.6 billion years. Key events were presented by the teacher along the way and discussed.

The design of the workshop Three Things

The workshop entitled *Three Things* was performed during a morning session when the class of 45 students were divided into three groups of 15 students who circulated between three different classrooms to enable small-group teaching in different subjects. The workshop was therefore repeated three times with three different groups, each workshop taking one hour. The workshop was introduced by the teacher, who presented three famous scientists who all had a major impact on evolutionary science: Carl von Linné (1707–1778), Mary Anning (1799–1847) and Charles Darwin (1809–1882). All three were presented in relation to their specific knowledge contribution to the field of evolution, while also highlighting how the sense of wonder was a driving force for their scientific endeavour. After this, three biological objects were presented to the students by the researchers: a tray of assorted lichens (*Cladónia spp., Cetrária islándica, Cladina spp.)*, a small trilobite fossil, and otoliths from whiting (*Merlangius merlangus)* (Figure 2). These three objects were carefully chosen for three reasons.

Figure 2

The three biological objects used in the teaching model Three Things: assorted lichens (Cladónia spp., Cetrária islándica, Cladina spp.), a trilobite, and otoliths from whiting (Merlangius merlangus)

First, these objects had been important triggers for the participating researchers' own wonder early in their careers, thus providing the students with a first-hand story of how the sense of wonder can be a driving force for scientists. Second, the objects were hypothesised to trigger the students' wonder through *aesthetic experiences*, *defiance of expectations* and *awareness of a mystery within the ordinary*. Although all of the objects were probably unfamiliar to the students, they were still expected to be perceived as ordinary (i.e., without spectacular features) at first glance. Third, all of the objects were judged to represent specific concepts that are central to learning about evolution and yet difficult to grasp: evolutionary time (the trilobite), diversity (the lichens) and organism (all three). In addition, all of the objects were reasonably accessible for a teacher and easy to handle in an ordinary classroom.

The students were divided into subgroups with five members, and each subgroup was assigned a table on which one of the objects was displayed. The students were then asked to reflect together about what they were observing when examining the object. Although the students had access to magnifying glasses during the workshop, they requested a stereo microscope, which the teacher provided for each group. After about five minutes, when the discussions seemed to be subsiding, the subgroups were asked to rotate to the next table. This procedure was repeated so that everyone had observed and examined all of the objects by the end of the workshop. The teacher and the researchers circulated among the subgroups to listen to the discussions, encourage further discussion and answer students' questions.

Students' logbook entries

In the last ten minutes of the workshop, the students were asked to reflect individually by making logbook entries on the Google Classroom learning platform. They were guided by two questions/instructions. The first instruction was: *Tell us as much as you can about what you thought about when you saw the fossil, the mushrooms/lichens, and the otoliths today*. Noteworthy here is that the teacher used the terms mushrooms and lichens interchangeably, which influenced the terms the students later used in their logbook entries. The second question was: *Do you often experience a sense of wonder? If so, what triggers this?* The students had one more opportunity to complete their reflection task. Three of the students did not attend the workshop and so only made entries corresponding to the second question.

Student interviews

At the end of the six-week period, we performed six semi-structured interviews with student pairs (Table 3). Each interview lasted about 13–16 minutes and followed an interview guide that was divided into three themes: a) the students' interpretation of the concept of wonder, b) the students' interpretation of the concept of evolution, and c) the students' experience of science teaching in general and in the three workshops of the intervention. Each interview was audio recorded and transcribed verbatim.

Analysis

Thematic content analyses were made of the logbook entries and the transcribed interviews (Table 3). Methodologically, thematic content analysis can be applied to both describing and interpreting qualitative data (Graneheim & Lundman, 2004). A central premise is that the same data material can be interpreted in several different ways. In our case, the analysis was aligned with our two research questions and made in collaboration between the authors in an iterative process for each research question, whereby we alternated between individual analyses and joint analyses of the empirical material.

Table 3
Empirical material analysed in the study

Empirical source	Description	Empirical material	Analysis
Logbook entries	Student reflections on the lesson, guided by two questions	45 digitally written individual entries	Thematic content analysis
Semi-structured and audio-recorded interviews	Student interviews in pairs, guided by thematic questions	6 audio recorded interviews with 12 students, (6 girls and 6 boys), approximately 15 minutes each	Thematic content analysis

Logbook entries

An important part of the first round of analysis was to establish how the students' expressed themselves when describing their experiences of wonder, as this would guide us in the next step, in which we wanted to analyse the students' expressions of wonder in relation to concepts connected to evolutionary processes. In order to establish how the students' expressed themselves when describing their experiences of wonder, we analysed the vocabulary they used in their entries in relation to the question: *Do you often experience a sense of wonder? If so, what triggers this?* We found a set of words that were used repeatedly by the students when they described what triggers their sense of wonder. Most commonly, the students used the words *cool* (47%) and *awesome* (36%). Other frequently used words were: *interesting*, *fascinating*, *wow!*, *weird* and '*new to me*'. For example: »*I feel a sense of wonder // when I see something that is **cool** or **interesting***« (Student 26).

After we had established how to guide our judgement of the students' expressions of wonder, we conducted a joint analysis of the entries that the students had made in response to the instruction: *Tell us as much as you can about what you thought about when you saw the fossil, the mushrooms/lichens, and the otoliths today*.

First, both of the researchers read all of the entries and highlighted key features of the data set in relation to research question 2. The key features were then coded individually into tentative themes. In the next step, the two sets of themes were compared and negotiated in order to consolidate them, but also to provide an opportunity for new insights into what the material could reveal in relation to the research question. This process was continued until the themes were considered stable by both researchers. Two overarching results emerged. The first comprised themes that together described *what* triggered the students' sense of wonder (Table 4), while the second set of themes described the fact that the students expressed three qualitatively different types of wonder (Table 5).

Student interviews

In order to create an overview and an overall picture of the material, the transcripts were analysed by repeated read-throughs. We then marked the sentence units, i.e., the statements in which the students' conversations were directed towards the role of wonder and learning about evolution. Other episodes were set aside. The sentence units were then analysed by condensing, coding, categorising and thematising them in the manner described above for the logbook entries (Graneheim & Lundman, 2004).

Results

Taken together, our results suggest that it is possible to design science teaching that triggers students' wonder in relation to an intended learning object. Our results also reveal that the students described their sense of wonder in qualitatively different ways, and that they still struggled to make sense of the concept of evolution after six weeks of teaching. These results are described in more detail below.

Expressing wonder associated to key and threshold concepts

Except for the three students who were absent that day, all of the students made logbook entries in which they described their experiences during the intervention. In most of the entries (25 of 42), the students' sense of wonder was triggered by one or more of the objects. On closer analysis of how the students expressed themselves, however, it was revealed that this sense of wonder could in fact be delineated into concepts that describe evolutionary or scientific processes rather than to the objects themselves.

As shown by the quotes in Table 4, the students, in their own words, associate the three objects with aspects that can be linked to evolutionary concepts such as *temporal scale, variation*, *diversity* and *interplay between organisms and habitat.*

Table 4

Students' expressions of wonder associated with evolutionary concepts

Object	Concept	Quotes	Number of entries
Lichen	Variation/ diversity	*The mushrooms were **cool** to look at with magnifying glasses; imagine how it is possible that they can look so different and still grow in the same places (log, Student 3).*	26
		The mushrooms [lichens] looked very different. Some looked very much like a mushroom and some really didn't look like a mushroom (log, Student 31).	
Trilobite	Temporal scale	*I thought the fossil [trilobite] was the **coolest** because it was about 500 million years old and yet it [the trilobite] still exists today (log, Student 15).*	25
		*It was **exciting**, it was a bit difficult to think that you can see something that existed before dinosaurs existed (log, Student 36).*	
Otolith	Variation/ diversity	*Then the one with the fish [the otolith] that you could see how long they had been alive and if they had been swimming in salt water or fresh water (log, Student 41).*	22
	The scientific process	*The otoliths were the **coolest** because there can be so much information in a tiny white blob (log, Student 34).*	
		*The otoliths were a bit **weird**, [I] didn't really know what it was used for when it was in the fish, // the fact that you can tell the age just by looking at it was really cool, but you wonder how, too (log, Student 5).*	

Note. In some cases, the student expressed wonder at more than one object. The words in bold denote the vocabulary that the students used in relation to wonder (see methods section).

The most common triggers for the students' wonder were aspects that can be related to *variation* (26 of 42 entries). As the students do not use discipline-specific language, and since their entries are rather short, it was not always possible to discern whether they were referring to variation on the individual level within one species or variation between different species. Nevertheless, the quote from Student 3 is an example of how many of the students wondered at the variation of characteristics among lichens. Student 3 remarks on the fact that the lichens looked very different even though they were all picked in the same forest. We interpret this as an emerging realisation of how variations in characteristics of an organism may, or may not, be connected to variations in the surrounding environment. Such an emerging awareness of the interplay between physical characteristics of organisms and the characteristics of the habitat in which they live is a recuring observation among the students. In several of the entries related to the otoliths, the students specifically wondered at how it was possible that the interplay between an individual and its environment could leave physical traces at a small part inside an organism.

Many of the students also wondered at the magnitude of the amount of time that has passed since the trilobites roamed the earth, and that they could nonetheless hold a specimen of this creature in their hand today. We interpret this as wonder connected to the *temporal scale* of evolutionary time, as the students explicitly describe how they find it hard to grasp the time span and fit it into their existing worldview.

Somewhat unexpectedly, our results also show that the students wonder at the scientific process itself. Student 5's comment that »*the fact that you can tell the age [of the fish] just by looking at it [the otolith] was really* ***cool****, but you wonder how, too*« was just one of several remarks that expressed wonder at how a biological object can carry information that can be interpreted and used by researchers to understand more about an individual.

Taken together, the results show that the setup of the intervention seems to have enabled most of the students to confront their own 'not-knowing' in relation to important concepts of evolutionary processes. This discovery of not-knowing was not induced by direct questions from the teacher; rather, it emerged within the students as they tried to make sense of what they were experiencing. The experience was, however, framed by an introduction that included a presentation of the concepts of both evolution and wonder. Our interpretation is that this introduction was enough to inspire most of the students to wonder about how and why the physical characteristics of species and individuals vary, as well as about the vastness of evolutionary time and the scientific process.

Three types of responses to not-knowing

When focusing our analysis on *how* the students described their experiences during the workshop, examples of the qualitatively different types of affective responses to not knowing described in Figure 1 emerged from the material (Table 5). The students described curiosity, inquisitive wonder and contemplative wonder, which we have interpreted as reflections of differences in their cognitive or/and emotional involvement.

Table 5

Types of not-knowing expressed by the students in relation to learning about evolution

	Description	Quotes	Number of entries
Curiosity	Refers to a cognitive experience. Defined by a desire to receive 'right answers'.	*There was a lot to see today, but with few answers, which was a shame (log, Student 5).*	10
		I would really like to learn more about what we learned today (log, Student 22).	
		It's like a new world that you enter and there were so many questions that came up in your head (log, Student 24).	
Inquisitive wonder	Refers to a cognitive, sensory and emotional experience. Defined by the student's full attention to the object of wonder and the use of both mind and body (senses) to make sense of the experience.	*When I saw the fossils it wasn't so* ***cool*** *– I've seen a lot of fossils before – but it was still nice that you could touch them, because last time I was in a place where there were fossils that you couldn't touch, but now you could (log, Student 18).*	17
		Everything felt and smelt different. Some things had patterns on them, so it was kind of neat (log, Student 20).	
		// when I looked with the magnifying glasses it looked much ***cooler*** *and I wanted to look a lot. It was kind of a neat pattern and it was* ***cool*** *to be able to see the eyes (log, Student 23).*	
		The most fun was when you got to touch them [the lichens], because they didn't feel like I thought they would, far from what I thought they would feel like (log, Student 24).	
Contemplative wonder	Refers to a cognitive, emotional and spiritual experience. Defined by shifts in perspective (scales, complexity), and/or imagination.	*When we looked at the lichens under the magnifying glass, it was very interesting; it was like looking into another world. Everything looks so different when it's magnified (log, Student 1).*	17
		It [the lichens] reminds me of when you were a little kid in the woods playing and seeing things like that; it was just cool and everything was ***awesome*** *(log, Student 24).*	
		I thought the fossils were ***cool****; the lichens were* ***cool*** *and looked like inspiration for children's movies with enchanted forests in them (log, Student 30).*	
		It was ***exciting****; it was a little hard to think that you can see something that existed before dinosaurs existed (log, Student 36).*	

In the first category, *curiosity*, we gathered the students' entries describing a state of not-knowing that can be resolved if, for example, someone (the teacher) gives them an answer or more information. The message conveyed by these entries corresponds in many ways with how curiosity is described in the literature. In some of the entries, we can sense frustration at the lack of information. This type of experience was the least common one.

The second category, *inquisitive wonder*, we interpret as a state of not-knowing that is simultaneously connected to cognitive, sensory and emotional qualities. The log entries reveal that the students responded to their experience of not-knowing by using both their mind and their senses to learn more. The students used sight, smell and touch to resolve their not-knowing rather than asking for information. This in turn resulted in an opportunity for sensory and emotional experiences.

The entries that were sorted into the third category, *contemplative wonder*, all reflect an emotional state in which the students let the mind wander and imagine new worlds or perspectives. Interestingly, most of these entries refer to experiences of viewing the objects through the magnifying glass or stereo microscope that the teacher provided. These devices seem to have sharpened the students' sight in a way that allowed them to enter new imaginary worlds (Students 1 and 30), but also to make way for free associations and existential thinking (Student 24).

Struggling to make sense of evolution

Learning about evolution can be challenging for students, as a full understanding may require them to see the world in a new and different way, as well as requiring a mastery of a disciplinary language and an understanding of complex processes. Accordingly, the interview transcripts revealed that, even after experiencing six weeks of teaching about evolution (encompassing approximately two lessons each week), many of the students were still struggling with how to conceptualise the main features of the evolutionary process. Our analysis of the interview transcripts reveals that the students are, as Walck-Shannon et al. (2019) put it, still in a liminal state where they are approaching and learning to master threshold concepts and a disciplinary language. When encouraged to describe what evolution is about, most of the students' descriptions were constructed by various relevant concepts, but stacked on top of each other without coherence. For example, in one of the interviews (Group 6) two students explain evolution together as follows:

Student 1: How species have changed over time to adapt more.
Student 2: Yes, adapted better. Adaptation and evolution. And species.

Even the students who specifically expressed that they perceived evolution to be logical struggled:

That like sea and land come before vertebrates in water or something like that. It's quite logical. It was quite difficult though (Group 4, Student 1)

Our interpretation of the interview data is that, at the end of the teaching period, the students had learned that there are specific concepts that should be used when describing the process of evolution. In the logbook entries made at the very beginning of the teaching period, none of the students used disciplinary concepts. Later, in the interviews, they used concepts such as *adaption*, *species* and *vertebrates*. The precision and accuracy of how to position these concepts in relation to each other and in a coherent context is, however, not yet fully developed. We suggest that this can be described as an *emerging disciplinary language*, and that the students are still struggling to master it.

In some cases (Group 5), the interview data also show, in a very explicit way, how the students were struggling with their awareness of not-knowing:

Student 1: We got to learn what came first, the atmosphere or this cell stuff and such. What else was there? We learned that humans, although we all know that from before, humans were monkeys. Or was it? Or did we bring it up? No, it wasn't that.

Student 2: No

Interviewer: Yes, what about that?

Student 2: I was told by somebody, // that you were a monkey first and then you evolved into a human being. Then more and more humans come along.

In summary, the results indicate that the full teaching period seems to have positioned the students in a liminal state where they were beginning to develop a disciplinary language but were still confused and uncertain in their understanding of evolution.

Discussion and Implications

Below we will discuss the educational implications that we identified in relation to our findings.

I. Mental guidance and providing material portals: Teachers tools for making room for wonder?

One purpose of the present study was to investigate whether it is possible to design teaching that trigger students' wonder in relation to predetermined science content. Our findings suggest that this is possible, as most of the students expressed a sense of wonder that could be connected to evolutionary concepts such as temporal scale, variation, diversity and the interplay between organisms and habitat. In previous literature, it has been suggested that the lack of empirical studies of wonder in science classrooms may be connected to the complex and challenging demands that 'teaching for uncertainty' and making room for emotions impose on teachers (Gilbert & Byers, 2017; Hadzigeorgiou, 2011; Wolbert & Schinkel, 2021). With this in mind, we were careful to plan the 'wonder workshops' based on the theoretical suggestion made by Trotman (2014) and Wolbert and Shinkel (2021) in close collaboration with the teacher who was going to perform the teaching. This teacher also had the last word on how the theoretical suggestions should be translated into teaching in her classroom. Drawing on the results of Stolberg (2008), who showed that it may be difficult to inspire teachers to make room for wonder because they doubt the place of such emotions in science education, we also placed particular emphasis on negotiating how the term wonder can be interpreted together with the teacher. This resulted in teaching in which the triggers *aesthetic experiences*, *defiance of expectations, agency* and *awareness of a mystery within the ordinary* were carefully planned for. Based on our results, we now suggest that our setup can be used by teachers as a mental tool for making room for wonder in ordinary science classrooms.

In our results, we also see examples of physical tools that directly triggered the students' sense of wonder. Since these tools seemed to instantly transfer the students to a sense of wonder, we have called them *portals*. The first portal was the carefully chosen objects (the lichens, the fossil and the otolith), which were hypothesised to trigger the students' wonder through *aesthetic experiences*, *defiance of expectations* and *awareness of a mystery within the ordinary*. In the results, there are several examples of how these objects did indeed trigger the students to express thoughts, questions and wonder. All of these objects were considered as coming from the 'real world' by the students; at the same time, the students had not experienced them in real life. It can therefore be argued that the objects made the students aware of unexpected aesthetic and mysterious qualities within something ordinary, which triggered a sense of wonder. However, our interpretation is that the pedagogical framing by the teacher was crucial for making way for their wonder. The teacher made it possible for the students to explore these objects at will, without the pressure of a predetermined learning goal. This in turn made it possible for the students to manifest *agency*, another of the theoretical prerequisites for making room for wonder. In addition, these explorations were framed by a short introduction about wonder, which may have made the students receptive to perceiving open questions and expressions of wonder as legitimate aspects of a science class. The second portal was the stereo microscope. In our empirical material, we have numerous examples of how the students were transferred to new worlds by looking through a stereo microscope and we believe that it has many functions that support this 'transfer'. First, looking through a microscope helps one to focus on an object by shielding off the classroom environment. Second, the magnification makes the details and colours of an ordinary object appear in new and unexpected ways, allowing possibilities for *aesthetic experiences*, *defiance of expectations* and *awareness of a mystery within the ordinary.* Third, the magnification provides a change in perspective related to scale, a feature previously described as an elicitor for wonder (Cuzzolino, 2021; Keltner & Haidt, 2003).

Our results exemplify how teachers can introduce objects or equipment that can function as portals for wonder in their science classroom. Most importantly, these objects and equipment do not have to be spectacular or involve advanced technology. All of the objects that were introduced in the present study are available for a teacher to bring into the classroom. Likewise, magnifying glasses and stereo microscopes can be considered to be common equipment in an ordinary classroom. This is an important result, as it exemplifies the fact that introducing wonder into the classroom can be accomplished with relatively simple means. In fact, there might be intrinsic value in choosing ordinary objects and equipment: it may serve as a strategy for ensuring that students keep their focus on the science learning object (Anderhag et al., 2016). However, using everyday equipment and ordinary objects to trigger students to wonder at our physical world requires a teacher who is able to identify the wonder within the ordinary (Wolbert & Schinkel, 2021) and who feels comfortable with introducing the concept of wonder into the science classroom (Stolberg, 2008). It is therefore important to bear in mind that the role of the teacher is crucial. In our example, the teacher not only provided 'portals', but did so in combination with explicit guidance that introduced the concept of wonder and demonstrated how this emotion is valid in science. The results can thus be related to the conclusions of a study by Gilbert and Byers (2017) in which the explicit use of the term wonder in connection with science teaching was described as working as a catalyst for early childhood student teachers' interest in and understanding of the scientific endeavour.

II. Students respond in different ways to teaching for wonder

Our results show that 'wonder-infused' teaching evoked students' *curiosity*, *inquisitive wonder* and *contemplative wonder* (Table 5). Based on the results, we suggest that teachers need to be sensitive towards the different ways in which students respond to teaching that makes room for wonder. Some students responded with *curiosity*, which contrasts with inquisitive and contemplative wonder in that it is primarily focused on a cognitive striving for answers. This response therefore lacks the sensory, emotional and spiritual dimensions that wonder encompasses. Curiosity is nevertheless an expected response to teaching that makes room for students' own explorations and open questions. According to Lindholm (2018), inquisitiveness for facts and classical knowledge is especially predominant in prepuberty, which is a phase that the students of the present study were just leaving. Teachers trying to elicit wonder in their lower secondary science classes should therefore also be prepared to support students who ask for more information. In the case of learning about evolution, facts and examples of diversity among species and animal anatomy, which the teacher is able to provide, can in the long run be sources of wonder.

In our material, the students predominantly expressed *inquisitive wonder*. Based on how the students expressed themselves, we conclude that their inquisitive wonder was mainly triggered because they were able to engage with the objects without a predetermined protocol. As discussed in the previous section, the students were empowered to pursue explorations of their own design. This resulted in physical explorations in which they used several of their senses. A number of the students noted in their logbooks that it was unusual to actually be able to touch and smell the objects that they encountered in science education. The sensory experiences seem to have opened the possibility of emotional responses towards the object in a way that a picture in a book or displayed in a PowerPoint presentation cannot accomplish. However, the students were also given an opportunity to experience authentic moments of discovery, which are common triggers for wonder (awe) for professional scientists (Cuzzolino, 2021).

A few of the students in our study also expressed *contemplative wonder* in their logbook entries. At first sight, this type of wonder might appear to be anti-educational, because, as Schinkel (2017, p. 538) remarks, »it is not inherently inquisitive like active [inquisitive] wonder and, as a response to mystery, may leave us lost for words«. However, we agree with Schinkel's conclusions that contemplative wonder may still have an important function in science teaching, as this emotion can make students receptive to discussions about different perspectives and the limits of our understanding. In relation to teaching and learning about evolution, such discussions can make way for the transformative experience that is necessary in order to fully understand evolutionary processes. We therefore propose that this type of wonder might be a specifically helpful tool for teachers to support students to accomplish the threshold crossing described by Walck-Shannon et al. (2019).

III. Crossing a threshold of learning requires support for disciplinary language acquisition

As previously described in the literature, threshold concepts are fundamental concepts that, once understood, transform a student's perception of an entire subject and enable access to a previously inaccessible way of thinking, understanding or interpreting something (Meyer & Land, 2003; Walck-Shannon et al., 2019). It is therefore interesting to note that the students involved in the present study *independently* wondered at concepts that are considered as key or threshold concepts for thinking about and understanding evolution. When doing so, the students did not use the specific concepts of evolution, but rather described the phenomena in their own words. This is not surprising, as the written reflections were made at a time when the students had not yet learned any of the relevant concepts. At the end of the teaching period, they nevertheless tried to use the concepts, but were still unsure of how to do so correctly. According to Walck-Shannon et al. (2019, p. 2), »the process of crossing a threshold of learning is accompanied with disciplinary language acquisition that is bounded and specific to the threshold concept«. We therefore suggest that making room for wonder when teaching evolution be combined with support for the student's development of a disciplinary language.

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Biographical note

Bodil Sundberg, PhD, is an associate professor in Science Education at the School of Science and Technology, Örebro University, Sweden. Her research focuses on teachers' professional development, early-year science education, and the role of wonder in science practices.

Magdalena Andersson is a science teacher and licentiate student at the School of Science and Technology, Örebro University. She also works as development manager for teacher training at the Municipality of Örebro. Her research focuses on the role of wonder for students' meaning-making in science.

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Relationships between Epistemological Beliefs and Conceptual Understanding of Evolution by Natural Selection

Andreani Baytelman*[1], Theonitsa Loizou[2] and Salomi Hadjiconstantinou[3]

This study researches relationships between 12th-grade students' epistemological beliefs towards science and their conceptual understanding of evolution by natural selection. Forty-two 12th-grade students in a suburban high school in Cyprus, who participated in a biology course, completed measures of their: (a) epistemological beliefs towards science before the intervention of being taught evolution (b) conceptual understanding of evolution by natural selection after evolution intervention, (c) epistemological beliefs towards science after evolution intervention. Based on previous research, we hypothesised there would be a significant relationship between students' epistemological beliefs and their conceptual understanding of evolution by natural selection after the evolution intervention. We also hypothesised that inquiry-based intervention on evolution by natural selection would foster students' epistemological beliefs. Our results indicate that participants' initial epistemological beliefs predict very modestly and statistically non-significant learning achievements on conceptual understanding of evolution by natural selection. However, our results show a significant improvement in participants' epistemological beliefs after engagement in an inquiry-based intervention on evolution by natural selection. The educational significance of this and its implications are discussed.

Keywords: conceptual understanding; epistemological beliefs; evolution by natural selection; inquiry-based teaching and learning, students

1 *Corresponding Author. Department of Education at University of Cyprus, Cyprus; baytel@ucy.ac.cy.
2 Lykeio Paralimniou, Cyprus.
3 Paralimni high school, Famagusta, Cyprus.

Razmerja med epistemološkimi verjetji in pojmovnim razumevanjem evolucije z naravno selekcijo

Andreani Baytelman, Theonitsa Loizou in Salomi Hadjiconstantinou

Študija se usmerja na odnose med epistemološkimi verjetji srednješolcev 12. razreda do znanosti in njihovim pojmovnim razumevanjem evolucije z naravno selekcijo. 42 srednješolcev 12. razreda primestne srednje šole na Cipru, ki so sodelovali pri pouku biologije, je opravilo meritve: a) epistemoloških verjetij do znanosti pred predstavitvijo evolucije; b) pojmovnega razumevanja evolucije z naravno selekcijo po intervenciji evolucije; c) epistemološka verjetja do znanosti po intervenciji evolucije. Na podlagi prejšnjih raziskav smo domnevali, da obstaja pomembna povezava med epistemološkimi verjetji srednješolcev in njihovim pojmovnim razumevanjem evolucije z naravno selekcijo po vpeljavi evolucije. Prav tako smo predpostavljali, da bi tovrstna intervencija na temo evolucije z naravno selekcijo, ki temelji na raziskovanju, spodbudila epistemološka verjetja srednješolcev. Izsledki kažejo, da izhodiščna epistemološka verjetja udeležencev napovedujejo zanemarljive in statistično nepomembne učne dosežke o pojmovnem razumevanju evolucije z naravno selekcijo, vendar pa naši izsledki dokazujejo znatno izboljšanje epistemoloških prepričanj udeležencev po izvedeni intervenciji, ki temelji na raziskavah o evoluciji z naravno selekcijo. Nazadnje se v prispevku razpravlja o izobraževalnem pomenu omenjenega in pripadajočih posledicah.

Ključne besede: pojmovno razumevanje, epistemološka verjetja, evolucija z naravno selekcijo, poučevanje in učenje na podlagi poizvedovanja, srednješolci

Introduction

Evolution by natural selection is the central and overarching theory in biology. Educating students about evolution by natural selection is vitally important because it is one of the most consistent and unifying theories, capable of explaining a large number of natural phenomena at different levels (Dobzhansky, 1973; National Research Council (NRC), 2012). While in everyday conversations, the term 'theory' often indicates the absence of data and well-supported explanations, in science, a theory, according to the US National Academy of Science (NAS), 'is a wellsubstantiated [sic] explanation of some aspect of the natural world that can incorporate facts, laws, inferences and tested hypotheses'. In this sense, evolution by natural selection is a scientific theory, representing a sophisticated body of explanations for the fact of evolution (Gregory, 2008; NAS, 1984, p. 15; NAS, 2008, p. 53).

Natural selection is a key mechanism of evolution and is responsible for the evolution of adaptive features. Without an understanding of natural selection, it is impossible to explain how or why living organisms that exist on the earth have come to exhibit their wide diversity and complexity. An understanding of natural selection also is getting more and more important in other contexts, including agriculture, resource management and medicine. In particular, evolution by natural selection improves our understanding of various public health issues such as vaccinations, epidemiology, and antibiotic resistance, biological impacts of climate change, ecological issues such as invasive species, and other environmental impacts of human activity such as climate change and pesticide resistance, as well as food security and similar issues. (Dunk & Wiles, 2018).

Despite the importance of the evolutionary theory by natural selection, it remains one of the most widely misunderstood concepts of contemporary science (Miller et al., 2006; To et al., 2017). In addition, although various scientific concepts present challenges for students, evolutionary theory by natural selection is considered to be particularly difficult to understand (Gregory, 2009) and is more likely to be rejected for religious, emotional, and ideological reasons than other scientific theories (Gregory, 2009). Several studies suggest that students, teachers, and the public have a variety of resistant misconceptions about evolution by natural selection (Baytelman, 2022; Harms & Reiss, 2019; Newbrand & Harms, 2017); sparse research and knowledge exist on educational approaches and teaching strategies that can effectively change the existing situation (Harms & Reiss, 2019).

Previous research suggests the association between students' epistemological beliefs and their understanding of evolutionary theory (Cho et al., 2011;

Kizilgunes et al., 2009; Sinatra et al., 2003). This indicates that the investigation of the interrelationship of epistemological beliefs and conceptual understanding of evolution is an important issue for research. However, existing research on students' epistemological beliefs and understanding of evolution by natural selection is rare, and the results are inconclusive (Athanasiou & Papadopoulou, 2015; Borgerding et al., 2017; Deniz et al., 2008; Sinatra et al., 2003; Southerland et al., 2001; Southerland et al., 2005;). That means that more research is needed in this field (To et al., 2017).

Our aim in this study is to explore the relationships between 12th-grade students' epistemological beliefs and conceptual understanding of evolution by natural selection. To this end, answers to the following research questions were sought:

1. What are the 12th-grade students' epistemological beliefs before and after inquiry-based intervention on evolution?
2. To what extent does inquiry-based intervention on evolution improve 12th-grade students' epistemological beliefs?
3. To what extent do 12th-grade students' initial epistemological beliefs predict their learning achievements regarding the conceptual understanding of evolution by natural selection after inquiry-based intervention?

By doing this, we hope to gain a better understanding of the relationships between epistemological beliefs and conceptual understanding of evolution by natural selection and contribute to the development of a relevant theoretical framework.

Evolution by natural selection and education

Evolution by natural selection is the unifying theme of all biology, through which living organisms and communities can be understood most clearly (Dobzhansky, 1973). This framework for the life sciences is reflected in the strong acceptance of evolutionary theory amongst biologists (AIBS, 1994, p.29; Lynn et al., 2017). However, acceptance of evolution is not nearly as universal amongst members of the general public as it is in the scientific community (Branch & Scott, 2008; Miller et al., 2006; Rosengren et al., 2012).

Furthermore, several studies indicate that evolution by natural selection remains poorly understood by students (Greene, 1990; Nehm & Reilly, 2007; Nehm et al., 2009; Shtulman, 2006; Spindler & Doherty, 2009), science teachers (Baytelman, 2022; Nehm et al., 2009), and the general public (Evans et al., 2010). This lack of understanding has been attributed to diverse cognitive, epistemological, emotional, and religious factors (Reiss, 2018; Rosengren et al., 2012).

At the core of many of these misunderstandings is a teleological concept in students' reasoning about natural selection. In general, teleological thinking is the assumption that things happen for a reason. According to Kampourakis:

> […] on the one hand, teleological explanations can be based on intentional design, that is, one can state that a feature exists because it was intentionally created for a purpose. On the other hand, teleological explanations can be based on functionality, that is, one can state that a feature exists in order to perform a function that is useful for the whole to which this feature belongs. (2020, p.3)

Several studies have shown that students believe that living organisms have the traits that they currently possess because those traits perform functions that aid survival (Jensen & Finley, 1995; Pedersen & Halldén, 1994; Tamir & Zohar, 1991).

Another conceptual bias is anthropomorphism, meaning to attribute human reasoning to non-human beings (Tamir & Zohar, 1991). Studies suggest that anthropomorphism is positively related to teleological beliefs about biological phenomena and facilitates them (Kelemen & Diyanni, 2005; Kelemen et al., 2013). Yet, as suggested by Gregory (2009), anthropomorphism is intimately tied to the misconception that individual organisms evolve in response to challenges imposed by the environment rather than recognising evolution as a population-level process.

Additional student misconceptions about the theory of evolution by natural selection include the following: organisms change because of the use or disuse of organs or because acquired traits can be transmitted to offspring (Kampourakis & Zogza, 2008); organisms change because of need (Shtulman, 2006; Sinatra et al., 2003; Sinatra et al., 2008); all mutations are harmful (Nehm & Reilly, 2007); sources other than mutations and recombinations are responsible for genetic diversity (Hallden, 1988); humans are not subject to evolution (Sinatra et al., 2003). These misconceptions are often very resistant to learning about evolution (Ferrari & Chi, 1998; Gregory, 2009; Jensen & Finley, 1995; Kampourakis & Zogza, 2008; Nehm & Reilly, 2007; Spindler & Doherty, 2009). This knowledge about evolution misconceptions is an invaluable resource for further research on evolution education in order to address students' misconceptions and foster their conceptual understanding.

Moreover, biology teachers also have problems understanding evolution-related topics (Baytelman, 2022; Reiss, 2018; Sinatra et al., 2003; Yates &

Marek, 2014). Evidence suggests that the lack of subject content knowledge by biology teachers can be a reason for the development of students' misconceptions about evolution and poorer knowledge after teaching it than before (Yates & Marek, 2014). In addition, teachers face many challenges in engaging students in designing and carrying out investigations and analysing data about evolutionary processes in the classroom. One such challenge is the long timescales for evolution to occur in most species. In particular, since evolution takes place over long periods and the geological notion of 'deep time' is one that is difficult to understand and teach, it forms one of the major cognitive difficulties that students have in learning about evolution by natural selection (Reiss, 2018). Other challenges include the fact that observing changes in populations does not necessarily help students to understand the mechanisms of evolution by natural selection (Sinatra et al., 2003). Technically demanding and cost-prohibitive materials are further challenges (Sinatra et al., 2003).

Students' Epistemological beliefs

Epistemology is 'an area of philosophy concerned with the nature and justification of human knowledge' (Hofer & Pintrich, 1997, p. 88). Epistemological beliefs refer to individuals' beliefs about the nature of knowledge and the nature of knowing (Baytelman et al., 2020a; Greene et al., 2016; Hofer & Pintrich, 1997; Muis et al., 2015; Schiefer et al., 2022; Sinatra et al., 2003).

Researchers in the field of epistemology have proposed a variety of models for conceptualising and examining epistemological beliefs (Baytelman et al., 2020a). Early studies focused on the way in which epistemological beliefs developed. Perry (1970) proposed a model that described nine levels in epistemological beliefs, ranging from the belief that knowledge is objective to the belief that knowledge is radically subjective, and finally, to the belief that knowledge has objective and subjective aspects. This type of model represents a developmental model of epistemological beliefs (Baytelman et al., 2016a, 2020a; Kuhn, 1991, 2001; Kuhn et al., 2000; Scheifer et al., 2022). Based on Perry's model, Kuhn and her colleagues (2000) developed a framework for the development of epistemological beliefs, describing different stages: realist, absolutist, multiplist, and evaluativist (Kuhn et al., 2000, p. 311; Scheifer et al., 2022).

Specifically, Kuhn and her colleagues (2000, p. 311) suggested that preschoolers can be described as realists but already show some epistemological awareness (assuming that assertions are copies of external reality; reality is directly knowable and knowledge comes from an external source and is certain) Children at the elementary school level are described as absolutists (assuming that assertions are correct and incorrect in their representation of reality, it is directly knowable and, knowledge is absolute, certain, non-problematic, right or wrong). Between middle and late childhood, students can be described as multiplistic (assuming that assertions are opinions freely chosen, reality is not directly knowable, and knowledge is generated by humans, is uncertain and might be considered as opinion). The later level of epistemological understanding is the evaluativist level, achieved usually in adulthood. Evaluativists reintegrate the objective dimension of knowing by acknowledging uncertainty without forsaking evaluation (assuming that assertions are judgments that can be evaluated, reality is not directly knowable, and knowledge is generated by humans and is uncertain) (Kuhn et al., 2000; Scheifer et al., 2022). They believe that there are 'shared norms of inquiry and knowing, and some positions may be reasonably more supported and sustainable than others' (Mason, 2016, p. 376).

Later studies showed epistemological beliefs to be multi-dimensional (Hofer, 2016; Schommer, 1990; Schommer et al., 1992; Schommer-Aikins, 2004), proposing a dimensional model. Although there is consensus on the existence of multiple more-or-less independent dimensions of epistemological beliefs (Hofer, 2016), a debate about the specific dimensions of the construct has evolved (Baytelman et al., 2016a, 2016b, 2020a, 2022). Schommer (1990) proposed that epistemological beliefs should be described as a system of basically independent beliefs (epistemological dimensions), conceptualised as beliefs about the simplicity (related to the structure of knowledge), certainty (related with the stability of knowledge), and source of knowledge, as well as beliefs about the speed and ability of knowledge acquisition (Baytelman et al., 2020a; 2022) While the dimensions of simplicity, certainty, and source in Schommer's conceptualisation fall under the more generally accepted definition of epistemological beliefs (known as beliefs about the nature of knowledge (simplicity, certainty) and knowing (source) (Hofer & Pintrich, 1997; Hofer, 2016)) the speed and ability dimensions are controversial because they mainly concern beliefs about learning (speed) and intelligence (ability) (Baytelman et al., 2020a; 2022).

As suggested by Hofer and Pintrich (1997), epistemological beliefs should be defined with two dimensions regarding the nature of knowledge and two dimensions concerning the nature of knowing. The two dimensions concerning the nature of knowledge (what one believes knowledge is) are (i) Simplicity of Knowledge, ranging from the belief that knowledge consists of an accumulation of more or less isolated facts to the belief that knowledge consists of highly interrelated concepts; and (ii) Certainty of Knowledge, ranging from the belief that knowledge is absolute and unchanging, to the belief that knowledge is tentative and evolving). The two dimensions regarding the nature of knowing (how one comes to know) are (iii) Source of Knowledge, ranging from the conception that knowledge originates outside the self and resides in external authority from which it may be transmitted to the conception that knowledge is actively constructed by the person in interaction with others; and (iv) Justification for Knowing, ranging from the justification of knowledge claims through observation and authority or on the basis of what feels right, to the use of rules of inquiry and the evaluation and integration of different sources (Baytelman et al., 2016a; 2016b; 2020a; 2022).

In addition, Conley and her colleagues (2004) proposed a new epistemological dimension under the dimensions concerning the nature of knowledge, which they named 'Development of Knowledge'. Although the developmental and multidimensional models have various differences, according to Pinitrich, (2002, p. 400), 'the fairly well-established trend is that individuals move from some more objectivist perspective through a relativistic one, to a more balanced and reasoned perspective on the objectivist–relativistic continuum, with this latter position reflecting a more sophisticated manner of thinking' (Baytelman et al., 2020a, 2022).

Later, epistemological beliefs were examined for their impact on learning (Schommer, 1990). Researchers have reported that epistemological beliefs are related to academic performance, comprehension, conceptual change and conceptual understanding, views of science, innate learning and choosing science as a career, conceptions of teaching, self-efficacy beliefs, students' motivation, and higher levels of self-concept and self-efficacy (Chen, 2012; Cheng et al., 2009; Mason et al., 2013; Trevors et al., 2017). Additionally, studies argue that students' epistemological beliefs have a direct impact on the selection of learning strategies or approaches, the process of shaping conceptions and problem-solving (Chan et al., 2011) and the individual's ability to generate alternative arguments and counterarguments (Baytelman et al., 2020a).

Given the great importance of epistemological beliefs in education, various attempts have been made to foster students' epistemological beliefs at different levels of education (Muis et al., 2016; Schiefer et al., 2020; Baytelman et al., 2020a, 2022). Since the multidimensional model concerning epistemological beliefs is a system of more or less independent epistemological dimensions, which are not necessarily developing in synchrony with each other (Baytelman et al., 2020a; Muis et al., 2015), it is important to make efforts to foster all dimensions of students' epistemological beliefs, using a variety of didactical approaches.

To promote students' epistemological beliefs, science educators have developed and implemented a range of didactical approaches to provide extra support for them (NRC, 2012). Inquiry-based learning (Shi et al., 2020) refers to the active learning processes in which students are inevitably engaged (Minner et al., 2010); inquiry-based teaching (Chinn & Malhotra, 2002; Shi et al., 2020) refers to the teacher's role concerning students' learning: a shift from 'dispenser of knowledge' to facilitator or coach for supporting students' learning (Anderson, 2002), dialogic argumentative activities, reflective judgment through socioscientific issues (Zeidler et al., 2009) and using the history of science (Matthews, 1992, 1994) are some of the recommended didactical approaches.

In particular, the term 'inquiry-based learning' refers to the engagement of students in active learning processes during which they ask questions about a particular domain, identify the problem, search for information, generate testable hypotheses, plan methods, collect evidence, analyse data, draw conclusions, and communicate them (Pedaste et al., 2015; Sandoval, 2004). In such a learning process, the teacher becomes a facilitator and guide, challenging students to think beyond their current processes by offering guided questions, scaffolding, and reflection opportunities (Anderson, 2002). Researchers reported that classroom inquiry can foster students' conceptual understanding of scientific concepts and phenomena (Schröder et al., 2007), higher-order thinking skills, such as critical thinking (Haury, 1993), investigation skills (Minner et al., 2010; Sandoval, 2004) modelling and argumentation skills (Beernärt et al., 2015), as well as communication and cooperation skills (Anderson, 2002; Minner et al., 2010) Additionally, classroom inquiry can offer experiences with science, promote the development of an epistemological awareness of how science operates (Chinn & Malhotra, 2002) and develop positive attitudes towards science (Shymansky et al., 1983).

Concerning epistemological beliefs, students engaging in inquiry-based learning activities can understand that (i) scientific knowledge is constructed by people and not simply discovered, (ii) scientific knowledge is socially constructed, (iii) scientific methods are diverse depending on scientific disciplines but rely on scientific standards (iv) scientific knowledge is tentative and can change as new observations, hypotheses, and ideas come to light (Sandoval, 2005). Such understanding about scientific knowledge, as well as reflection and explicit epistemological discourse, can improve students' epistemological beliefs (Sandoval & Morisson, 2003; Sandoval & Reiser, 2004; Sandoval, 2005, 2014).

Furthermore, engagement in dialogic argumentative activities may support the development of students' awareness of the complexity, source, and justification of scientific knowledge (Iordanou, 2016). In addition, the utilisation of the history of science instructional approach might facilitate students' understanding of the tentative and uncertain nature of scientific knowledge and how scientific knowledge is developed and created (Matthews, 1994). However, the recommended didactical approaches are synergistic, built upon one another, and provide opportunities for fostering students' epistemological beliefs.

Epistemological beliefs and conceptual understanding of evolution

Studies on students' epistemological beliefs and understanding of biological evolution by natural selection are very rare, and the results are inconclusive (Borgerding et al., 2017; Deniz et al., 2008; Sinatra et al.; 2003; Southerland et al., 2001; Southerland et al., 2005; To, et al., 2017).

Data from Sinatra and her colleagues (2003) suggested an association between epistemological beliefs, particularly beliefs about the tentative nature of knowledge and acceptance in human evolution, but they found no significant relationship between epistemological beliefs and understanding of evolution. Moreover, Deniz and his colleaques (2008) found no significant positive correlation between epistemological beliefs and an understanding of evolutionary theory. In contrast, Cho et al. (2011), investigating the role of epistemological beliefs on students' conceptual change in the learning of evolutionary theory, found a positive relationship between students‘ epistemological beliefs, particularly beliefs about the certainty and source of knowledge, and their conceptual change in the learning of evolution.

In the present work, we aim to gain a deeper understanding of the relationships between epistemological beliefs and conceptual understanding of evolution by natural selection.

Method

Participants

Forty-two (42) secondary school students participated in the study. They were 12th-grade students, 17.5 years old (SD = 0.5); 26 of them were girls, and 15 were boys. The school was a suburban high school in Cyprus. The participants were Caucasian native speakers of Cyprus and shared the Greek language and a homogeneous middle-class social background. Students participated in the study as part of their biology classes (elective course), taught by their biology school teachers, who received specific training for evolution teaching from the Cyprus Ministry of Education and the University of Cyprus. Both biology school teachers had a master's degree and more than 15 years of experience. The students were taught biology in Grade 7 (two 45-minute class periods per week), in Grade 8 (one 45-minute class period per week), in Grade 9 (two 45-minute class periods per week), in Grade 10 (one 45-minute class period per week), and in Grade 11 (four 45-minute class periods per week- elective course). However, according to the Cyprus National Curriculum, they did not have any lessons on biological evolution before Grade 12.

All materials and assessment tools that were used for this study were in the Greek language.

Instructional Material

In the revised National Curriculum for Biology in Cyprus, 12th-grade students are introduced to the topic of evolution by natural selection in Grade 12. Between Grades 7 and 11, students learn about biodiversity and inheritance, including the approach of reproduction, chromosomes, DNA, and genes. In particular, students learned about heredity as a genetic process, that differences between and within species can be interpreted as a result of differences in genetic information, and about the need to preserve biodiversity and protect endangered species (Cyprus Ministry of Education National Curriculum, 2021).

The unit on evolution by natural selection introduces 12th-grade students to biological evolution by exploring the ideas proposed by different prominent naturalists before Charles Darwin, which were important for the development of evolutionary thought, and the ideas proposed by Darwin about evolution by natural selection. Specifically, at the introduction of the unit, teachers use a history of science approach, discussing with students the development of evolutionary thought, making mention of the ancient Greek philosophers Anaximander and Empedocles, the restraining influence of the church during the Middle Ages and the ideas of the prominent naturalists of the Enlightenment. Then, special mention is made to Lamarck's work and its contribution to later studies about biological evolution, as well as to the founder of the modern theory of evolution, Charles Darwin. The unit continues with inquiry-based learning activities to teach students the evidence for evolution from geology, anatomy, embryology, biogeography and molecular biology, as well as the adaptation of organisms to their environment. Furthermore, students learn that genetic mutation causing variation occurs at the gene level; monohybrid inheritance occurs when there are dominant and recessive alleles; sexual reproduction contributes to variation within a population; there are differences in genotypes or phenotypes between populations that inhabit different areas (geographic variation), the evolution of new species can be obtained over time through natural selection; genetic drift, gene flow, environmental factors contribute to biological evolution, phylogeny and human evolution, covering many generations.

For this study, the teaching intervention involved the implementation of a curriculum for evolution by natural selection, using the textbook entitled *Biology 12th* Grade Student Book: Evolution of Living Organisms, which not only covers the 12th-grade biology curriculum but extends it, specifically in relation to human evolution (Baytelman et al., 2020c). This textbook was developed by experienced biology educators, biology curriculum experts, and university biology professors. The teaching intervention took place over five 90-minute class periods, twice per week, in a total of 10 sessions.

The textbook is based on sequences of inquiry-based learning activities, which include adequate provisions for the identification of students' preconceptions and alternative ideas (misconceptions) on concepts related to evolution by natural selection. Additionally, the activities allow students to work collaboratively in a guided inquiry approach in order to investigate specific concepts and problems related to evolution by natural selection and obtain a deep conceptual understanding of the related mechanisms of evolution, epistemological understanding about different aspects of the nature of science, and thinking skills. In general, each activity has oriented questions on the topic that students are asked to investigate, as well as scientific information that students could use in order to formulate hypotheses, make predictions, obtain evidence, analyse data, create arguments, draw conclusions, and communicate their answers. The information is provided in the form of text, diagrams, models, infographics, historical reports, biographies, conceptual maps and geographical maps, among others. Teachers' competences for coordinating and facilitating inquiry-oriented learning processes are essential. The students work in groups (3–5 students), except for those activities that require individual work and reflection or those that require whole-class discussions.

The learning activities that stimulate the active engagement of students include hands-on learning and facilitate discussion, interaction, and reflection on the tasks. In general, the activities aim to develop students' conceptual understanding of evolution by natural selection, high-order thinking skills, such as critical and creative thinking, communication and collaboration skills and awareness of the nature of science. Further, the textbook includes different assessment tasks that can be applied for formative and summative purposes. Table 1 displays the activities presented in the textbook, which were used for the teaching intervention, by session.

Table 1
Activities presented in the textbook, by session

Session	Activity	Mobilising Skills
Sessions: 1-2	Introduction. Brief history of the development of evolutionary thought before Darwin, using a history of science approach. Darwin and his ideas about evolution. Evidence for evolution: Students study scientific information for collecting evidence for evolution from geology, anatomy and embryology, biogeography, and molecular biology, and constructing a concept map.	Epistemological awareness of the nature of science and how it operates Systematic observation skills Critical thinking skills Investigation skills, relying on different sources of evidence. Collecting and explaining relevant evidence. Communicating results. Communication, Collaboration skills.
Sessions: 3-4	Genetic and phenotypic diversity within and between populations. Students study scientific information for formulating hypotheses, making predictions, and carrying out investigation in order to obtain evidence and answer related questions related to genetic and phenotypic diversity. Examples of questions: How differences in skin colour among people are related to their adaptation and survival? What do dark-coloured mice have that allows them to have higher survival rates and leave a greater number of offspring than light-coloured mice?	Cognitive skills such as analysing data, creating a hypothesis and making predictions. Critical thinking and evaluative system thinking. Investigation skills relying on different sources of evidence. Collecting and explaining evidence. Analysing and drawing conclusions. Communicating results. Communication, Collaboration skills. Epistemological awareness of how science operates.
Sessions: 5-6	Mechanisms or phenomena responsible for genetic diversity in a population: Mutations, Sexual Reproduction, Random fertilisation, Random distribution of homologous chromosomes during metaphase of the 1st meiotic division, Random recombination of genes. Students study scientific information for formulating hypotheses, making predictions, and carrying out investigations in order to obtain evidence and answer related questions: Example of questions: Please explain: how the pathological gene that causes sickle cell anaemia which resulted from gene mutation is an adaptive advantage in areas with malaria? In people, 60% of the human olfactory genes are inactive, while in the mouse only 20%. Please explain the mechanism of the increase or decrease of the number of genes for a specific feature in a living organism.	Cognitive skills such as analysing data, creating hypotheses and making predictions. Critical thinking and evaluative system thinking, decision-making. Investigation skills relying on different sources of evidence. Collecting and explaining evidence Analysing and draw conclusions. Communicating results. Communication, Collaboration skills. Self-regulated learning skills. Epistemological awareness of how science operates.

Session	Activity	Mobilising Skills
Sessions: 7-8	Evolutionary Mechanisms: Natural Selection, Genetic drift (Bottlenecks and founder effects), Gene flow, Sexual selection. Students are engaged in authentic, problem-based learning activities, modelling procedures and 'hands-on' activities, discursive argumentation and communication with peers. Students use models to explain Natural selection, Bottlenecks and Founder effects and make predictions. Additionally, they use historical reports to explain the high incidence of carriers of inherited diseases in small communities in their own country (e.g., cystic fibrosis)	Critical thinking and evaluative system thinking, decision-making. Systematic observation skills. Modelling skills. Argumentation skills. Collecting and explaining evidence Analysing and draw conclusions. Communicating results. Communication, Collaboration skills. Self-regulated learning skills. Epistemological understanding of how science operates
Sessions: 9-10	Speciation, Phylogenetic trees, Human evolution. Students use Phylogenetic trees to illustrate and explain genetic relationships among different species of organisms and evolutionary relationships for organisms with a shared common ancestor. Additionally, they study and explain infographics related to morphological and behavioural characteristics of distinct Anthropidae, including humans.	Critical thinking and evaluative system thinking. Modelling skills. Argumentation skills. Explaining evidence, analysing and drawing conclusions. Communication, Collaboration skills. Epistemological understanding of how science operates. Self-regulated learning skills.

Instruments

Students' epistemological belief measures

To measure students' epistemological beliefs, we used the Dimensions of Epistemological Beliefs toward Science (DEBS) Instrument (Baytelman, 2015; Baytelman & Constantinou, 2016a; Baytelman et al., 2016b, 2020a, 2020b), which is based on the multidimensional perspective of epistemological beliefs. DEBS has been validated in the particular culture in which the research was conducted. The 30-item DEBS Instrument captures five epistemological dimensions: three dimensions related to the nature of knowledge (Certainty, Simplicity, and Development of Knowledge), and two dimensions related to the nature of knowing (Source and Justification of Knowledge). Each dimension of this instrument consists of six items rated on a four-point Likert scale with the following scoring options: strongly disagree=1, disagree=2, agree=3 and strongly agree=4. High scores on this measure represent more sophisticated epistemological beliefs, while low scores represent less sophisticated beliefs. The DEBS Instrument is suitable for high school and university undergraduate students. The 30-item DEBS Instrument is given in Appendix A.

Students' conceptual understanding of evolution measures

To assess participants' conceptual understanding of evolution by natural selection, we developed the *Conceptual Understanding of Evolutionary Theory Instrument* for this study using items of *The Knowledge About Evolution* (KAEVO) 2.0 instrument (Kuschmierz et al., 2020b) and new items according to the National Curriculum for evolutionary theory in Cyprus and the relevant textbook (Baytelman et al., 2020c). KAEVO 2.0 contains aspects of biological evolution that high school students are expected to know. The development of this questionnaire was based on a curriculum and textbook analysis to address content validity, and European experts in biology education and evolutionary biology reviewed the instrument (Kuschmierz et al., 2020b). It is considered to be an 'allrounder' among instruments measuring knowledge about evolution. Moreover, KAEVO 2.0 is suitable for various target groups (high school and university students in biology-related and non-biology-related fields of study; Kuschmierz et al., 2020b). All data and analyses are available in Kuschmierz et al. (2020b).

The *Conceptual Understanding Evolutionary of Theory Instrument* for this study consists of two parts with different answer formats: a) 5 multiple-choice questions, b) 1 matching question, c) 4 true/ false questions, d) 6 short-answer questions, and e) 3 open-ended questions. The instrument covers the concepts of adaptation, mutation, variation, inheritance, natural selection, sexual selection, genetic drift, gene flow, and phylogeny. Two experts of evolution by natural selection and two biology teachers reviewed the instrument for content validity. Sample items are given in Appendix B.

The multiple-choice questions, matching questions, and true/false questions were scored from 0 to 0.5. Three short-answer questions were scored from 0 to 1, and the other three short-answer questions were scored from 0 to 1.5 on the basis of their correctness. The open-ended questions were scored from 0 to 2 on the basis of their correctness and completeness by the first and second authors with Cohen's Kappa values k = .90. The possible maximum score of the instrument was 20.

For all questions, a zero score corresponds to a completely false answer. For the open-ended questions, a score of one (1) corresponds to a semi-correct or incomplete answer, and a score of two (2) corresponds to a fully correct and complete answer. No responses were treated as nonresponses and were excluded from the analysis.

Research procedure

This study was conducted in the second semester of the 2021/22 school year, from February to April 2022. The procedure of this study is described below.

1. Epistemological beliefs assessment before evolution teaching and learning intervention
   At the beginning of the second semester, before the evolution teaching and learning intervention, the biology teacher of each class administered the DEBS epistemological beliefs instrument (pre-test of epistemological beliefs). This lasted 20 minutes.
2. Evolution teaching and learning intervention
   From March to April, for five weeks, the evolution intervention took place. The intervention involved the implementation of a national curriculum about evolution. There were five (5) 90-minute class periods, twice per week, in the biology lab of the school.
3. Understanding Evolutionary Theory assessment after evolution intervention
   The *Conceptual Understanding of Evolutionary Theory Instrument* was administered one week after the end of the evolution intervention and lasted 30 min.
4. Epistemological beliefs assessment after evolution teaching and learning intervention
   One week after the administration of the *Conceptual Understanding of Evolutionary Theory Instrument*, the DEBS epistemological beliefs instrument was administered (post-test of epistemological beliefs) and lasted 20 min.

First, the means, standard deviations, minimum and maximum scores, and values of skewness and kurtosis of all variables of this study were calculated. Then, to investigate if the variables of the study were positively or negatively and significantly correlated among them, Pearson correlations were calculated.

To determine whether evolution by natural selection intervention improves 12^{th}-grade students' epistemological beliefs, paired samples t-tests were carried out. To answer whether the 12^{th}-grade students' initial epistemological beliefs can predict their learning achievements regarding their conceptual understanding of evolution by natural selection after the intervention, multiple regression analyses were carried out. This approach enables examining a relationship between a dependent variable (conceptual understanding of evolution by natural selection after instruction) and multiple independent variables (dimensions of epistemological beliefs). All participants completed the tasks in the same order. Two participants were excluded from the analysis because they did not complete all tasks.

Results

Table 2 displays the means, standard deviations, minimum and maximum scores, and values of skewness and kurtosis of all variables of this study. Participants' scores on the epistemological beliefs measure before evolution intervention suggested relatively sophisticated beliefs about the dimensions of nature of knowing (source and Justification of knowledge) and slightly less sophisticated beliefs about the dimensions of nature of knowledge (certainty, simplicity (structure of knowledge) and development of knowledge). Participants' scores on the epistemological beliefs measure after evolution intervention suggested relatively sophisticated beliefs about the dimensions of the source, justification, and development of knowledge and slightly less sophisticated beliefs about the dimensions of certainty and simplicity of knowledge. The more sophisticated epistemological beliefs before and after the evolution intervention were justification beliefs.

The measures of skewness and kurtosis indicated that all score distributions were approximately normal and thus appropriate for use in parametric statistical analyses.

Table 3 displays the Pearson correlations between all variables for epistemological beliefs before and after the evolution intervention and the conceptual understanding of evolution by natural selection. First, the Pearson correlation values indicated that the 12^{th}-grade students' initial epistemological beliefs were not significantly correlated with their conceptual understanding scores about evolution after intervention (dependent variable).

Second, the Pearson correlations indicated asignificant positive correlation (Cohen, 1988, 1992) between simplicity beliefs (structure of knowledge) after evolution intervention and conceptual understanding of evolution by natural selection ($r=.35$, $p < .05$), indicating that more sophisticated epistemological beliefs about the structure of knowledge were correlated with high conceptual understanding scores on evolution by natural selection.

Third, the Pearson correlation measures showed that there was a statistically significant positive correlation between certainty beliefs after evolution intervention and conceptual understanding of evolution by natural selection ($r=.33$, $p < .05$), suggesting that more sophisticated epistemological beliefs about the certainty of knowledge were correlated with high conceptual understanding scores on evolution by natural selection.

To examine the 12th-grade students' epistemological beliefs before and after inquiry-based teaching and learning intervention regarding evolution by natural selection, the measures of Table 2 were used. As illustrated in Table 2, participants' scores on the epistemological beliefs measure before the evolution intervention indicated relatively sophisticated beliefs about the nature of knowing (dimensions of source and justification of knowledge) and very slightly less sophisticated beliefs about the nature of knowledge (dimensions of certainty, simplicity and development of knowledge). Participants' scores on the epistemological beliefs measure after evolution intervention suggested relatively sophisticated beliefs about the dimensions of source, justification and development of knowledge and very slightly less sophisticated beliefs about certainty and the simplicity of knowledge. However, students held more sophisticated epistemological beliefs about the justification of knowledge before and after evolution intervention.

Table 2

Descriptive statistics for all variables related to the research questions (N = 40)

Variable	M		SD		Min		Max		Skewness (SE)		Kurtosis (SE)	
Conceptual understanding of evolution	14.61		4.79		6.00		20.00		-0.461(0.37)		-1.29 (0.73)	
Epistemological beliefs Dimensions	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Certainty of knowledge	2.57	2.63	0.38	0.48	1.50	2.00	3.16	3.50	-0.65(0.37)	0.43(0.37)	1.51 (0.73)	0.41(0.73)
Simplicity of knowledge	2.51	2.58	0.38	0.39	1.66	1.66	3.33	3.66	-0.23(0.37)	0.47(0.37)	-0.48 (0.73)	1.07(0.73)
Source of knowledge	2.74	2.94	0.49	0.47	2.00	1.50	3.66	4.00	0.46 (0.37)	-0.16(0.37)	-0.80 (0.73)	1.30(0.73)
Justification of Knowledge	2.88	3.07	0.37	0.37	2.16	2.50	4.00	3.66	0.56 (0.37)	0.01(0.37)	0.92 (0.73)	-1.32(0.73)
Development of knowledge	2.57	2.82	0.28	0.36	1.83	2.16	3.00	3.50	-0.95 (0.37)	0.46(0.37)	1.26 (0.73)	-1.29(0.73)

Table 3

Pearson correlations for all variables of the current study (N = 40)

	Variable	1	2	3	4	5	6	7	8	9	10	11
1.	Conceptual understanding of Evolution	-										
	Epistemological beliefs' dimensions											
2.	Certainty of knowledge Pre-test	0.23	-									
3.	Simplicity of knowledge Pre-test	0.23	0.10	-								
4.	Source of Knowledge Pre-test	0.12	0.26	0.17	-							
5.	Justification of Knowledge Pre-test	.031	0.22	0.11	0.16	-						
6.	Development of knowledge Pre-test	-0.04	0.29	0.30	-0.15	0.27	-					
7.	Certainty of knowledge Post-test	0.32*	0.49*	0.16	0.09	0.19	0.46**	-				
8.	Simplicity of knowledge Post-test	0.35*	0.07	0.19	-0.09	0.32*	0.20	0.28	-			
9.	Source of Knowledge Post-test	-0.29	0.22	0.03	0.42**	0.23	0.30	0.33*	-0.28	-		
10	Justification of Knowledge Post-test	0.10	0.13	0.33*	0.14	0.51**	0.23	0.23	0.13	0.27	-	
11	Development of knowledge Post-test	0.11	0.11	0.94	0.23	0.30	0.40*	0.35*	-0.01	0.40*	0.54**	-

Note. ***p < .001, **p < .01, two-tailed; *p < .05, two-tailed.

To investigate whether evolution by natural selection inquiry-based teaching and learning intervention improves 12th-grade students' epistemological beliefs, pre-and post-test scores were compared using paired samples test at 95% confidence. Table 4 displays Paired samples t-test results (α =0.05) comparing epistemological beliefs assessment scores before the evolution intervention with scores after the evolution intervention. The results indicated that all epistemological dimensions improved, but the source, justification, and development epistemological beliefs scores at the end of the semester, after the evolution intervention, were statistically significantly higher than the scores before the evolution intervention.

Table 4

Paired samples t-test results (α =0.05) comparing students' Epistemological beliefs before and after the evolution instruction.

Variable	M	SD	t(df)	Sig. (2-tailed)
Certainty of knowledge before evolution instruction	2.57	0.37	-0.52 (39)	0.60
Certainty of knowledge after evolution instruction	2.61	0.34		
Simplicity of knowledge before evolution instruction	2.51	0.38	-0.98 (39)	0.33
Simplicity of knowledge after evolution instruction	2.58	0.39		
Source of knowledge before evolution instruction	2.73	0.49	-2.41 (39)	0.02
Source of knowledge after evolution instruction	2.94	0.47		
Justification of knowledge before evolution instruction	2.88	0.37	-3.21 (39)	0.003
Justification of knowledge after evolution instruction	3.07	0.37		
Development of knowledge before evolution instruction	2.57	0.28	-4.44 (39)	0.00
Development of knowledge after evolution instruction	2.82	0.36		

To investigate, whether 12th-grade students' initial epistemological beliefs predict their learning achievements regarding the conceptual understanding of evolution by natural selection after inquiry-based teaching and learning instruction, multiple regression analysis was conducted using epistemological beliefs (epistemological dimensions according to the multidimensional perspective) as predictor variables.

The unstandardised regression coefficients (B) and intercept, the standardised regression coefficients (β), R^2, and adjusted R^2 after entry of all independent variables (IVs) are reported in Table 5.

Table 5

Results of linear regression analyses for variables predicting learning achievements regarding the conceptual understanding of evolution by natural selection after the intervention

Predictor variables **Initial epistemological beliefs** (before intervention)	**Conceptual understanding of evolution by natural selection** (after intervention)	
	B(SE)	β
Certainty of knowledge	3.96 (2.18)	0.31
Simplicity of knowledge	3.53 (2.11)	0.28
Source of knowledge	2.41 (1.64)	0.25
Justification of knowledge	0.80 (2.11)	0.06
Development of knowledge	-0.45 (3.07)	-0.26

Note. R = 0.42, R^2 = 0.17, Adjusted R^2 = 0.05

As illustrated in Table 5, with all IVs (Certainty, Simplicity, Source, Justification, and Development of Knowledge) in the equation, $R^2 = .17$, $F(5,34) = 1.37$, $p=.26$. The adjusted R^2 value of .17 indicates that 17% of the variability in the 12th-grade students' achievements of conceptual understanding of evolution by natural selection after teaching and learning intervention is predicted by their initial epistemological beliefs. That means that the initial epistemological beliefs contribute very modestly and non-significantly to that prediction.

Discussion and Conclusions

The aim of the present study was to investigate possible relationships between 12th-grade students' epistemological beliefs (epistemological dimensions) towards science and their conceptual understanding of evolution by natural selection. Regarding the relationship between epistemological beliefs and conceptual understanding of evolution by natural selection, our results indicate that the 12th-grade students' initial epistemological beliefs predict very modestly and statistically non-significantly their learning achievements on the conceptual understanding of evolution by natural selection after inquiry-based teaching and learning, measured via a specifically developed assessment tool.

In contrast, our results show a statistically significant improvement in some of the participants' epistemological beliefs (source, justification, and development of knowledge) after students' engagement in an inquiry-based intervention on evolution by natural selection. This finding of our study provides support to our hypothesis that inquiry-based intervention on evolution by natural selection would foster students' epistemological beliefs towards science. In addition, this result is consistent with previous findings reported in the literature (Shi et al., 2020) suggesting that inquiry-based teaching and learning is one recommended didactical approach for the promotion of epistemological beliefs.

Furthermore, the statistically significant improvement of students' source, justification, and development epistemological dimensions over the evolution intervention extends the literature in an important way, showing that engagement in inquiry-based teaching and learning activities on evolution by natural selection over an extended period of time can promote significant their epistemological beliefs. The opportunities provided in the context of the curriculum and in the textbook used for evolution teaching and learning intervention to articulate, explain, find relevant evidence, form arguments and counter-arguments to convince peers, and reflect upon their own reasoning may have supported students to think deeper about the nature of the process through which knowledge develops (Greene et al., 2016; Hofer & Pintrich, 1997; Muis et al., 2015). The current research design does not enable us to identify exactly the mechanism that supported the epistemological gains observed, but our evidence indicates the contribution of guided inquiry-based teaching and learning activities to students' epistemological beliefs.

Moreover, our findings indicated a significant positive correlation between the simplicity beliefs dimension (beliefs that knowledge consists of highly interrelated concepts), after the evolution intervention, and conceptual understanding of evolution by natural selection, suggesting that more sophisticated epistemological beliefs about the structure of knowledge were correlated with high conceptual understanding scores on evolutionary theory. In particular, this finding suggests an association between an epistemological understanding of theorising knowledge as a complex system of organised theoretical principles and ideas (sophisticated simplicity epistemic beliefs) and the competence to deal effectively with complex issues like evolutionary theory (Baytelman et al, 2020a).

Our results further show that more sophisticated certainty epistemological beliefs (beliefs that knowledge is tentative and evolving) after evolution instruction were correlated with high conceptual understanding scores on evolution by natural selection. This finding is consistent with previous findings reported in the literature and highlights that students who believe that knowledge is tentative and evolving according to new evidence, new hypotheses or new interpretations of data may accept evolution by natural selection. In addition, students who believe that knowledge is tentative and evolving may perceive the existing scientific knowledge as the most valid and reliable according to the available data thus far, and may desire to continue to learn more about it, and investigate specific concepts, mechanisms and processes related to evolution, regardless of their religious beliefs or personal emotions (Harms & Reiss, 2019).

In summary, the present study extends the current literature examining relationships between epistemological beliefs and the conceptual understanding of evolution by natural selection. The findings of the present study show a statistically significant improvement in participants' epistemological beliefs (about certainty, simplicity, source, justification, and development of knowledge) after engagement in an inquiry-based intervention on evolution by natural selection over an extended period of time. Our findings also indicated a significant positive relationship between epistemological beliefs about the nature of knowledge (simplicity and certainty dimensions) before intervention and conceptual understanding of evolution by natural selection, after participants' engagement in an inquiry-based intervention on evolution.

Some limitations of this study that may give impetus to further work in this area are important to mention. The first limitation concerns the sample size. Although the issues addressed in the current study are of international applicability, we cannot generalise our results based on a relatively small sample consisting of 42 participants. The second limitation concerns the impact of the teacher on the intervention. With another teacher and the same intervention, the results may be different. The third limitation concerns the type of instrument that was used to assess epistemological beliefs. We used only a single instrument, a questionnaire, which does not probe elaborated participants' responses to items as in-depth interviews would do. Future studies could usefully take a closer look at the interplay between epistemic beliefs and argument construction using a multiplicity of methods, such as interviews and think-aloud protocols. Nevertheless, our study has important educational implications, showing improvement of participants' epistemological beliefs, after engagement in an inquiry-based intervention on evolution, over an extended period of time, as well as a significant positive relationship between epistemological beliefs of the nature of knowledge and conceptual understanding on evolution by natural selection.

In conclusion, engagement in an inquiry-based intervention on evolution by natural selection, involving collaborative work in inquiry teaching and learning activities in order to investigate specific concepts and problems related to evolution and obtain a deep conceptual understanding of the related mechanisms and processes, and facilitate discussion, interaction, and reflection upon the tasks might be a promising way for supporting both objectives, namely, acquiring content knowledge and developing more sophisticated epistemological beliefs.

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Biographical note

Andreani Baytelman, PhD, is research scientist in the field of Science Education at the Department of Education at University of Cyprus, Cyprus. Her research interests include curriculum development, instruction design, development and evaluation of biology teaching and learning material, epistemology, informal reasoning, socioscientific issues and professional development of teachers.

Theonitsa Loizou, MA, is a Biology teacher at Lykeio Paralimniou, Cyprus. Her research interests include specialized pedagogical knowledge on the fields of organization, administration, evaluation and curriculum in education, as well as in the cognitive fields of didactics of Biology and professional development of teachers.

Salomi Chatzikonstantinou, BSc, is a Biology teacher at Paralimni high school, Famagusta, Cyprus. Her reserch interests include teaching and learning biology in secondary education, as well as design, organisation and implementation of environmental and health school projects.

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Conceptions of Portuguese Prospective Teachers about Real-Life Evolution Situations

Bento Cavadas*[1] and Xana Sá-Pinto[2]

The importance of introducing evolution in primary schools has been highlighted in evolution education research, but few studies have approached the understanding of evolution of prospective teachers who are being prepared to teach at primary school level. The present exploratory study aims to answer three research questions about the ability of Portuguese prospective teachers to apply evolution to two real-life situations: 1) Are prospective teachers able to identify evolution misconceptions in online newspaper articles? 2) What misconceptions are expressed by prospective teachers when explaining real-life evolution situations? and 3) Which key evolution concepts do prospective teachers apply to make sense of real-life evolution situations? Twelve prospective teachers participated in the study. In the first situation, the prospective teachers were asked to identify statements from a newspaper article that would reveal evolution misconceptions and justify their choices. In the second situation, they were asked to read a text about SARS-CoV-2 and explain why scientists were worried about uncontrolled outbreaks of the virus. The prospective teachers' answers were analysed through content analysis. Regarding the first research question, our results show that only half of the prospective teachers were able to identify teleological misconceptions in the newspaper article. Concerning the second research question, some of the prospective teachers either identified misconceptions in information in which there was no misconception, or revealed their own misconceptions in their explanations. Regarding the third research question, although more than half of the prospective teachers identified at least two key evolution concepts, some of them found it difficult to explain how evolution is related to the situation described. Although this is an exploratory study, it shows which key concepts of evolution the prospective teachers mobilised and identifies their misunderstandings, thus highlighting dimensions that should be addressed in their evolution education.

Keywords: evolution, evolution education, evolution key concepts, evolution misconceptions, prospective teachers

1 *Corresponding Author. Polytechnic Institute of Santarém/School of Education; Lusófona University, CeiED – Interdisciplinary Research Centre for Education and Development, Portugal; bento.cavadas@ese.ipsantarem.pt.

2 Research Centre on Didactics and Technology in the Education of Trainers, Department of Education and Psychology, University of Aveiro, Portugal.

Predstave portugalskih bodočih učiteljev glede resničnih razmer evolucije

Bento Cavadas in Xana Sá-Pinto

Smisel uvajanja evolucije v osnovne šole je bil poudarjen v raziskavah evolucijskega izobraževanja, toda zelo malo študij se je približalo razumevanju evolucije, ki ga imajo bodoči učitelji med usposabljanjem za osnovnošolsko poučevanje. Namen te eksplorativne študije je odgovoriti na tri raziskovalna vprašanja o sposobnosti portugalskih bodočih učiteljev, da uporabijo znanje evolucije v dveh situacijah resničnega življenja: 1) Ali so bodoči učitelji sposobni prepoznati napačne predstave o evoluciji v poljudnih člankih na spletu? 2) Katere napačne predstave izražajo bodoči učitelji, ko razlagajo evolucijske situacije v resničnem življenju? 3) Katere ključne evolucijske koncepte uporabljajo bodoči učitelji, da bi osmislili resnične evolucijske situacije? V raziskavi je sodelovalo 12 bodočih učiteljev. V prvi situaciji so bili pozvani, da naj v časopisnem prispevku prepoznajo izjave, ki bi razkrile napačne predstave o evoluciji, in utemeljijo svoje odgovore. V drugi situaciji so morali prebrati besedilo o SARS-CoV-2 in pojasniti, zakaj so znanstveniki zaskrbljeni zaradi nenadzorovanih izbruhov virusa. Odgovore bodočih učiteljev smo analizirali z vsebinsko analizo. Glede na prvo raziskovalno vprašanje naši izsledki kažejo, da je le polovica bodočih učiteljev znala prepoznati teleološke napačne predstave v časopisnem prispevku. Pri drugem raziskovalnem vprašanju pa so nekateri bodoči učitelji ugotovili napačne predstave v informacijah, v katerih napačnih predstav sploh ni bilo, ali pa so v svojih razlagah razkrili lastne napačne predstave. Glede tretjega raziskovalnega vprašanja, čeprav je več kot polovica bodočih učiteljev identificirala vsaj dva ključna koncepta evolucije, so nekateri težko razložili, kako je evolucija povezana z opisano situacijo. Čeprav gre za eksplorativno študijo, ta vseeno prikazuje, na katere ključne koncepte evolucije so se bodoči učitelji sklicevali, obenem pa prav tako odkriva njihova nerazumevanja, s čimer osvetljuje dimenzije, ki bi jih bilo treba obravnavati v njihovem evolucijskem izobraževanju.

Ključne besede: evolucija, evolucijsko izobraževanje, ključni koncepti evolucije, napačne predstave o evoluciji, bodoči učitelji

Introduction

Many contemporary sustainability problems are related to species that evolve too slowly or too fast for humans to find solutions (Carrol et al., 2014). In the first group are species that evolve too slowly to cope with the pace of human and natural environmental changes. Some of these species are now facing extinction. The second group includes pathogens and many pest species that threaten human survival and/or well-being (Carrol et al., 2014), as shown by the recent global pandemic of coronavirus SARS-CoV-2. Understanding how viruses evolve, how new variants emerge, spread and become dominant, and how resistance to vaccines may evolve is relevant to increasing public understanding of and support for the policy measures taken in many countries.

Public understanding of evolution is thus fundamental to developing long-term solutions for these sustainability problems as well as public support for their implementation. This is one of the factors that have led several institutions and researchers to argue that evolution should be introduced from the first years of mandatory education (NRC, 2012). In fact, research (e.g., Naldelson, 2009) suggests that teaching evolution concepts to early primary school students can contribute to changing the levels of understanding and acceptance of the theory of evolution (Brown et al., 2022; Sá-Pinto et al., 2023; Sá-Pinto et al., 2021). However, this requires primary school teachers who are able to teach this subject.

In order to increase quality in evolution education, Tekkaya et al. (2012) argue that teachers should possess accurate conceptions and be adequately prepared to teach evolution with confidence. When teachers lack pedagogical content knowledge and believe they do not understand evolution, as well as other curriculum topics, that could undermine the confidence they need to be effective in teaching evolution (Tekkaya et al., 2012). Therefore, to prepare them to teach evolution, Sickel and Friedrichsen (2013) suggest that teachers should develop content knowledge on evolution, understand the nature of science related to evolution, increase their acceptance of evolution and their willingness to teach the topic, and develop their knowledge on strategies for handling controversy and their pedagogical content knowledge for teaching evolution. These goals accord with the conclusion of the study by Tekkaya et al. (2012), which shows that teachers' acceptance of the scientific validity of evolution and their perceptions about the importance of addressing evolution in their classes is related to a good understanding of evolution and the nature of science. Following this line of reasoning, Tekkaya et al. (2012) suggest that it is important to adequately design teacher education programmes to enhance teachers' understanding of evolution and the nature of science.

Preparing prospective teachers (PTs) to teach evolution is a multifaceted task. Nadelson (2009) noticed that, after exploring in-depth tutorials, preservice teachers integrate the nature of science and biological evolution concepts more often than the relationship between uncertainty and evolution in their lesson ideas for teaching evolution. However, some preservice teachers maintained misconceptions about evolution and the nature of science. This is a problem because there is potential for these views to be taught to young students by their teachers (Fisher, 2004). Nadelson (2009) also noticed that some American preservice teachers showed reduced acceptance of evolution and, in their lesson ideas, proposed teaching creationism as an equally acceptable explanation for the origin of species. This vision is also shared by some Portuguese preservice teachers (Cavadas & Sá-Pinto, 2021), which could be partially explained by the lack of preservice teachers' understanding of the meaning of scientific theories (Nadelson, 2009).

Several authors argue for the importance of introducing evolution in primary schools, but few have studied the understanding of evolution of preservice teachers who are being prepared to teach at that level. Research suggests that primary teachers are not well positioned to teach evolution (Herman, 2018; Prinou et al., 2011). Hermann (2018) found that the willingness of preservice primary teachers to specialise in science increases as their acceptance of evolution rises, and vice versa. Furthermore, Hermann (2018) noticed that the willingness of prospective primary teachers to specialise in science increased, although not significantly, with their understanding of natural selection. The implication of Hermann's (2018) study is that the preservice teachers who could serve as science specialists in primary schools are those who have both a willingness to specialise in science and a higher acceptance of evolution. Within their functions as science specialists, prospective primary teachers could develop curricula, create educational resources and work with their peers in effective science learning experiments for primary school children (Hermann, 2018). Therefore, more studies that research future teachers' understanding of evolution are needed.

Evolution misconceptions

Having misconceptions related to evolution may hinder the ability to learn new concepts and develop effective science-based solutions for diversified sustainability problems (Jørgensen et al., 2019; Nadelson, 2009). In a study involving 9,200 participants, Kuschmierz et al. (2021) found that European first-year university students mostly accept evolution but lack substantial knowledge about it. Furthermore, they found that country affiliation and education system play only a minimal role in the acceptance of evolution. Even among students enrolled in biology-related programmes, the level of knowledge varies greatly, and religious faith was a better predictor of students' acceptance of evolution than their knowledge about evolution (Kuschmierz et al., 2021).

Some important misconceptions about evolution are related to teleological thinking. Wagner-Egger et al. (2018) defined teleological thinking as the attribution of purpose and a final cause to natural events and entities. Many studies report a high frequency of misconceptions related to teleological thinking in young adults, which are persistent and difficult to change, even using educational programmes specifically designed to address them (Bishop & Anderson, 1986; Nehm & Reilly, 2007). Some researchers have proposed that teleological thinking is innate or developed in early childhood (reviewed in Kelemen, 1999a). Young children apply teleological thinking indiscriminately to both biological and non-biological agents, while adults seem to selectively apply it to human-made artefacts and biological agents (Kelemen, 1999b). Kelemen (1999b) also showed that a very large proportion of adults still provide teleological explanations to biological parts of living organisms and even to biological entities (e.g., babies or plants).

Several studies have suggested that teleological thinking in evolution can be reinforced throughout a person's life by teachers, books, the media and even by the way evolutionary biologists speak about evolution (Nehm et al., 2010; Prinou et al., 2011). This hypothesis is supported by recent findings that show that primary school students provide few teleological explanations (Sá Pinto et al., 2021) and that they can easily overcome these with instruction (Brown et al., 2020). Together, these results support the importance of the early introduction of evolution in students' education. However, Prinou et al. (2011) showed that primary school teachers hold evolution misconceptions themselves, further supporting the importance of providing PTs with training on evolution and on evolution misconceptions. Prinou et al. (2011) also noted that, in Greek primary education textbooks, the concept of 'adaptation' is presented through misleading teleological explanations, highlighting the fact that teleological explanations are used by schools to explain the origin of the features in organisms. In fact, only a small percentage of the primary education teachers who participated in the Prinou et al. (2011) study interpreted the origin of adaptation in a scientific way, mixing their answers with ideas that have teleological connotations.

Evolution key concepts

In order to fully understand evolution by natural selection and use this knowledge to grasp biological systems and address problems caused by biological agents, students need to understand, articulate and put into action several concepts. Different authors have proposed distinct lists of concepts that, according to them, are fundamental to understanding evolution by natural selection (Anderson et al., 2002; Nehm & Ridgway, 2011; Tibell & Harms, 2017). Recently, Tibell and Harms (2017) reviewed previous works and proposed a list of principles, key concepts and threshold concepts that they believe are fundamental to understanding natural selection. Key concepts are purely biological concepts, which Tibell and Harms (2017) organised into three main principles: variation (which includes the key concepts of mutations as the cause for variation, phenotypic variation and differential fitness), heredity (which includes the key concept of traits that are heritable through reproduction) and selection (which includes the key concepts of selective pressure, differential survival, differential reproduction, changes in populations and speciation). According to the same authors, threshold concepts are concepts that, when acquired, are transformative and open new possibilities for students to develop their knowledge, thus facilitating conceptual change. Tibell and Harms (2017) propose that randomness, probability, spatial scales and temporal scales are the threshold concepts that facilitate the learning of evolution, and claim that key concepts and threshold concepts should always be considered when teaching about evolution. They also suggest that these concepts may be combined to facilitate students' learning processes and promote a deeper understanding of evolution and its implications in and applications to daily life situations. However, teachers' themselves need to be empowered with knowledge and skills about these concepts in order to better teach evolution.

Aim and research questions

Kuschmierz et al. (2020) point out that a comprehensive overview of the state of knowledge about evolution and acceptance of evolution in different educational settings is needed. The present study aims to make a small contribution to that overview, presenting data about Portuguese PTs' knowledge of evolution. The aim of the present study was to explore PTs' performance in applying evolution to real-life situations. The research questions (RQ) that guided this study are:

1. Are PTs able to identify evolution misconceptions in newspaper articles?

2. What misconceptions are expressed by PTs when explaining real-life evolution situations?
3. Which principles, key concepts and threshold concepts for understanding natural selection do PTs apply to make sense of the real-life evolution situations presented?«

Method

Research design and data collection

The participants were 12 senior PTs of a three-year initial teacher education programme from a Portuguese higher education institution. In this programme, PTs attend general education subjects, as well as specific content knowledge subjects, such as Portuguese, arts, mathematics, science, history and geography. The programme also includes an introduction to the didactics of these subjects as well as short internships.

The present study was implemented when the PTs were coursing the subject of Earth and Life Sciences in the final semester of their programme. A number from 1 to 12 was used to identify each PT (e.g., PT1, PT2). All of the participants were informed about the context of the study and provided their informed consent to data collection, analysis and publication.

Two problems related to real-life evolution situations using online newspaper articles were presented to the PTs (Table 1).

Table 1
Real-life evolution situations and problems proposed

Situation 1 Plant evolution problem	The PTs had to identify evolution misconceptions in a news article published online about the plant *Fritillaria delavayi*, the headline of which is »Meet the Chinese plant that changes colour because it is afraid of man« (Tempo.pt, 2020). The article presents the common misconception that natural selection implies that organisms try to adapt to a certain situation to survive. Specifically, the text suggests that the plant changed its colour to better camouflage itself in the environment, thus avoiding being picked by humans.
Situation 2 SARS-CoV-2 evolution problem	The PTs had to read a news article about a real-life evolution situation concerning the SARS-CoV-2 virus (Otto, 2021). The article presented the researchers' concern about the new variants of the virus and the areas where virus infections were not controlled.

Situation 1 was chosen because it is a news article that describes a macro-organism – a plant – that, according to the text, had intentionally evolved to cope with human harvesting. Situation 2 was chosen because it is related to acellular microorganism evolution, namely SARS-CoV-2, which is a relevant context for understanding evolution. Situation 2 was presented to the PTs during the pandemic, so increased interest for this situation by the PTs was expected. Other authors, such as Hsu (2020), have used data related to the evolution and transmission of SARS-CoV-2 as a context to promote students' discussion and learning of evolutionary principles.

In the first situation, the PTs were asked to identify the misconceptions about evolution in the article and to justify their answer. In the second situation, they were asked to explain, in the light of evolution principles, why it is dangerous to allow the uncontrolled reproduction of the virus.

The PTs received a form that included the two newspaper articles, their respective problems and a blank space for them to write their answers. Both of the situations were proposed to the PTs by the teacher of Earth and Life Sciences in an in-person class. They had a week to individually search for information related to these situations in order to support their answers to the problems presented. They had to present the references of the books, papers or online pages they used to create the answers. Each answer was limited to maximum of 300 words, excluding references. The PTs wrote their answers on a form and submitted it on a learning management system platform (Moodle). All of the PTs submitted their answers within the determined timeframe.

Data analysis

The PTs' answers were subjected to content analysis. RQ1 was mostly answered based on the PTs' outputs to Situation 1. To this end, the two authors of the paper identified the statements in the text that expressed misconceptions. Five statements with clear misconceptions were identified in the main text of the news article: Statement 1 – »Meet the Chinese plant that changes colour because it is afraid of man«; Statement 2 – »A plant used in traditional Chinese medicine may have evolved to become less visible to humans«; Statement 3 – »Over time, it evolved to go unnoticed in our eyes, transforming its striking greenish colour into a withered brown that blends with the soil«; Statement 4 – »The fear of man had made plants change colour in an ingenious strategy to survive«; Statement 5 – »Many plants use the cloaking mechanism to hide from the herbivores that can eat them, but in this case camouflage has evolved as a response to human collectors«. The authors analysed the PTs' answers and registered which statements they correctly identified as expressing misconceptions. As the PTs were asked to identify misconceptions and not to identify all of the statements that expressed a misconception, in the final results the authors counted the number of PTs who correctly identified at least one of the respective misconceptions.

RQ2 was answered by analysing both situations. For Situation 1, in order to answer RQ2 the authors: i) identified the statements that the PTs incorrectly classified as misconceptions; ii) analysed the justifications provided by the PTs and identified misconceptions they expressed, classifying them into categories based on the ideas presented by the PTs, which is a procedure also used by other researchers (e.g., Merriam, 2009). The latter procedure was also used to identify the misconceptions expressed by the PTs in Situation 2.

In order to answer RQ3, the authors designed and applied a system of categories of analysis based on the principles, key concepts and threshold concepts of evolution by natural selection proposed by Tibell and Harms (2017). Three categories were created for the principles of evolution, one for each of the three principles described by the authors (variation, heredity and selection). To further refine the analysis, subcategories within each category were created, reflecting the key concepts for each principle suggested by Tibell and Harms (2017; see the categories of analysis in Table 1). Two of the key concepts mentioned by the authors – differential fitness and frequency change through time – were excluded from the analysis of Situation 1. Differential fitness was omitted from the analysis because this key concept is based on the concepts of differential survival and differential reproduction, which are two of the subcategories of the selection principle. Frequency change through generations was also excluded from the analysis of Situation 1 because this key concept was explicitly described in the newspaper article provided to the PTs. Finally, speciation was not included either, as we were mostly interested in the microevolutionary process taking place at the population levels. For Situation 2, the key concepts of differential survival and differential reproduction were excluded because they are difficult to observe, distinguish and explain for a virus infecting hosts. As a proxy for these concepts, we used the key concept of differential fitness, which results from a combination of survival and reproduction. To identify differential fitness, evidence of the PTs mentioning variations in terms of replicative fitness, transmission fitness and epidemiological fitness was searched (following Wargo & Kurath, 2012). Following Tibell and Harms (2017), four categories were created for the threshold concepts: randomness, probability, temporal scale and spatial scale. For each category, the analysis was refined using subcategories based on the evidence that we would expect to find in a complete and correct answer to the question that would fit each of the four categories (see the categories of analysis in Table 1). For Situation 1, the threshold concepts were not analysed in the PTs' answers because the task submitted to them was more focused on their ability to detect misconceptions.

At the beginning of the coding process, both of the authors read all of the PTs' answers and collaboratively: i) defined the categories of analysis relative to RQ1 and RQ2; and ii) redefined the categories of analysis for RQ3. After this initial step, one of the authors coded all of the PTs' answers by looking for the presence or absence of evidence supporting each category. When a PT's answer could not be clearly classified as belonging to a given category, the PT was not counted in the analysis of this category. This is why the PT count in Table 1 and Table 2 is not equal to the sample size of 12 in some categories. To analyse the reliability of the analysis, 25% of the PTs' answers were independently read and coded by the other author. Given the evaluators' training, interrater reliability was estimated as the percentage of initial agreement between the evaluators (McHugh, 2012). Interrater reliability was higher than 70%, the threshold for the reliability to be considered as acceptable according to Stemler (2004).

Results

Situation 1 | Plant evolution problem

RQ1) Misconceptions identified by the prospective teachers

The results from Situation 1 (Table 1) revealed that 8 of the PTs (67%) were able to correctly identify statements with teleological misconceptions in the text. To justify their choices, half of the PTs stated that evolution does not have a purpose, nor does it depend on the individuals' needs, as exemplified by the following statement: »The first misconception that the article presents is that the plant has evolved over time to go unnoticed by our eyes« (PT11).

RQ2) Misconceptions revealed by the prospective teachers

Of the 12 PTs, 64% either: a) identified as misconceptions information that was not related to a misconception, or b) revealed their own misconceptions in their explanations (Table 1). The most frequent misconception in the text was that humans were not able to cause the species' evolution. The PTs who revealed this misconception most often state that humans were not the cause of the mutation giving rise to the brown phenotype, failing to identify that the humans were the cause for the selective pressure (plant collection) that caused the frequency change. An example of this misconception is expressed by PT2, who seems to believe that humans can cause the extinction of genes, but cannot act as selective pressure on genes: »Therefore, evolution does not occur, but the extinction of a certain genetic code. In this case, the human being is not the cause of evolution, but the cause of extinction. To be the cause of evolution, as the article claims, it would have to interfere directly with the DNA of plants«. However, the online newspaper article clearly states that the level of camouflage in that plant species was related to human harvesting pressure. It also states that the most camouflaged specimens took longer to be detected and were more frequent in places with higher harvesting pressure, including a citation from the researcher conducting the study stating that »commercial harvesting is a selective pressure stronger than many others in nature«.

Another misconception expressed by the students was that evolution is only a slow process. An example of this is the following reasoning of PT1: »Also in the same paragraph of the article it is mentioned that it is possible that the plant evolved in a short period of time. Now, according to the theories of evolution, these major transformations of species occur gradually and over a long period of time«. Other stated misconceptions included teleological explanations and ideas that expressed the inheritance of acquired features.

RQ3) Principles and key concepts of evolution mobilised by the prospective teachers

Ten of the PTs tried to explain the evolutionary process presented in Situation 1 by the means of natural selection. Of these, three were able to correctly mention and connect five of the six key concepts, and only two mentioned all six key concepts. Heredity was commonly approached, and some PTs expressed ideas about that process, e.g., PT2: »the genetic code is transmitted between generations, through the process of heredity«. However, the PTs did not clearly mention reproduction in their reasoning about the process that causes the transmission of the genetic code between generations.

The least mentioned key concepts were 'mutations are the cause of variation' and 'differential reproduction'. Differential survival and differential reproduction are clearly mentioned, for example, by PT2: »If humans are harvesting plants with a certain genetic code *en masse*, the ones that survive will be those that have a chance to reproduce and consequently generate new plants with their DNA« (PT2).

Situation 2 | SARS-CoV-2 evolution problem

RQ2) Misconceptions revealed by the prospective teachers

Teleological misconceptions about the evolution of SARS-CoV-2 were presented by the PTs. One example of such a misconception is evident in the following statement: »The characteristics of SARS-CoV-2, which is being refined through its many genetic variants« (PT1). Another PT reported about the

HIV virus and presented teleological conceptions: »In short, we cannot let the virus reproduce uncontrollably because we have HIV in our society, which has modified its genetics to become immune« (PT12).

When asked to explain, in the light of evolution, why it is dangerous to allow uncontrolled reproduction of the virus, the PTs applied several evolution key and threshold concepts.

RQ3) Principles and key concepts of evolution mobilised by the prospective teachers

Regarding the key concepts, all or almost all of the PTs identified the existence of intraspecific variation and stated that this variation was due to mutations (one PT also mentioned recombination as a source of diversity). One PT related the new variants to higher risks of transmission: »These (variants) have a genome that is distinct from the original genetic code and presents a much higher risk of transmissibility, as well as the possibility of causing more serious damage in certain organisms« (PT5). None of the PTs mentioned that the mutations that occur in a particular virus would be transmitted to its descendants. In fact, the notion that traits are passed from one virus to another through reproduction was only expressed by one PT: »when they (viruses) enter the cells they exploit the cellular machinery by making copies of themselves over and over again« (PT2). Moreover, although seven of the PTs identified vaccines, the immunological system or drugs as factors imposing selective pressures that could differently impact the ability to reproduce, the transmissibility or epidemiological behaviour of the diverse SARS-CoV-2 variants, they mostly expressed this idea by mentioning that new variants of the virus could reduce the protection conferred to humans by those factors. They did not further elaborate on this idea to describe how this would differently impact the frequency of the strains across time and space. Seven of the PTs mentioned the existence of differential fitness between distinct variants, while five mentioned that this would lead to variants' frequency change through time and/or space. However, the differential fitness processes mentioned by most of the PTs are caused by the increased ability to infect or be transmitted between humans, and are not directly linked to vaccines, immunological system or drug resistance. One PT described the process of natural selection, but taking place in humans, stating that individuals who were not resistant to SARS-CoV-2 had increased mortality.

Regarding the threshold concepts, more than half of the PTs applied the concept of randomness to the mutations, as exemplified by this statement: »these copies (of the virus) can mutate, due to random errors during protein synthesis, generating variants with new properties« (PT2). Six of the PTs applied the concept of probability to describe the low probability of an adaptive mutation happening (2), or to explain that the higher the population size, the higher the possibility of having an adaptive mutation (4). This was the case of PT7, who stated: »The more the virus replicates, the more mutations will occur. New variants will emerge and within them there will be a greater probability of being more infectious, since there are more variants.«

A high proportion of the PTs (90%) were able to apply more than one spatial scale in their answers, typically mentioning the mutations taking place in virus RNA within our cell and impacting the pandemic at a global level. Fewer of the PTs specifically mentioned changes in the variants' frequencies through space (7) and time (4). One exception is PT11, as exemplified in the following statement: »It is dangerous to allow the SARS-CoV-2 virus to reproduce uncontrollably because new variants of it emerge, as has already happened with variants in South Africa, the UK and Brazil!». None of the PTs mentioned genetic drift as a cause of variants' frequency changes. Three of the PTs revealed teleological misconceptions in their explanation.

Table 1

Results obtained for Situation 1: Frequency of prospective teachers who identified or expressed a misconception and applied the evolution principles and key concepts to answer the problem about plant evolution

Prospective teachers	Misconceptions identified	Misconceptions expressed				Principles and key concepts of evolution					
						Variation		Heredity	Selection		
	Identification of at least one teleological idea	Humans do not affect plant evolution (evolution = mutation)	Teleological	Inheritance of acquired features	Evolution cannot be a fast process	Mutations are the cause of variation	There is individual phenotypic variation	Some traits are heritable and passed from parents to offspring	Selective pressure	Differential survival	Differential reproduction
Absolute frequency	8	5	1	3	2	2	10	8	8	8	6
n	12	12	12	11	12	10	10	10	10	10	10
Relative frequency	0.67	0.42	0.08	0.27	0.17	0.20	1	0.80	0.80	0.80	0.60

Note. n – total number of PTs' answers coded for each criterion without doubts.

Table 2

Results obtained for Situation 2: Frequency of prospective teachers expressing misconceptions, applying principles, key concepts and threshold concepts to answer the problem about SARS-CoV-2 *evolution*

Prospective teachers	Misconceptions expressed	Principles and key concepts of evolution						Threshold concepts of evolution						
		Variation		Heredity	Selection			Randomness		Probability		Temporal scale	Spatial scale	
	Teleological	Mutations are the cause of variation	There is individual phenotypic variation	Heritable traits are passed from parents to offspring	Selective pressure	Differential fitness	Changes in population	Mutations are random	Genetic drift	The probability of a mutation being fitter is low	The higher the population size the higher the probability	Frequency change through time	Frequency change through space	More than one spatial scale is mentioned
Absolute frequency	3	10	12	0	7	7	5	7	0	2	4	3	7	11
n	12	11	12	12	12	12	12	12	12	12	12	12	12	12
Relative frequency	0.25	0.91	1	0	0.58	0.58	0.42	0.58	0	0.17	0.33	0.25	0.58	0.92

Note. n – total number of PTs' answers coded for each criterion without doubts.

Discussion and implications for the evolution education of prospective teachers

This section presents a discussion of the results of the PTs' answers about the problems of both of the real-life evolution situations and their implications for their evolution education.

RQ1) Misconceptions identified by the PTs in Situation 1

Most of the PTs who participated in the present study revealed an awareness of teleological misconceptions regarding evolution. In Situation 1, most of the PTs perceived that the plant, *Fritillaria delavayi*, did not evolve to achieve a purpose. However, a significant proportion of the PTs (33%) failed to identify the misconceptions present in the text. These results are in line with those of Fischer et al. (2021), who showed that PTs find it hard to identify teleological misconceptions. This suggests that further training is needed to empower PTs to identify evolution misconceptions. Such training could also lead them to prepare better interventions to support their own students in overcoming their misconceptions when addressing evolution situations, as suggested by Brown et al. (2020).

RQ2) Misconceptions expressed by the PTs in Situations 1 and 2

Although most of the PTs were able to identify misconceptions, some of them also expressed misconceptions when justifying their reasoning. For example, some of the PTs expressed the misconception that humans do not affect, or have a small influence on, plant evolution in Situation 1. PT1 illustrates this point clearly: »It is also unlikely that the camouflage of *Fritillaria delavayi* is directly due to the human action of harvesting«. This reveals the importance of PTs' evolution education to clarify that humans can directly impact the strength and direction of selection, either intentionally or inadvertently. Moreover, it should be clarified that this process is led by the selective pressure imposed by humans as they cause differential survival and reproduction in a population, and not by evolutionary 'needs' or 'purposes' of the target species. Some of the PTs who mentioned that humans could not drive evolution revealed an additional misconception, as they seem to think that evolution is only the initial mutation. They failed to understand evolution as the gene frequency change through time, and that the human harvesting was the selective pressure driving such change. It is thus fundamental to clarify that evolution is the process of frequency change through time, and that this process requires diversity (originated initially by mutation) in heritable characters (Tibell & Harms, 2017).

Research shows that students tend to apply different normative ideas and misconceptions to similar evolutionary problems if these differ in superficial features (e.g., if one problem involves a plant and the other an animal; Nehm & Ridgway, 2011; reviewed in Nehm, 2018). This is explained by the fact that the different surface features of the problems result in the activation of distinct concepts and problem-solving schemas that lead to different approaches and explanations being provided by the students. This may explain the higher number of PTs expressing teleological ideas to reason about the evolution of viruses, as viruses have very different biological properties from the species usually used to teach evolution. Our results thus support the thesis that the evolution of viruses should be addressed in PTs' education, given its very different biological properties.

Although only three of the PTs presented the idea of inheritance of acquired features, resembling Lamarckian explanations, this alerted the authors of this paper to the fact that the topic 'history of science' should be reinforced in the evolution education of PTs, who should be taught why the Lamarckian evolution ideas proposed in the nineteenth century are not accepted nowadays.

Another misconception identified in two of the PTs is that evolution is a very slow process. One model of macroevolution, called phyletic gradualism, proposes that »most speciation events are the result of a gradual and uniform transformation of one species into a new one through a process called anagenesis« (Sesink Clee & Gonder, 2012). In this model of macroevolution, the key element is vast amounts of time (Sesink Clee & Gonder, 2012). The need for vast amounts of time for macroevolution to occur could have influenced the reasoning of the PTs in the present study. Furthermore, this idea could result from an unclear conceptualisation of microevolution, which describes mechanisms that alter the frequencies of alleles in gene pools within species (Reznick & Ricklefs, 2009). These mechanisms include mutation, migration, genetic drift and natural selection (Sesink Clee & Gonder, 2012). For PT1, for example, the colour change of a plant was due to a major phenotypic transformation and was not perceived as the change in the frequencies of alleles in the population, which can be a fast process. Microevolution can be observed over a short period of time, such as across a few generations (Choudhuri, 2014). Although only two of the PTs considered that evolution is always a very slow process, we suggest that, for a proper understanding of evolution, the distinction between macroevolution and microevolution, as well as the features of these processes, should be addressed in PTs' evolution education.

RQ3) Principles, key concepts and threshold concepts of evolution mobilised by the PTs about Situations 1 and 2

Principles and key concepts of natural selection

Some relevant differences were found in the frequency of the PTs' applying the principles and key concepts to explain Situations 1 and 2. This can be explained by the differences between the two questions (the type of task submitted to the PTs, the material provided for them to read about the situation, etc.). However, given the different organisms and biological scenarios used to explore evolutionary processes, the different concepts used could also be due to the distinct concepts and problem-solving schemes that these activate in PTs (Nehm & Ridgway, 2011; reviewed in Nehm, 2018). The PTs' previous knowledge of the biology of plants and viruses may have influenced the concepts used in each situation.

While variation and selection principles of natural selection were mobilised by the PTs to answer both Situation 1 and 2, heredity was only mobilised to explain Situation 1. The idea that heritable traits are passed from parents to offspring (Tibell & Harms, 2017) was commonly used by the PTs in Situation 1, but only one PT applied it properly to Situation 2. The difficulty of understanding the cellular process of virus reproduction could be one of the reasons behind the reduced mobilisation of this concept by the PTs when addressing Situation

2. Another possibility is that the PTs used ‘propagation’ (PT11) to refer not only to virus dissemination in human populations, but also to consider virus reproduction. These results suggest that it is important to explore the specificities of viruses’ reproduction in PTs’ evolution education.

Regarding the key concepts applied, a great difference was found between Situations 1 and 2 concerning variation as a result of mutation. In the first situation, only two of the PTs mentioned this idea, which was used by the majority of PTs to make sense of the second situation. One reason for the observed difference is that the term ‘mutation’ is often used in the text of Situation 2 but is absent in Situation 1. The term mutation was also frequently employed by mainstream Portuguese newspapers to explain the emergence of SARS-CoV-2 variants (see two examples from two different newspapers in Serafim, 2020 and in Novais, 2021). Given that mass media played a very important role in the dissemination of SARS-CoV-2-related information (e.g., Corine et al., 2022; Dhanashree et al. 2021), the use of this concept by the Portuguese media when communicating about SARS-CoV-2 may also have contributed to its activation in the PTs when addressing this situation.

Regarding the principle of selection, many of the PTs identified human harvesting as the selective pressure that had caused the plant’s evolution in Situation 1, while vaccines, the immunological system or drugs were identified as a selective pressure that differently affects the transmissibility or epidemiological behaviour of the SARS-CoV-2 variants in Situation 2. In Situation 1, it was noticed that the concept of differential survival was more often mobilised by PTs than that of differential reproduction, which is consistent with studies carried out with primary school students (e.g., Brown et al., 2020; Sá-Pinto et al., 2021). However, differential reproduction – a process by which some individuals leave more offspring in the next generation than others, often due to traits that confer advantages in survival and/or reproduction (UC Museum of Paleontology Understanding Evolution, s.d.) – is much closer to the concept of fitness and is in fact what drives evolution (reviewed in Sá-Pinto et al., 2017). It is thus important that PTs recognise the importance of this concept and are able to use it to make sense of and teach about situations of biological evolution.

Although some of the PTs mobilised differential fitness, the probabilistic nature of this process was not explicitly mentioned in their answers. Therefore, highlighting the probabilistic nature of differential reproduction, as well as differential survival and reproduction, as suggested by Tibell and Harms (2017), should be considered in PTs’ evolution education.

In Situation 2, the key concept of change in population was addressed only by five PTs. The fact that SARS-CoV-2 has many variants, and that, over time, some variants prevailed replacing others (facts that were mentioned in the text that supports Situation 2) may have contributed to the mobilisation of this key concept. Furthermore, although the PTs identified vaccines, the immunological system or drugs as selective pressures, they did not connect this concept to the change in the populations. In fact, it seems that PTs did not understand the impact of the selective pressures on the frequency of the virus variants and on the consequent changes in the SARS-CoV-2 virus population. This knowledge fragmentation, expressed by the inability to link key concepts required to understand a process, can prevent PTs' deep understanding of situations involving evolutionary processes. According to Vergnaud (2009), this knowledge fragmentation pattern can be specific to the situation addressed and can only be overcome by exploring a variety of distinct situations that allow students to identify the set of a concept's invariants (objects, properties and relationships), thus allowing students to apply it to make sense of new situations and to solve new problems. This further supports the need to explore evolutionary processes under a variety of distinct contexts and model species.

Threshold concepts of evolution

The threshold concepts of evolution were unequally mobilised by the PTs in Situation 2. Randomness is defined as the »lack of pattern and predictability in events« (Tibell & Harms, 2017, p. 959). Seven of the PTs approached the random nature of virus mutations, which is good evidence of their understanding of the way this process leads to new ways of biological variation. However, none of them applied the concept of genetic drift to Situation 2, which could be an indicator of their lack of knowledge about this concept and the need to reinforce it in the evolution education of PTs.

Regarding probability, only four of the PTs presented this threshold concept in their reasoning about SARS-CoV-2 evolution. The idea that the larger the population size, the higher the number of mutations that take place (including adaptive mutations), was uncommon and should be properly addressed in the evolution education of PTs. This is particularly worrying, as failing to understand how population size affects biodiversity and the adaptive potential of the species (reviewed in Funk et al., 2019; Sato et al., 2020) may prevent people from understanding the importance of support measures taken in the management of diseases, pest species and endangered species.

As stated by Tibell and Harms (2017), understanding natural selection requires understanding multiple levels of organisation, such as the temporal and spatial scales of natural selection processes. In this exploratory study, the spatial scale threshold concept was mobilised more often by the participants than the temporal scale. This difference suggests that these threshold concepts should also be approached in the evolution education of PTs, with special attention to the temporal scale. It is also interesting to note that the PTs show clear evidence of being able to think over multiple spatial time scales (from the microscopic scale of virus reproduction to the global scale of the spread of new variants across countries and continents), an ability that is needed for systems thinking, one of the key competencies in sustainability (Wiek et al., 2011).

Suggestions for evolution education with prospective teachers

One idea that emerges from the analysis of the results is that PTs sometimes lack substantial knowledge about evolution key concepts, a result that supports the findings of Kuschmierz et al. (2021). Therefore, as a consequence of the above results and discussion, the following suggestions for evolution education with prospective teachers are presented.

In order to avoid evolution misconceptions, prospective teachers should understand that:

1. Evolution is not teleological, which means it has no direction or goal. Evolution does not have a purpose, nor does it tend to perfect organisms over time.
2. Human actions may become important selective pressures and can therefore influence evolution (e.g., the reduction of adult fish in nature due to fishing pressure (Kuparinen et al., 2016); the introduction of exotic species (Mooney & Cleland, 2001).
3. Evolution can, under some conditions, be a fast process.

In order to improve prospective teachers' understanding of evolution, the following should be stressed:

1. The meaning of microevolution and how it relates to macroevolution.
2. The meaning of adaptation.
3. Genetic variation is the primary cause of phenotypic variation.
4. Evolution is the change of gene frequency in populations over time.
5. Different situations and organisms should be used to explore evolution, including plants and viruses, to allow students to identify the key principles and concepts, and how these are linked, so as to apply them to a variety of situations.
6. The meaning of fitness, differential survival and differential reproduction, and how these key concepts are related and can be applied to make sense of adaptive processes.
7. Genetic drift, as an important process driving biological evolution.

8. The correlation of population sizes with the adaptive potential of a species.
9. Understanding evolutionary processes requires thinking at multiple levels of organisational, temporal and spatial scales.

Further research could study whether a better understanding of the principles and key concepts of evolution is related to a reduced or non-existent expression of misconceptions about evolution, specifically teleological conceptions. Another recommendation for research is focusing on students' ability to make sense of antimicrobial resistance and conservation problems from an evolutionary perspective, as these are important global sustainability problems that require long-term solutions informed by evolutionary biology.

Conclusion

The PTs who participated in the present study were able to identify misconceptions. Most of them identified teleological conceptions in Situation 1, showing their awareness that evolution is a natural process and not driven by a goal or cause.

However, misconceptions were also expressed by the PTs. For example, some teleological ideas arose concerning the intentional evolution of viruses to become more transmissive to humans, and attention should therefore also be paid to this aspect in the evolution education of PTs. Although the number of PTs who participated in the study was limited, from the misconceptions they expressed some insights emerged that could inform future evolution education of PTs, such as highlighting the idea that humans can impact evolution, exploring the notion that evolution is gene frequency change and that it can be a fast process, detailing the meaning of adaptation, and approaching the history of the science of evolution, with an emphasis on Lamarckism and why this explanation has not prevailed through time.

Concerning the key concepts of evolution mobilised, it was noted that individual phenotypic variation was an easier concept to grasp than genetic variation, and that differential survival was also easier to mobilise than differential reproduction. Differential fitness seemed to be easier to apply to viruses, rather than differential survival and reproduction. The threshold concepts of probability and temporal scale, especially when applied to viruses, also deserve further attention. Therefore, we suggest these concepts be reinforced in PTs' evolution education.

By addressing the above topics in the evolution education of PTs, their pedagogical content knowledge and confidence to teach evolution may increase, thus improving their performance when teaching this topic.

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Biographical note

Bento Cavadas, PhD, is a professor in the Polytechnic University of Santarém/School of Education, in Portugal. He is a researcher at CeiED, from Lusófona University. Author of textbooks of natural sciences, biology and geology. His main research interests include science education, teacher education, science textbooks and integration of science and mathematics.

Xana Sá Pinto has a PhD in Biology. Since 2015 member of the Research Centre on Didactics and Technology in the Education of Trainers at the University of Aveiro (CIDTFF.UA). Since then, her research focuses on how to promote students' scientific literacy and the impact of this in their attitudes towards nature conservation and sustainability problems. She works in the context of transdisciplinary research networks that involve academic and non academic stakeholders with diverse and complementary profiles.

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The Impact of Exploring Sexual Selection on Primary School Students' Understanding of Evolution

Xana Sá-Pinto*[1], Patrícia Pessoa[2], Alexandre Pinto[3], Pedro Cardia[4] and Joaquim Bernardino Lopes[5]

Several researchers and scientific institutions argue that evolution should be explored from the first school years. However, few studies have analysed primary school students' understanding of evolutionary processes or evaluated the impact of educational activities on such knowledge. The available data: i) suggest that primary school students can learn about evolution; and ii) identify differential reproduction as the key evolution concept less often used by students to make and justify evolutionary predictions. In the present study, we evaluate the impact of an educational programme on primary school students' level of understanding of evolution by sexual selection and on their ability to employ differential reproduction to propose and justify evolutionary predictions. An evaluation framework was applied to estimate primary school students' level of understanding of evolution by sexual selection in third- and fourth-grade classes, before and after the students were exposed to the educational programme. A significant increase in the level of understanding of evolution by sexual selection was observed in the target classes, but not in the control classes. This result was primarily driven by a significant increase in the students' justifications employing the concept of differential reproduction. The results suggest that activities that model and simulate biological evolution through sexual selection can contribute to primary school students' understanding of evolutionary processes.

Keywords: primary school, sexual selection, evolution education, conceptual understanding, model-based learning

1 *Corresponding Author. Research Centre on Didactics and Technology in the Education of Trainers, Education, Department of Education and Psychology, University of Aveiro, Portugal; xanasapinto@gmail.com.
2 Research Centre on Didactics and Technology in the Education of Trainers, Education, Department of Education and Psychology, University of Aveiro, and University of Trás-os-Montes e Alto Douro, Portugal.
3 Center for Research and Innovation in Education, ESE (School of Education), Polytechnic of Porto, Portugal.
4 Ambiente e Inovação, Portugal.
5 Universidade de Trás-os-Montes e Alto Douro, Portugal.

Vpliv raziskovanja spolne selekcije na razumevanje evolucije pri osnovnošolcih

Xana Sá-Pinto, Patrícia Pessoa, Alexandre Pinto, Pedro Cardia in Joaquim Bernardino Lopes

Več raziskovalcev in znanstvenih ustanov trdi, da je treba evolucijo raziskovati že v prvih šolskih letih, vendar pa je malo študij analiziralo razumevanje evolucijskih procesov pri osnovnošolcih ali ovrednotilo vpliv izobraževalnih dejavnosti na tako znanje. Razpoložljivi podatki: i) nakazujejo, da se osnovnošolci lahko učijo o evoluciji; ii) opredeljujejo diferencialno reprodukcijo kot ključni koncept evolucije, ki ga učenci redkeje uporabljajo za navedbo in utemeljitev evolucijskih napovedi. V tej študiji ocenjujemo vpliv izobraževalnega programa na raven razumevanja osnovnošolcev glede evolucije s spolno selekcijo in na njihovo sposobnost uporabe diferencialne reprodukcije za predlaganje in utemeljitev evolucijskih napovedi. Pri tem je bilo uporabljeno evalvacijsko ogrodje za oceno stopnje razumevanja evolucije s spolno selekcijo osnovnošolcev v oddelkih tretjega in četrtega razreda, pred tem in po tem, ko so bili učenci izpostavljeni izobraževalnemu programu. Znatno povečanje stopnje razumevanja evolucije s spolno selekcijo so opazili v ciljnih, ne pa tudi v kontrolnih razredih. Ta rezultat je bil predvsem posledica znatnega povečanja utemeljitev učencev, ki uporabljajo koncept diferencialne reprodukcije. Izsledki kažejo, da lahko dejavnosti, ki modelirajo in simulirajo biološko evolucijo s spolno selekcijo, prispevajo k razumevanju evolucijskih procesov pri osnovnošolcih.

Ključne besede: osnovna šola, spolna selekcija, evolucijska vzgoja, konceptualno razumevanje, modelno učenje

Introduction

Although evolution understanding is fundamental for students in order to address important sustainability problems (Jørgensen et al., 2019), several studies show that many people are unable to understand, or even to accept, evolution (see, for example, Miller et al., 2006; Kuschmierz et al., 2021).

In order to overcome this problem, several researchers and scientific institutions argue that evolution is a core idea around which learning progressions in biology should be built from the first school years (Nadelson et al., 2009; National Research Council [NRC], 2012, 2013; Wagler, 2010, 2012; see also the review of Treagust & Tsui, 2013 by Torkar, 2017). Despite this, few studies have analysed the ability of primary school students to learn about evolution, or evaluated the impact of educational activities on primary school students' understanding of evolutionary processes (see, however, Berti et al., 2015; Brown et al., 2020; Campos & Sá-Pinto, 2013; Emmons et al., 2017; Kelemen et al., 2014; Sá-Pinto et al., 2021a). In a systematic literature review conducted by Bruckermann et al. (2020), aimed at identifying which precursory concepts in evolution early childhood and primary school children already possess or develop after an educational intervention, the authors found that even children aged up to seven years are able to understand the basic mechanisms of the core concepts in evolution, such as variation, inheritance and natural selection. Grether (2021) used lesson plans with active learning activities to teach specific evolutionary learning objectives (fossils, vestigial traits, common ancestry, heritability, natural selection and evolutionary time) to primary school students (grades 3–5). This author reports a substantial improvement in the students' understanding of evolutionary concepts after engaging in these activities. Using a storybook intervention that explored the concepts of intraspecific diversity, heredity, environmental change, differential survival, differential reproduction and frequency change over generations, two studies show that kindergarten and primary school students can learn about evolution by natural selection (Emmons et al., 2017; Kelemen et al., 2014). Sá-Pinto et al. (2017a) proposed a framework to evaluate primary school students' level of understanding of evolution by natural selection and Sá-Pinto et al. (2021a) adapted it to evaluate an educational transdisciplinary activity that used a problem-based learning approach to teach fourth graders about natural selection and numerical sequences related to geometric growth. This study shows that primary school students can learn about evolution and are able to apply the key concepts related to natural selection (selective pressure, differential survival, differential reproduction, frequency change; following Tibell and Harms, 2017) to explain or predict biological scenarios (see Mestrinho et al., 2023 for students' mathematics learning). A study by Brown et al. (2020) also shows that, although primary school students reveal some common evolution misconceptions, these are easily overcome with instruction, a picture that strongly contrasts with what is known regarding older students, whose misconceptions are shown to resist instruction (Bishop & Anderson, 1986; Nehm & Reilly, 2007). Although these studies support primary school students' ability to learn about natural selection, the results of Sá-Pinto et al. (2017a, 2021a) show that differential reproduction is not frequently mentioned by students. This is particularly worrying, as differential reproduction is the most important parameter determining individuals' fitness, and because students tend to believe that fitness is determined by the individual's ability to survive, their strength or intelligence (Gregory, 2009). These results highlight the importance of further exploring the concept of differential reproduction. Recently, Sá-Pinto et al. (2017b) have argued that exploring sexual selection may help students to further understand evolution, as this process focuses on the parameter that defines an individual's fitness: its reproductive output.

Although sexual selection was only named later (Darwin, 1871), the importance of this process for species' evolution has been recognised since the first joint publication of Darwin and Wallace (1858). In this publication, Darwin wrote that »Besides this natural means of selection, by which those individuals are preserved, whether in their egg, or larval, or mature state, which are best adapted to the place they fill in nature, there is a second agency at work in most unisexual animals, tending to produce the same effect, namely, the struggle of the males for the females. These struggles are generally decided by the law of battle, but in the case of birds, apparently, by the charms of their song, by their beauty or their power of courtship, as in the dancing rock-thrush of Guiana. The most vigorous and healthy males, implying perfect adaptation, must generally gain the victory in their contests. This kind of selection, however, is less rigorous than the other; it does not require the death of the less successful, but gives to them fewer descendants« (Darwin & Wallace, 1858, p. 50).

Since Darwin's first description, the process of sexual selection has been strongly debated by the research community, with several authors arguing that it would be a component of 'broad sense' natural selection (reviewed by Andersson, 1994; Shuker & Kvarnemo, 2021). Several studies have supported the importance of the competition for mates in species evolution and speciation processes (reviewed by Andersson, 1994; Andersson & Simmons, 2006). Furthermore, the effect of sexual selection in some traits opposes the effect of natural selection (when defined in its 'narrow sense' emphasising the viability or fecundity components of fitness; this definition of natural selection will be used throughout the present article) as it occurs, for example, in the evolution of ornaments (reviewed by Andersson, 1994; Shuker & Kvarnemo, 2021). Given this, the concept of sexual selection has been retained and is widely used to refer to the fitness component related to success in the competition for access to mates, or gametes. Andersson defined sexual selection in a trait as »differences in reproductive success, caused by competition over mates and related to the expression of the trait« (Andersson, 1994, p. 7). More recently, Shuker and Kvarnemo have proposed an alternative definition of sexual selection as »any selection that arises from fitness differences associated with non-random success in the competition for access to gametes for fertilisation« (Shuker & Kvarnemo, 2021, p. 781), thus emphasising that, although access to mates (pre-copulatory mating success) may be the first step, sexual selection can still occur after mating (post-copulatory mating success). Several factors may affect the strength of sexual selection acting in a sex, including sex differences in parental investment, mating systems, sex ratios or operational sex ratios (extensively reviewed by Andersson, 1994 and summarised in Sá-Pinto et al., 2017b). Although females are often the limiting sex for reproduction (thus imposing a stronger sexual selection in males), there are numerous exceptions to this pattern (see examples in Sá-Pinto et al., 2017b). Sexual selection will favour traits that improve the ability of individuals of a sex to maximise their access to mates (or gametes). These include traits that allow them to find mates faster than others, to attract more (or better) partners of the limiting sex, to keep rivals away, to keep reproductively active for a longer period, and to produce more gametes (summarised in Sá-Pinto et al., 2017b). Importantly, favoured traits may act before and/or after copulation, as pointed out by Shuker and Kvarnemo (2021).

The teaching of sexual selection is fundamental for students to make sense of the surrounding world. Palanza and Parmigiani (2016) argue that the combined teaching of sexual and natural selection is fundamental for medicine and psychology students to understand the anatomy, physiology and behaviour of humans, the selective pressures that condition the evolution of these features, and how the mismatch between past and present conditions cause human vulnerabilities to diseases and behavioural disorders.

Despite the importance of sexual selection for biological processes and for fostering students' understanding about these processes, few educational activities designed to promote learning about this process are described, and even fewer studies have analysed students' knowledge or ability to learn about this process (reviewed in Sá-Pinto et al., 2017b). Kalinowski et al. (2013) describe six activities that were implemented with students in introductory biology courses to promote their learning about evolution by natural selection. One of them was a class discussion related to peacock feathers, in which students were asked to propose explanations for the evolution of this trait before and after being presented data regarding female mating preferences. The other activities explored the selection of dog breeds to introduce the concept of selection, the coat colour in oldfield mice (*Peromyscus polionotus*) to introduce the sources of variation, human evolution to introduce natural selection, antibiotic resistance to introduce complex traits evolution, and the apparent suicide of lemmings to introduce behavioural evolution. The authors show that, after exploring this pack of six activities, students increased their understanding of natural selection. Luttikhuizen (2018) described a card game for students to learn about processes that are frequency dependent, including cases of sexual selection. Although the authors do not present data for the students' learning evaluation, they report that these activities were successfully explored with university students. Kane et al. (2018) developed a series of activities for middle school students to use trinidadian guppies (live animals and models of the species *Poecilia reticulata*) to explore several evolutionary processes, including sexual selection (through mathematical modelling situations). Although the authors did not evaluate the impact of the activities on students' learning, both teachers and students praised these activities. Bouwma-Gearhart and Bouwma (2015) also propose using live crickets from the species *Acheta domesticus* to help students build progressively better models of evolution that account for both natural and sexual selection, as well as the interplay between these two processes, an approach that was applied to high school and university students. However, no information is provided on how these activities contributed to students' learning. Fee and Alfano (2013) propose a set of activities that explore several species of birds of paradise as models for students to learn about both natural and sexual selection. Lawson (2003) proposed an activity to be explored by sixth graders or older students that uses coins to model evolution by sexual and natural selection. Sá-Pinto et al. (2017b) propose two activities for students to learn about sexual selection by mate choice and male-male competition that model these processes through a card game and balloon sword contests. These few studies show that: i) most of the activities were proposed and implemented with older students (university and high schools); ii) the impacts of the activities on students' learning are most often assumed rather than evaluated. The latter means that no information is available on the impact of exploring sexual selection on primary school students' understanding of evolutionary processes. In the present study, we aim to contribute to overcoming this lack of information by studying: i) whether activities modelling biological evolution through sexual selection can assist primary school students to learn and apply the concept of differential reproduction; and ii) whether these students can understand the processes of sexual selection and apply this knowledge to predict biological scenarios.

Method

Educational activity

In order to promote students' learning about evolution by sexual selection, we planned an educational programme that included four sessions of approximately two hours each. The first and second sessions were introductory sessions exploring two key principles that, according to Tibell and Harms (2017), are fundamental to understanding evolution: the variation principle and the heredity principle. To explore the variation principle, the students explored the intraspecific variability in humans through an activity adapted from Campos and Sá-Pinto (2013). In a class discussion, the students were initially asked to identify variable human traits. In small groups, they were then asked to choose two traits from those initially listed to describe, categorise, quantify and depict the different phenotypes, and to group their classmates according to these phenotypes. During this activity, the students mentioned and explored mostly observable traits (such as skin, hair and eye colour, height, etc.), but traits such as 'voice' and 'blood types' were also mentioned and analysed. At the end of the session, the students were asked to observe the chosen traits in their family members and to register the information in a genealogical tree provided to them. The genealogical trees were used in the second session to explore the principle of heritability. Following Campos and Sá-Pinto (2013), we asked the students to analyse with whom they each shared a higher number of features and, for each feature, which of their family members displayed such features. After the students noticed that some phenotypes 'jumped' generations, the researchers explored with the children the concept of dominant, recessive and co-dominant phenotypes, using blood types and imaginary genealogical trees to exemplify the transmission and expression of these features.

The students were only introduced to sexual selection in the third and fourth sessions, through two activities that model a scenario of mate choice and male competition, as described by Sá-Pinto et al. (2017b). Briefly, in the activity of the third session, the students were asked to model sexual selection occurring in a male-biased population. They played the role of the females and were asked to choose their mates from a pool of cards that initially displayed four distinct and equally frequent phenotypes. The individuals chosen reproduce, each giving rise to three fertile descendants (one female – the student – and two males – two cards with the same phenotype of the one chosen by the student) and then die. This model was used for three generations. The frequency of each phenotype in each generation was recorded on the blackboard and the changes observed across generations, as well as the causes for those changes, were discussed with the entire class. In order for students to understand how the sex ratio could affect the strength of sexual selection, the same model was applied to a scenario in which the students were at the same number of the cards. The results of this scenario were compared to those previously obtained and the reasons for the differences were discussed in the classroom. Some examples of species with biased and unbiased sex ratios and their sexual dimorphism were then presented to the students using a resource provided by Sá-Pinto et al. (2017b). In the fourth session, the students explored intrasexual competition, modelling this process through balloon sword fights. They were asked to play the role of males who had to fight with other males to secure access to mates with balloon swords that modelled a body feature such as horns or antlers. Balloon swords of two very distinct sizes were randomly assigned to the students, who were randomly assigned to pairs. In each pair, the student who first touched their opponent three times with their sword wins and reproduces leaving two descendants with a sword of the same size as their parent's sword. The student who loses the fight does not reproduce her/his sword. In each generation, the frequency of the size of the swords, which was initially equal, was registered on the board and the reasons for the frequency changes observed across generations were discussed with the students.

Evaluation of students' understanding of evolution by sexual selection

The sessions were applied in a convenience sample of one third-grade class (N = 19, ages ranging from 8 to 9 years old) and one fourth-grade class (N = 15, ages ranging from 9 to 10 years old) recruited from a Portuguese public school. Informed consent to perform the study and collect the students' answers was obtained from the students' legal guardians. Consent to perform the study was also obtained from the teachers and the school board. No personal data was collected from the students, who were identified only with a code number.

The students were tested for their ability to use knowledge on sexual selection to predict the evolutionary outcome of a biological system two days before and one day after the sessions. The evaluation instrument was inspired by the one proposed by Sá-Pinto et al. (2017a), but adapted to a sexual selection scenario. The test introduced students to a beetle population (see Figure 1a), initially presenting polymorphism in males' mandible sizes. The students were asked to predict the frequency of the jaw sizes after one hundred years, knowing that: i) male beetles used their mandibles to fight other males and move them away from females; ii) each beetle only lives one year; and iii) mandible size is a heritable trait. The English translation of the test presented to the students can be found in Figure 1a. The test was read aloud to the entire class, and the researchers further clarified the task orally by asking the students to make their predictions and justifications considering the three mandible male phenotypes already depicted in the figure. The researchers also clarified the meaning of some terms, such as mandibles. The students were asked to draw and provide a written justification for their predictions, and were given 15 minutes to complete these tasks. Following Sá-Pinto et al. (2017a), after the tasks were completed, each student was asked to verbally explain their predictions and their justifications before handing in the test. Irrespective of the type of student answer, when the students verbally provided more information to the researcher than was written or drawn on the test, they were asked to add that information to their answer. Approximately 30 minutes were necessary for all of the students to complete this process in each class. The pre- and post-tests were similar. Control classes were used to verify the impact of the students' double exposure to the test and to evaluate the internal validity of the process (Lahm, 2004). The two control classes (one third- and one fourth-grade class) were from the same school as the target classes, but were not exposed to the educational programme. The tests were applied on the same days in all of the control and target classes. No significant differences were found between pre- and post-test in the control classes, thus ensuring the internal validity of our evaluation instrument (Lahm, 2004).

The students' answers were analysed using content analysis. The key concepts related to the selection dimension proposed by Tibell and Harms (2017) were used as categories of the analysis: selective pressure; differential survival; differential reproduction; trait relative frequency change in population (Table 1). We did not look for evidence of students mentioning speciation as divergence between populations, as it was not an expected outcome from the proposed biological scenario. Furthermore, we did not evaluate the key concepts related to the dimensions of heredity and variation, as, following Sá-Pinto et al. (2017a, 2021a), the information related to these key concepts was provided to the students in the test. The expected fittest phenotype was considered to be the larger mandibles, unless the student provided information in the answer to support a credible biological scenario in which other phenotypes increase the progeny of the individuals more than the larger mandibles.

Table 1

Categories of the content analysis, their definition and examples of answers attributed to each category of the analysis. The section of the answer that justifies its attribution to the specific category is highlighted in bold

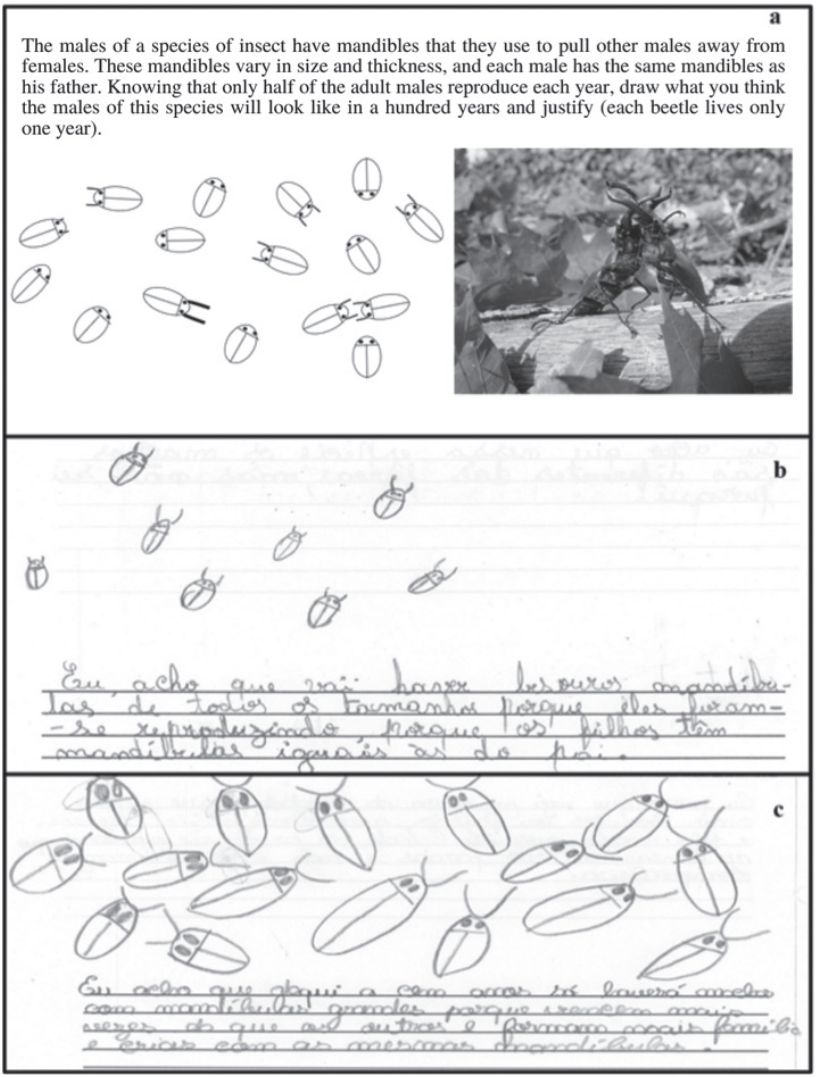
Category of analysis	Definition	Example of an answer classified as evidence for a category
Trait relative frequency change	the student predicts that the expected fittest phenotype would become the most frequent	*I think that **in one hundred years there will be only males with big mandibles,** as these win more often than the others and form more families and have more offspring with the same mandibles*
Selective advantage	the student states that the expected fittest males would win more fights	*I think that in one hundred years there will be only **males with big mandibles, as these win more often than the others** and form more families and have more offspring with the same mandibles*
Differential reproduction	the student justifies the frequency increase of the expected fittest male phenotype mentioning its differential reproduction advantage.	*I think that in one hundred years there will be only males with big mandibles, as these win more often than the others and **form more families and have more offspring with the same mandibles***
Differential survival	the student justifies the frequency increase of the expected fittest male phenotype mentioning its differential survival advantage.	*Because the **males with small beaks die more often in the fights.***

A score of one was attributed to each category except differential survival, as sexual selection does not require differential survival to take place. The level of understanding of evolution by sexual selection (LUESS) revealed by each answer, regarding both predictions and corresponding justifications, was determined by summing the scores attributed to each rubric item identified in that answer. The LUESS could range between L0: no evolutionary thinking involved in the answer (see example in Figure 1b), to L3: the ability to correctly predict population evolution and justify it with differential reproduction due to differential ability to win fights (Figure 1c).

Two science education researchers evaluated all of the students' answers: one with a background in primary school teacher training (AP), and one with an evolutionary biology background (XSP). Given the evaluators' training, interrater reliability was estimated as the percentage of initial agreement between the evaluators (McHugh, 2012). Interrater reliability was higher than 94.8% for all of the items analysed, a reliability considered as acceptable (Stemler, 2004, p.3). Answers not equally rated by the two researchers were discussed and, failing a consensus, removed from the analyses. The McNemar test was used to estimate the statistical significance of the changes in the frequency of each coding rubric item and the Wilcoxon test was used to estimate the statistical significance of students' LUESS between pre- and post-tests. All of the statistical analyses were performed with SPSSv23.

Figure 1

Test presented to the students before and after the intervention and (a) example of students' answers classified as L0 (b) and L3 (c)



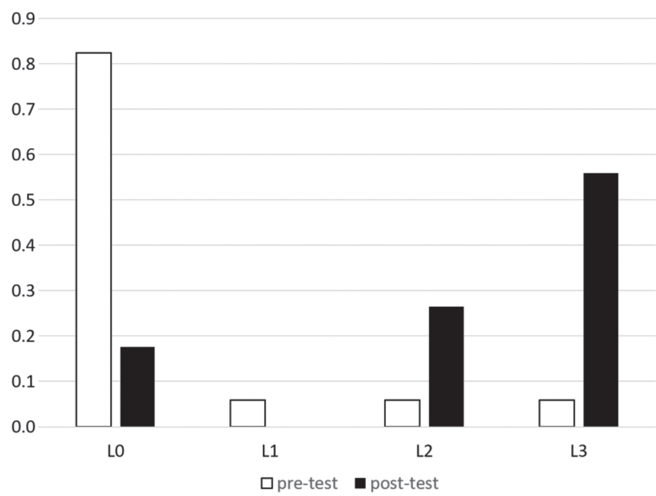
Translation of the student's answer in b) »I think that there will be beetles of all mandible sizes because these reproduced and the mandibles of the sons are similar to those of their fathers«. Translation of the student's answer in c) »I think that in one hundred years there will be only males with big mandibles as these win more often than the others and form more families and have more offspring with the same mandibles«. Photo in a) reproduced under the creative commons share alike license from Von Anaxibia H. Rothacher. Original upload was de: User: Matthias1987 - {own} http://h-r.gmxhome.de/index.htmltransfered from de:Datei:Lucanus cervus73.jpg, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=8768963.

Results

Table 2 shows the relative frequency of the answers that were assigned to each category of analysis (examples of answers can be found in Figure 1). When the two target classes are considered, more than 82% of the students revealed an L0 of the LUESS in the pre-tests. After engaging in the educational activities, 56% of the students achieved L3 of the LUESS (Figure 2). Thus, there was a significant increase in the target classes' LUESS in the post-tests (Table 2) in both classes.

Figure 2

Frequency of students attributed to each level of understanding of evolution by sexual selection (LUESS) when the two target classes are considered in both pre- and post-tests



The increase in students' LUESS from the pre-test to the post-test was due to a significant increase in the proportion of students who i) predicted that the expected fittest phenotype would become the most frequent and justified this prediction by ii) the increased ability of individuals with longer mandibles to win fights (selective advantage, Table 2), which would result in iii) an increased chance to secure females and have more progeny (differential reproduction; Table 2). No significant increase was observed in the frequency of students mentioning differential survival of the two phenotypes in any of the classes.

Table 2

Results of pre- and post-tests evaluating the students' ability to apply sexual selection to predict biological scenarios

Classes	Tests	% of students' answers including the analysed criteria				
		Trait relative frequency *change*	*Differential reproduction*	*Selective advantage*	*Differential survival*	*Average LUESS*
K3T N = 19	Pre	10.5	5.3	5.3	0.0	0.21
	Post	84.2	78.9	63.2	10.5	2.26
	Dif.	**73.7 (p = 0.001)**	**73.7 (p = 0.000)**	**57.9 (p = 0.003)**	10.5 (p = 0.500)	**2.05 (Wp < 0.001)**
K3C N = 12	Pre	50.0	0.0	9.1	10.0	0.55
	Post	41.7	0.0	8.3	25.0	0.50
	Dif.	-8.3 (p = 1.000)	0.0	-0.8 (p=1.000)	10.0 (p = 1.000)	0.05 (Wp = 0.317)
K4T N = 15	Pre	26.7	13.3	13.3	0.0	0.53
	Post	80.0	60.0	73.3	0.0	2.13
	Dif.	**53.3 (p = 0.008)**	**46.7 (p = 0.039)**	**60.0 (p = 0.004)**	0.0	**1.6 (Wp = 0.004)**
K4C N = 12	Pre	0.0	0.0	0.0	0.0	0
	Post	8.3	8.3	0.0	0.0	0.17
	Dif.	8.3 (p = 1.000)	8.3 (p = 1.000)	0.0	0.0	0.17 (Wp = 0.317)

Note. K3T – Target third-grade class; K3C – Control third-grade class; K4T – Target fourth-grade class; K4C – Control fourth-grade class; N – sample size; Dif. – difference between results obtained in the pre-test (Pre) and the post-test (Post) by the same students; p – p values obtained in McNemar tests; Wp – p values obtained in Wilcoxon tests. All statically significant differences are highlighted in bold.

Discussion

The results from the present study support the hypothesis that students in third- and fourth-grade classes can learn about sexual selection when they engage in activities that model sexual selection by mate choice and intrasexual competition. This is supported by the strong and significant increase in the students' LUESS from the pre-test to the post-test in the two target classes (Figure 2). The students were shown to learn about the key concepts related to sexual selection: selective advantage, differential reproduction and trait relative frequency change. Although students have already been shown to be capable of learning about natural selection (Brown et al., 2020; Campos & Sá-Pinto, 2013; Emmons et al., 2017; Kelemen et al., 2014; Sá-Pinto et al., 2021a), to our knowledge, this is the first study analysing the ability of primary school students to learn about sexual selection. Although sexual selection has been given much less attention in evolution education than natural selection, this evolutionary process strongly impacts species' evolution and speciation processes. It therefore allows students to understand patterns of sexual dimorphism and the persistence of some features related to reproduction that may decrease individuals' survival, such as the tail of the peacock (reviewed in Sá-Pinto et al., 2017b). The results of the present study also support the potential of exploring sexual selection in order for students to learn about the role of differential reproduction, which is a key concept for the understanding of evolution that has been shown to be difficult for primary school students (Sá-Pinto et al., 2017a; Sá-Pinto et al., 2021a). In fact, after engaging in the educational activities, 60% and 78.9% of the students in the fourth- and third-grade classes, respectively, correctly applied the concept of differential reproduction to justify their prediction. This strongly contrasts with results reported in studies where students were engaged in activities exploring natural selection. After engaging in a storytelling activity and in a transdisciplinary project-based learning activity about natural selection, only 32% and 25% of the students, respectively, applied the concept of differential reproduction to explain or justify the predictions made about biological scenarios (Brown et al., 2020; Sá-Pinto et al., 2021a). The differences observed between the latter studies and the present one suggest that activities exploring sexual selection may contribute more effectively to students' understanding of the importance of differential reproduction than activities exploring natural selection. However, the different studies were performed with distinct students, by distinct people, using distinct educational approaches and in distinct cultural backgrounds, thus precluding a direct comparison between them. The ability to compare the results is further limited by the low number of students involved in the three studies. Furthermore, the time between the activities and the post-tests was shorter in the present study than in the previous ones, which may have impacted students' outcomes. Accordingly, additional studies are needed to comparatively evaluate the impact of activities exploring sexual and natural selection on students' learning about differential reproduction.

An alternative explanation for the differences observed in the use of the concept of differential reproduction in the present and previous studies may lie in the different biological scenarios presented in the evaluation instruments used, which may have caused students to mobilise the concept of differential reproduction differently. In fact, the test used in this study presents a single biological scenario (trait gain in animals), precluding observation of whether the effects reported here are context-dependent, as it has been shown to occur in other situations (Nehm, 2018). Furthermore, this test presents the students with a very simplified model of what happens in the real species in terms of genetic diversity, heredity and trait expression. Additional studies exposing students to evaluation instruments with distinct and more realistic scenarios of natural and sexual selection would be needed to understand how the biological scenarios used impacted the mobilisation of the concept of differential reproduction.

We should also highlight the fact that the model we implemented in this activity mostly explored the effects of biased sex ratios in evolution by sexual selection, without providing any reason for the observed sex bias. However, several studies have shown that, with the exception of a small number of species, biased sex ratios do not explain the patterns of sexual selection observed (Andersson et al., 1994). In fact, operational sex ratios and Bateman's principles better explain the patterns of the observed sexual selection (Andersson et al., 1994; Jones et al., 2005). Accordingly, future studies could explore how students learn about the factors driving sexual selection and focus on the reasons for biased operational sex ratios. For older students, Bateman's principles may also be explored to promote a deeper understanding of the causes of sexual selection. Future studies should also analyse whether the activity reported here results in students' misconceptions about natural populations' sex ratios or whether it fosters teleological explanations.

In any case, our results support the importance of exploring sexual selection during mandatory education and from the initial school years, as well as the importance of introducing this concept in curricula and textbooks. The Portuguese official standards and the next generation science standards from the United States of America do not explicitly mention sexual selection, although some of the learning goals detailed allow or even require this concept to be explored (reviewed in Sá-Pinto et al., 2017b). A better picture of how this concept is explored is hampered by the lack of comprehensive comparisons of curricula of different countries in terms of their evolution concepts (Sá-Pinto et al., 2021b). Regarding textbooks, Cavadas (2017) has shown that sexual selection was historically covered by Portuguese seventh-grade textbooks from 1890 to 1955, but no information is available on how this concept is present in today's textbooks, thus suggesting the importance of analysing recent textbooks. However, textbooks have also been reported to display important misconceptions on evolution (Cavadas, 2017; Nehm et al., 2008; Prinou et al., 2011) and a lack of concepts such as the Nature of Science (Kapsala et al., 2022), which are considered important for evolution understanding (Sá-Pinto et al., 2021b). Another important aspect to consider for introducing natural and sexual selection in primary schools is teacher training, as several studies report low pedagogical content knowledge and low willingness to teach evolution (Cavadas & Sá-Pinto et al., 2021; Prinou et al., 2011), as well as other topics of biology (see, for example, Yli-Panula et al., 2017), among many primary school teachers.

Conclusion

In the present study, we show that there is a positive impact of the early introduction to evolution by sexual selection to students. Our results support the importance of developing and testing active learning activities that allow students to learn about this process from the first school years, with increasing complexity. In fact, when compared to natural selection, much fewer activities have been described for students to learn about sexual selection (and even fewer have been studied for their impacts on student knowledge; however, see Bouwma-Gearhart & Bouwma, 2015; Fee & Alfano, 2013; Lawson, 2003; Moore et al., 2012; Sá-Pinto et al., 2017b). The study also supports the importance of explicitly introducing this concept in national curricula in order to promote a deeper understanding of evolutionary processes and the impacts of these processes on our own features and on daily life problems.

The present study has some limitations that should be taken into consideration and that highlight the importance of performing additional studies: i) the limited number of students, school contexts and countries do not allow us to generalise our results; ii) the post-test was done one day after the students explored the last activity, thus precluding an understanding of the long-term learning impacts of the activity; iii) the test used presents students a single biological scenario (trait gain in animals), thus precluding gaining an insight into whether the effects reported here are context-dependent, as has been shown to be the case in other situations (Nehm, 2018). Accordingly, there is a need for studies that involve a higher number of students and school contexts, that include an additional post-test performed to study the long-term learning effects of the educational programme, and that use tests with at least one additional biological scenario that would result in trait loss.

The present study should be taken as an initial step to understand the impact of introducing primary school students to sexual selection in their understanding of evolution. The results support suggestions previously made by several authors and institutions (Nadelson et al., 2009; NRC, 2012, 2013; Wagler, 2010, 2012) that students should explore evolutionary processes from the first school years in order to foster their evolution understanding.

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Biographical note

Xana Sá-Pinto has a PhD in Biology. Since 2015 member of the research centre in didactics and technologies in teacher training at the University of Aveiro (CIDTFF.UA). Since then, her research focuses on how to promote students' scientific literacy and the impact of this in their attitudes towards nature conservation and sustainability problems. She works in the context of transdisciplinary research networks that involve academic and non academic stakeholders with diverse and complementary profiles.

Patrícia Alexandra Fonseca Pessoa, PhD student, is an elementary school teacher doing her PhD in Didactics of Science and Technology at the University of Trás-os-Montes e Alto Douro. Her research interests include addressing socioscientific issues related to sustainability in light of biological evolution at early grade levels.

Alexandre Pinto, PhD, Professor of Science Education at the Polytechnic Institute of Porto – School of Education, Portugal. His research interest is Science and Technology Education namely: teaching practices, teacher training and professional development.

Pedro Cardia, PhD, is a biologist and, since July 2022, a senior ornithologist at STRIX - Ambiente e Inovação. His research interests lie at the intersection of ornithology, conservation biology and scitizen. Between 2019 and 2020 served as the national coordinator for the III Portuguese Breeding Bird Atlas and the country's new Red List of Birds.Is a national eBird reviewer for Portugal. Currently working in several biodiversity monitor.

Joaquim Bernardino Lopes, PhD and Habilitation, is associate professor in the field of physics education at UTAD (Universidade de Trás-os-Montes e Alto Douro), Portugal. His research interest is Sciences and Technological Education, namely: teaching practices, teacher training and professional development, students' epistemic practices; orchestration of digital tools in epistemic learning contexts, and articulation between arts and S&T in educational contexts.

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Evolution in the Spanish Primary Education Autonomic Curricula and Textbooks. A Geographic Analysis

Mª Arritokieta Ortuzar Iragorri*[1] and Teresa Zamalloa[2]

Evolution by natural selection is a theory that constitutes a powerful paradigm capable of conveying the teaching-learning of multiple concepts in biology. However, it has been controversial from its formulation to the present, which also affects education. For instance, while some of the basic curricula of primary education in Europe are arranged around the concepts that are considered necessary for structuring the scientific model of evolution (i.e., Sweden), other curricula do not contemplate such concepts. The last is the case of the basic curriculum of primary education in Spain. However, in Spain, on the basis of such a curriculum, there are 17 different primary education curricula corresponding to each of the autonomous communities of the state. The objective of this work is to state a detailed geographical picture of the presence of the concepts necessary to articulate the model of evolution through the analysis of the autonomic curricula of Spain. With such an aim, words that represent such concepts (evolution, inheritance, selection, adaptation and biodiversity, etc.) have been searched for in the natural sciences and social sciences areas of the autonomous curricula of primary education. Furthermore, a search for such evolution-related concepts has also been performed in the activities of eighteen Spanish primary education textbooks on natural and social science subjects. For this purpose, two aspects were considered: characterisation and scientific skills. Both the autonomous curricula of primary education and the textbooks hold important gaps when addressing evolution. The texts include activities that prioritise basic cognitive skills over the more demanding ones associated with scientific competence.

Keywords: primary education, autonomic curricula, progression, evolution model, textbooks

1 *Corresponding Author. Faculty of Education of Bilbao at University of the Basque Country, Spain; arritxu.ortuzar@ehu.eus.
2 Faculty of Education of Bilbao at University of the Basque Country, Spain.

Razvoj avtonomnih učnih načrtov in učbenikov v španskem osnovnošolskem izobraževanju – geografska analiza

Mª Arritokieta Ortuzar Iragorri in Teresa Zamalloa

Evolucija z naravno selekcijo je teorija, ki predstavlja močno paradigmo, sposobno transfera poučevanja – učenja več konceptov v biologiji. Prav od svoje formulacije in vse do danes pa ostaja sporna, kar vpliva tudi na izobraževanje. Medtem ko so na primer nekateri osnovni učni načrti osnovnošolskega izobraževanja (OI) v Evropi urejeni okrog konceptov, za katere se predvideva, da so bistveni za osnovanje znanstvenega modela evolucije (tj. na Švedskem), drugi tega niti približno ne odražajo. Zadnji tak primer za OI prihaja iz Španije. Tam na podlagi takega učnega načrta obstaja 17 različnih učnih načrtov, ki ustrezajo vsaki izmed avtonomnih skupnosti države. Cilj te raziskave je podati podrobno geografsko sliko prisotnosti konceptov, potrebnih za artikulacijo modela evolucije z analizo avtonomnih učnih načrtov Španije. S tem v mislih so bile besede, ki se sklicujejo ne te koncepte (evolucija, dedovanje, izbor, prilagoditev, biodiverziteta itn.), raziskane v sklopu naravoslovnih in družboslovnih znanosti znotraj avtonomnih učnih načrtov osnovnošolskega izobraževanja. Nadalje, lociranje tovrstnih konceptov je bilo opravljeno tudi z analizami 18 španskih osnovnošolskih učbenikov s področij naravoslovja in družboslovja. V ta namen sta bila upoštevana dva vidika: karakterizacija in znanstvena znanja. Tako avtonomni učni načrt primarnega izobraževanja kot učbeniki vsebujejo bistvene pomanjkljivosti, vrzeli pri obravnavanju evolucije. Besedila vključujejo dejavnosti, ki dajejo prednost osnovnim kognitivnim veščinam pred zahtevnejšimi, povezanimi z znanstveno usposobljenostjo.

Ključne besede: osnovnošolsko izobraževanje, avtonomni učni načrt, napredovanje, evolucijski model, učbeniki

Introduction

The theory of evolution is considered one of the greatest scientific achievements in the history of science because it changed the concept of fixed species and replaced it with the view that new species can arise from old species. It lies at the core of current biological knowledge and enables making sense of biological diversity and its change over time (National Science Teaching Association [NSTA], 2013). However, evolutionary theory tends to create a public controversy that makes teaching evolution a difficult task for teachers who need to consider various domains when teaching about it: a) the conceptual domain, which includes both scientifically accepted evolutionary concepts and students' non-scientific conceptions related to evolutionary theory, b) the epistemic domain, c) the worldview/religious domain, and d) the social and cultural domain (Deniz & Borgerding, 2018). This controversy has impacted education as the concepts necessary for the subsequent structuring of the scientific model of evolution are not contemplated in some of the European Primary Education (PE) curricula, including in Spain (Vázquez-Ben & Bugallo Rodríguez, 2018).

According to the Organic Law 8/2013 for the quality of Education (LOMCE) and the recent Organic Law 3/2020 that modifies it (LOMLOE), it is the duty of the Ministry of Education and Vocational Training to design the basic PE curriculum. Hence, the autonomous communities plan the autonomous curricula of Primary Education (APEC) based on the aforementioned basic curriculum (Eurydice, 2022). Thus, there are 17 different PE curricula for each of the 17 autonomous communities of Spain. They will soon be rearranged to meet the standards of the new law LOMLOE. Nowadays, autonomous curricula are organised into core and non-core subjects and, within them, blocks are established. Natural Sciences (NatSci) and Social Sciences (SocSci) are core subjects; the first has five blocks: i) introduction to scientific activity, ii) the human being and their health, iii) the living beings, iv) matter and energy, and v) technology, objects and machines; SocSci comprehends the following blocks: i) common contents, ii) the world we live in, iii) to live in society, and iv) traces of time. Thus, the contents related to evolution are approached both in the area of NatSci and SocSci.

Since evolution by natural selection enables understanding the complexity of biological processes and helps to explain multiple socio-scientific issues (Working Group on Teaching Evolution [WGTE], 1998), NatSci and SocSci classrooms are crucial for teaching about this topic. Furthermore, one of the objectives of science education is to aid students in becoming scientifically literate citizens so that they are able to engage with science-related issues, and with the ideas of science, as reflective citizens (Organization for Economic

Cooperation and Development [OECD], 2019). Such a goal requires not only knowledge about scientific concepts and theories but also about scientific practices and how they enable science to advance (Jiménez-Aleixandre & Crujeiras, 2017), as well as being able to apply them in a variety of contexts and situations (De Pro, 2013). Thus, selecting socio-scientific issues that induce the student to intervene to solve them contributes to the development of critical thinking (Blanco López et al., 2017). In fact, Sadler (2005) suggested that students' understanding and acceptance of evolution can significantly influence how they negotiate and resolve socio-scientific issues.

Therefore, teaching must involve students in authentic scientific practices that need to provide opportunities for students to use inquiry skills to generate new ideas in response to questions or problems and to evaluate their validity using arguments based on empirical evidence but also to model outlines in order to generate explanations from the existing evidence (Osborne, 2014). In fact, Gilbert (2004) states that the science curriculum should be structured to facilitate students' progress towards expert modelling status. To achieve it in evolution, a specific progression of ideas is described by the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) of the United States of America, which, like Spain, is part of the OECD. The NGSS are not a curriculum, but a series of objectives and good practices, which include the following core ideas for evolution: inheritance of traits, variation of traits, evidence of common ancestry and diversity, natural selection/artificial selection, adaptation, and biodiversity and people (Vázquez-Ben & Bugallo-Rodríguez, 2018).

Unfortunately, there is a consensus regarding the poor results obtained from compulsory education in many countries in terms of the meaningful learning of evolution (Alters & Nelson, 2002; Smith, 2010). One of the different factors that have been identified as a possible cause is the inadequacy of teaching materials, including textbooks (Demastes et al., 1995; Nehm & Schonfeld, 2007). Thus, although in recent decades the need to moderate the use of textbooks has been highlighted (Del Carmen & Jiménez, 2010), it has been shown that the majority of teachers use textbooks in their classrooms, making them the main source of information available to students and the most used resource in the classroom (Caixeta de Castro Lima & De Souza Silva, 2010). In this sense, teachers find security in them, so they tend to defend their use, because it facilitates teaching as they are a source of organisation, guidance, and consultation and offers material already elaborated in a visually attractive manner for the students (López Hernández, 2011; Monereo, 2010). Furthermore, Kova and Moharthat (2022) indicate that for some types of reading printed texts are better than screens, and interactivity and dynamic design require coherent design to improve reading performance and higher-level thinking skills. Therefore, one of the keys may lie in the choice of a suitable textbook. Indeed, Pavešić and Cankar (2022) observed that there were significant differences in knowledge and attitudes toward mathematics and science subjects in primary schools between groups of students using different textbooks and even revealed that certain contents were not taught in schools because they were not present in outdated editions of textbooks.

The development of scientific skills depends, in addition to good teacher practices (Blanco-López et al., 2015; Lupión-Cobos et al., 2017), on the quality of the textbooks, which are an important mediator of student learning. Therefore, the aim of this work is to assess the weight of evolution and evolution-related terms in both the APEC and the teaching activities proposed by the textbooks of the last three years of PE. More specifically, the following research questions are raised:

- To what extent are evolution and evolution-related terms present in the PE curricula corresponding to all the autonomous communities of Spain?
- What are the characteristics of the activities related to evolution in PE textbooks in both NatSci and SocSci in terms of their dimension, situation in the text, contextualisation, and material necessary?
- What specific skills associated with scientific competence allow these activities to be developed?
- Are there any differences between subjects (NatSci and SocSci) to which the activities are directed regarding the skills they promote?

Method

Analysis of the curricula

Table 1 shows the 17 different APEC for each of the 17 autonomous communities of Spain. Sá-Pinto et al. (2021) described a framework to assess school curricula according to whether the students address the ideas, concepts, and mechanisms that are necessary to understand evolution. However, since the diversity of the APEC documents in terms of their extension and arrangement was high (Alonso et al., 2015), the 'text mining' technique (Kaushik & Naithani, 2016) was selected to assess a global analysis.

As mentioned, the concepts regarding the inheritance of traits, natural selection/ artificial selection, adaptation, and biodiversity are signalled to set the scaffolding, level by level, to the knowledge of evolution by the *Next Generation Science Standards* (NGSS Leas States, 2013). Thus, besides 'evolution', the words chosen to be searched for in the NatSci area of the APEC as respectively representative of the previously mentioned disciplinary core ideas were 'inheritance', 'selection', 'adaptation', 'biodiversity' and 'people'. Since evolution helps to explain many socio-scientific issues (WGTE, 1998) and thus in Spain, the topic of evolution is also included in the SocSci area, the analysis was also driven in the SocSci area of the APEC. In addition, while performing the analysis, the words 'extinction' and 'time' came up, and the authors of this work decided to include them in the analysis: in the case of 'extinction' because of its relationship with biodiversity and in the case of 'time' because evolution involves time. However, the words (and/or their derivatives) were only accounted for when related to evolution; specifically, 'selection' was not considered when it referred to the duty of the students to select information or 'evolution' when referring to the progress of the students.

Table 1

Primary Education curricula per autonomous community and the corresponding decrees

Autonomous Community	Normative
Andalusia	97/2015 Decree of March the 3rd
Aragon	ECD/850/2016 Order of July the 29th
Asturias	82/2014 Decree of August the 28th
Balearics	32/2014 Decree of July the 18th
Canary Islands	89/2014 Decree of August the 1st
Cantabria	27/2014 Decree of June the 5th
Castile La Mancha	54/2014 Decree of July the 10th
Castile and Leon	26/2016 Decree of July the 21st
Catalonia	119/2015 Decree of June the 23rd
Valencia	Decrees 108/2014, of July the 4th and 88/2017 of July the 7th
Estremadura	103/2014 Decree of June the 10th
Galicia	05/2014 Decree of September the 4th
Madrid	89/2014 Decree of July the 24th
Murcia	198/2014 Decree of September the 5th
Navarra	60/2014 Regional Decree of July the 16th
Basque Country	236/2015 Decree of December the 22nd
La Rioja	24/2014 Decree of June the 13th

While performing the analysis, the words 'extinction' and 'time' were seen, and the authors of this work decided to include them in the analysis. As mentioned, the APEC widely differed, also regarding their length. Thus, the frequency with which the selected terms were mentioned was relativised to the addition of the frequencies with which each of the eight terms appeared in each area (Eq. 1) (Ortuzar-Iragorri & Diez-López, 2021).

$$f_{Ri} = \frac{f_i}{\sum_i^8 f_i} \qquad \text{[Eq. 1]}$$

Where f_{Ri} = Relative frequency for the i term in the area.
f_i = Absolute frequency of the i term in the area.

Textbook analysis

In Spain, the first concept in the progression to the evolution model, the topic of human reproduction, is usually addressed from the 4th EP grade onwards. Accordingly, the teaching activities proposed by textbooks for the last three years of Primary Education (9–10-, 10–11, and 11–12-year-old children in the 4th, 5th and 6th grades, respectively) of three widely established Spanish publishers, SM, Santillana, and Anaya, (hereinafter A, B, and C) were analysed (18 textbooks). The textbooks corresponded to the two subjects of interest (NatSci and SocSci).

In total, 105 activities were analysed, distributed, as shown in Table 2.

Table 2
Distribution of the activities analysed according to the editorials and curricular area

Subject	4th grade			5th grade			6th grade		
	Ed A	Ed B	Ed C	Ed A	Ed B	Ed C	Ed A	Ed B	Ed C
NatSci	0	5	11	12	6	16	0	0	13
SocSci	7	3	6	3	1	1	15	1	5

As previously described by García Barros et al. (2021), two aspects were considered for the analysis of the activities: characterisation and scientific skills.

First, for the characterisation of the activities, their length, situation, context and material needed were taken into account (García Barros et al., 2021). Furthermore, taking into account the disciplinary core ideas regarding evolution previously searched in the different APEC, the concept related to evolution that was most present in the activities was analysed.

Second, for the scientific skills that the activities enable to work on, the scientific competence described in the Program for International Student Assessment (PISA) (OECD, 2019) and the skills linked which are related to higher-order cognitive processes (i.e., applying, analysing, evaluating) and to lower-order cognitive processes (i.e., remembering, analysing, evaluating) were considered (García Barros et al., 2021). Specifically, four types of categories were established: a) Type 1: basic cognitive abilities, such as identifying characteristics, establishing relationships, classifying, comparing, and defining; b) Type 2: abilities related to the use of knowledge to describe, explain causes or effects or justify phenomena scientifically using a theoretical model; c) Type 3: abilities related to the search of information, from observation or the use of other sources of information, to the approach to inquiry, the formulation of hypotheses, the design of experiments, carrying out experiments; and d) Type 4: abilities linked to the scientific interpretation of data and evidence (using evidence/data; formulating conclusions and elaborating arguments justifying the validity of an idea or the adoption of behaviour, based on theoretical or empirical knowledge) (Table 3).

The analysis was performed independently by the two authors; when disagreements or doubts arose, they were discussed until a consensus was reached.

When comparisons were made, the Chi-square test (SPSS-version 27) was used, and a significance level of p 0.05 was considered.

Table 3

Criteria used for the analysis of the scientific skills that activities enable to work

	Types	Abilities	Examples
Scientific abilities	Type 1	Identify characteristics	Identify two adaptations of the living being in the photograph.
		Classify	Classify in a table the natural and artificial changes that can destroy ecosystems.
		Compare	Look at the drawings on the two pages. Note the actions that damage the environment (marked with red dots) and indicate the actions taken to repair this damage (marked with blue dots).
		Define	Write in your notebook the meaning of the following: species, endangered, captive breeding, and biodiversity.
	Type 2	Describe facts or phenomena	Look at both pictures and describe the
		Explain/justify	The following images
	Type 3	Observe	Observe the following images and describe....
		Search for information	Find information on what creatures living on a coastline with daily high and low tides have to adapt to.
		Propose hypothesis	What do you think would occur if they were no seas or oceans? Would there be life? Why?
		Design experiments	-
		Experiment	-
	Type 4	Use evidence/data	-
		Formulate conclusions	Explain how the artificial elements and the actions of human beings influence the environment shown in the image and conclude what measures we can take to reduce their impact.
		Elaborate arguments	-

Note. Adapted from García Barros et al., 2021.

Results

Overall, the word 'evolution' was mentioned 11 times in the NatSci area of the 17 APEC. That is less than once per APEC. When it was mentioned, it was usually in the NatSci introductive area of the APEC within the phrase 'The development of Science and scientific activity is one of the essential keys to understanding the evolution of humanity'. Such a phrase refers to the impact of science on humanity rather than to the concept of biological evolution. In the case of SocSci, the word 'evolution' appears 206 times at the 17 APEC. That is 12 times on average per APEC, more than all the times the term was found in the NatSci area of the APEC. However, it refers to the historical, cultural, demographic, and landscape evolution of humans and their settings.

Regarding the words that represent the progression to the evolution model (inheritance, selection adaptation, biodiversity and the terms extinction and time), 'extinction' was, on average, the word whose relative frequency (58.7%) was highest in the NatSci area of the APEC (Figure 1A) followed by 'biodiversity' (18.6%), 'adaptation' (8.2%), 'time' (2.5%) and inheritance (1.8%). 'Selection' (0.0%) was not mentioned in any of the NatSci areas of the APEC. It is also noticeable that while all the other words were not mentioned in some of the NatSci areas of the APEC, 'extinction' was mentioned in all of them, except for Catalonia, at least once. In fact, its relative frequency is 100% in the NatSci area of the PE curricula of two autonomous communities (Madrid and Murcia) (Table 4). As expected, 'extinction' and 'biodiversity' were often found together in Block 3 (living beings) in the sense that the extinction of species causes a loss in biodiversity.

Table 4

Relative frequency with which each of the selected words appears in the autonomous curricula, in the NatSci field and in the SocSci field

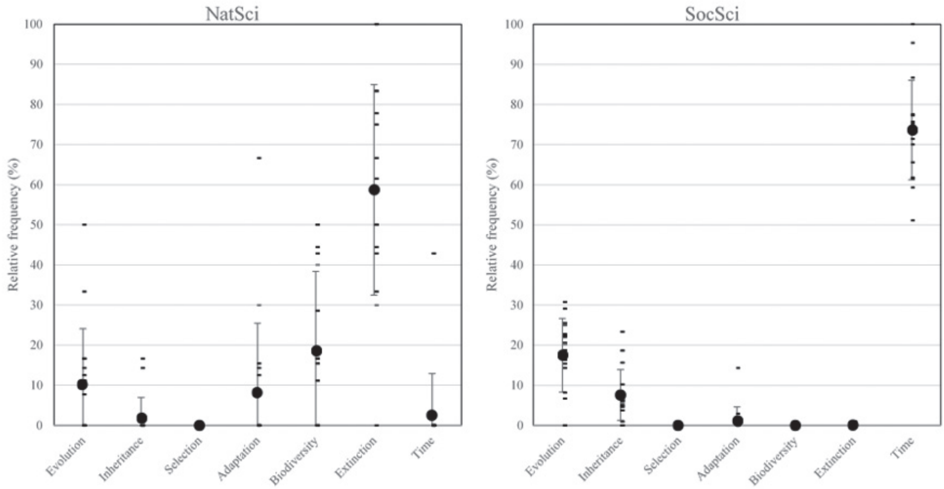
Autonomous community	Relative frequency (%)														
	Evolution		Inheritance		Selection		Adaptation		Biodiversity		Extinction		Time	
	Nat Sci	Soc Sci	Nat Sci	Soc Sci	Nat Sci	Soc Sci	Nat Sci	Soc Sci	Nat Sci	Soc Sci	Nat Sci	Soc Sci	Nat Sci	Soc Sci
Andalusia	14.3	25.6	14.3	23.3	0.0	0.0	0.0	0.0	28.6	0.0	42.9	0.0	0.0	51.1
Aragon	16.7	14.3	16.7	7.6	0.0	0.0	0.0	2.9	16.7	0.0	50.0	0.0	0.0	75.2
Asturias	7.7	30.8	0.0	7.7	0.0	0.0	15.4	0.0	15.4	0.0	61.5	0.0	0.0	61.5
Balearics	0.0	15.4	0.0	10.3	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	0.0	74.4
Canary Islands	0.0	25.0	0.0	5.0	0.0	0.0	0.0	0.0	16.7	0.0	83.3	0.0	0.0	70.0
Cantabria	0.0	18.8	0.0	15.6	0.0	0.0	66.7	0.0	0.0	0.0	33.3	0.0	0.0	65.6
Castile-La Mancha	33.3	20.6	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.9	0.0	74.8
Castile and León	11.1	0.0	0.0	4.6	0.0	0.0	0.0	0.0	11.1	0.0	77.8	0.0	0.0	95.4
Catalonia*	0.0	22.7	0.0	0.0	0.0	0.0	14.3	0.0	42.9	0.0	0.0	0.0	42.9	77.3
Valencia	16.7	8.2	0.0	6.1	0.0	0.0	0.0	14.3	0.0	0.0	83.3	0.0	0.0	71.4
Extremadura	12.5	22.0	0.0	18.6	0.0	0.0	12.5	0.0	0.0	0.0	75.0	0.0	0.0	59.3
Galicia	0.0	20.2	0.0	5.6	0.0	0.0	30.0	0.0	40.0	0.0	30.0	0.0	0.0	74.2
Madrid	0.0	6.7	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	86.7
Murcia	0.0	16.3	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	77.6
Navarra	11.1	22.3	0.0	1.0	0.0	0.0	0.0	0.0	44.4	0.0	44.4	1.0	0.0	75.7
Basque Country	50.0	29.1	0.0	7.3	0.0	0.0	0.0	1.8	0.0	0.0	50.0	0.0	0.0	61.8
La Rioja	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	0.0	100.0

Note. *The areas 'Knowledge of the Natural Environment' and 'Knowledge of the Social and Cultural Environment' in Catalonia are equated to the Natural Sciences and Social Sciences areas, respectively.

Regarding the SocSci area, the relative frequencies of the words that represent the progression to the evolution model were the following: 'time' (73.6%), 'evolution' (17.5%), 'inheritance' (7.6%), 'adaptation' (0.3%), 'extinction' (0.1%), 'selection' (0%), and 'biodiversity' (0%) (Figure 1B). The term 'time' was frequently mentioned within Block 4: *traces of time,* which embeds the word in its title. However, its mentioning refers to demographic, landscape, and cultural evolution, and it might have been accompanied by the very same word 'evolution' itself (i.e., '[…] to initiate students in the knowledge of the construction and **evolution** of societies over **time**, starting from a contextualisation in their closest environment').

Figure 1

Relative frequency of the words in the NatSci and SocSci areas of the autonomic PE curricula and their average value. The bar errors accompanying the average value correspond to the standard deviation.



In relation to the textbooks, Table 5 shows the characteristics of the activities analysed. Specifically, more than 77% of the proposals responded to a reduced format (short questions). The activities were spread evenly across the different topics, although there were generally more activities at the end of each topic than at the beginning or throughout it. In relation to the context, it is interesting to note that, even in the case of SocSci, most of the activities were integrated into an environmental context. As expected, in the SocSci textbooks, there were significantly more activities framed in a socio-technological context than in the NatSci textbooks (90.48% and 79.37%, respectively). Pencil and paper were the material most frequently needed in both topics, followed successively by the use of drawings and diagrams and bibliographic or websites. In general, more material apart from pencil and paper was needed to do the activities from the NatSci textbooks. Finally, only in activities from the NatSci textbooks was practical material needed (Table 5).

Table 5

Descriptive statistics of the characterisation of the activities, core ideas, and type of scientific skills: Relative frequency, χ^2 results and p-values in comparisons of Nature Sciences (NatSci) activities and Social Sciences (SocSci) activities

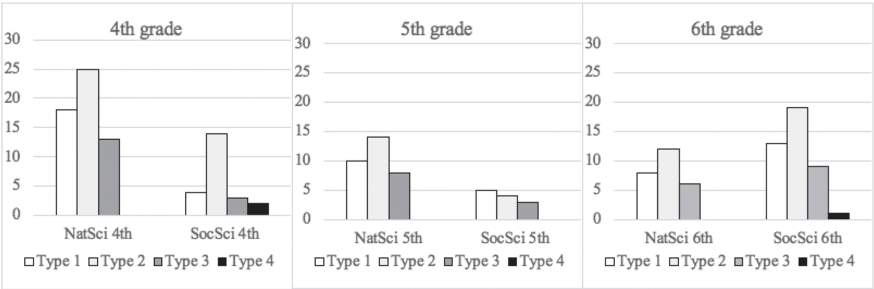
		NatSci (%)	SocSci (%)	χ^2	P
Length	Short	77.78	85.71	1.029	0.310
	Broad	22.22	14.28		
Situation	Initial/Integrated	46.03	30.95	2.388	0.122
	Final	53.97	69.05		
Context	Day to day	9.52	0	4.242	4.242
	Social/technological	25.39	59.52	12.331	<0.001*
	Environmental	79.37	90.48	2.293	0.130
	Academic	17.46	14.29	0.187	0.187
Material needed	Pen and paper	96.83	100	1.359	0.244
	Practical material	1.59	0	0.673	0.412
	Drawings/diagrams	11.11	2.38	2.729	0.099
	Bibliographic material/Webs	12.70	2.38	3.243	0.064
Core ideas	Inheritance	4.76	0	2.059	0.151
	Selection	14.29	7.14	1.270	0.260
	Adaptation	49.21	66.67	3.121	0.077
	Biodiversity	38.10	85.71	23.333	<0.001*
	Extinction	20.63	45.24	7.199	0.007*
Scientific skills	Type 1	57.14	52.38	0.231	0.631
	Type 2	80.95	88.10	0.948	0.330
	Type 3	42.86	35.71	0.536	0.464
	Type 4	0	7.14	4.632	0.031*

With regard to the core ideas, the most present in the activities from NatSci textbooks was 'adaptation' (49.21%) and, in the case of SocSci textbooks, 'biodiversity' (85.71%), whose presence was surprisingly significantly larger than in the activities from the NatSci textbooks (38.10%). 'Inheritance' and 'selection' are the core ideas with less presence in both cases, although there was a slightly higher presence of them in NatSci textbooks than in SocSci textbooks (Table 5).

In relation to the skills promoted by the activities, it can be observed (Figure 2) that Type 2 skills were the most frequent in both subjects, followed successively by Type 1, 3, and 4 skills. In fact, considering that the student can work on one or several types of skills with each activity, most activities included Type 2 skills along with other types of activities in both cases. Although the frequency of Type 4 activities was significantly higher in SocSci than in NatSci, it is interesting to note that, in general, there was hardly any presence of Type 4 activities (0 in NatSci; 3 in SocSci) (Table 5).

Figure 2

Types of scientific skills promoted in the NatSci and the SocSci textbook activities in 4th, 5th, and 6th grades



Discussion

The results of this study show the concept of biological evolution is only slightly present in the APEC in Spain. In the case of NatSci, the term 'evolution' is not included in every APEC; in most cases, it refers to the impact of science on humanity rather than to the concept of biological evolution. The same occurs in the SocSci area, where 'evolution' refers to the historic, cultural, demographic and landscape evolution of humans and their settings. In fact, when analysing the presence of the progression of ideas needed to achieve the evolution model, such as inheritance, selection, adaptation, and biodiversity (Bybee, 2012), we observe an important gap in the construction of the model of evolution in the APEC in Spain. Thus, only the NatSci area covers the topic regarding biodiversity, which represents only the last step of the progression to the knowledge of the NGSS model of evolution (NGSS Lead States, 2013). It should be noted that the idea of selection is not present in any of the areas of any of the APEC, neglecting the aspects of evolution regarding the evidence for shared ancestry, the genetic variation impact on reproduction chances and how natural selection leads to adaptation (Bybee, 2012). These results differ from other countries, such as Sweden, France, England, and the United States, where the core ideas of evolution are included in their EP curricula, and designed progressions are offered in additional official documents (Vázquez-Ben & Bugallo-Rodríguez, 2018). Soon, the APEC will be restructured according to the new Spanish Education law (LOMLOE) and, seemingly, the NatSci and SocSci areas of the APEC will be merged. Such a scenario offers the chance to grasp a deeper view of evolution by studying, in connection, aspects of evolution across topics in areas that were previously disconnected.

In contrast, with regard to the characterisation of the activities, in general, they respond to a short format, mostly at the end of each topic, which requires few resources, with drawings/sketches followed by a bibliography, being the most requested, while specific material for observation/experimentation is hardly necessary. This is in line with previous studies where they observed that, in spite of the changes in format, the textbooks maintain a practically identical structure (Hidalgo Herrera, 2014), with traditional learning processes, in which the exercises are sometimes simple, mechanical, and repetitive and, in many cases, they are limited to filling in gaps, looking at pictures, and copying sentences (Molina Puche & Alfaro Romero, 2019). In relation to the context, most of the activities are integrated into an environmental context. Such fact, together with the fact that the core ideas most present in the NatSci area and the SocSci area are 'adaptation' and the change in 'biodiversity' often as consequences of human activity, seemingly respond to the strong desire to educate children about sustainability in a sustainable manner.

Relegating the evolution to the SocSci area, the topic is addressed from a cultural and social perspective. This may lead to a possible loss of the scientific perspective when addressing the topic, failing to promote the scientific education of citizens in accordance with the social and environmental demands of our times. Indeed, cognitive factors, such as reasoning and perception, influence effective decision making and those with functional scientific literacy will use science content knowledge to make informed decisions (Zohar & Nemet, 2002). Therefore, individuals' conceptions of evolution can alter the manner in which they consider personal and social issues (Brehm et al., 2003) and can also influence socio-scientific decision-making (Sadler, 2005). Thus, understanding evolution is necessary to make effective and informed decisions about socio-scientific issues such as cloning, stem cell research, gene therapy, vaccines, and biodiversity, among others.

Finally, in relation to the types of scientific skills promoted by the activities related to evolution, we observe that the activities mainly promote Type 2 skills, followed successively by Type 1, 3, and 4 skills. In all cases, the skills that are usually prioritised are those corresponding to the lower cognitive level (identify, describe, observe) and higher cognitive skills such as 'design experiments', 'use evidence/data' or 'elaborate arguments' are not present, or they are very scarce in the textbooks analysed. Other studies have emphasised that school textbooks fail to provide students with satisfactory opportunities to promote scientific skills and facilitate a better understanding of scientific ideas and concepts (García Barros et al., 2021; Martínez Losada & García Barros, 2003; Sideri & Skoumios, 2021).

Therefore, considering teaching should provide opportunities for students to use inquiry skills (Osborne, 2014) and apply them in a variety of contexts and situations (De Pro, 2013), the curricula and textbooks activities related to evolution should avoid 'rote' knowledge aimed at 'knowing the world', but not at explaining or investigating it and promote higher cognitive scientific skills.

Conclusions

In conclusion, the APEC in Spain and science textbooks of the fourth, fifth and sixth PE grades have significant gaps when addressing evolution; therefore, they do not provide opportunities for students to develop scientific skills deeply. As Vázquez-Ben and Bugallo-Rodríguez (2018) suggested, if we approach the teaching of evolution too late, learning it will be more difficult. In fact, studies show that students who do not start with certain science topics until secondary school rarely manage to reach the same learning objectives as those who achieved them in primary school (Marco-Bujosa & Levy, 2016). This indicates that helping students to build the model of evolution requires starting at early stages so that they can progress in biological knowledge to be able to make decisions and act correspondingly.

The upcoming restructuring of the APEC contents to accommodate them to the new LOMLOE education law provides the opportunity to update the evolution contents. Such a reformation should include contents and activities on evolution that students can approach both from the SocSci and NatSci areas and require the development of scientific skills.

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Biographical note

Mª Arritokieta Ortuzar Iragorri, PhD, is an assistant professor in the field of didactics of experimental sciences on the Faculty of Education of Bilbao at University of the Basque Country, Spain. She researches on context selection for science teaching in First Childhood, Primary Education and Higher Education to favour the students´ scientific competence as well as sustainability and/or the students' caretaking skills.

Teresa Zamalloa, PhD, is an assistant professor in the field of didactics of experimental sciences on the Faculty of Education of Bilbao at University of the Basque Country, Spain. Her research interests include the teaching/learning of geology (teacher profile, interpretation centers and student attitudes) and the teaching/learning of science (development of scientific competence). Nowadays she investigates on the performance of students in scientific practices so as to develop their scientific competence.

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Analysing the Montessori Principles from the Perspectives of Schools, Teachers, and Families

Aida Macià-Gual[1] and Laura Domingo-Peñafiel*[2]

Education, especially early childhood education, is a responsibility that both families and schools share, so much so that children find themselves in two differentiated learning environments. Educational and parenting styles may join forces, sharing values and behaviours that enhance children's development, just as the Montessori Pedagogy has shown. It is for this reason that the present study will attempt to analyse the relations established between the opinions and the application of the principles of such pedagogy focusing on the first six years of life, both in educational and family environments, considering the degree of commitment the school has towards the Montessori Pedagogy.

Keywords: child development, educational style, Montessori Pedagogy, parenting style

1 Montessori Palau Girona, Spain.
2 *Corresponding Author. Faculty of Education, Translation, Sport and Psychology, University of Vic - Central University of Catalonia, Spain; laura.domingo@uvic.cat.

Analiza načel montessori z vidika šol, učiteljev in družin

Aida Macià-Gual in Laura Domingo-Peñafiel

Vzgoja, predvsem predšolska, je odgovornost, ki si jo delijo družine in šole, in to tako, da se otroci znajdejo v dveh različnih učnih okoljih. Vzgojno-izobraževalni in starševski slogi so se zmožni združiti, deleč si vrednote in vedenja, ki spodbujajo razvoj otrok, kot je pokazala pedagogika montessori. Prav zaradi tega razloga ta študija preiskuje odnose med mnenji in izvedbo načel tovrstne pedagogike, pri čemer se osredinja na prvih šest let življenja v vzgojno-izobraževalnem in družinskem okolju, vseskozi upoštevajoč raven institucionalne pripadnosti pedagogiki montessori.

Ključne besede: razvoj otroka, vzgojni stil, pedagogika montessori, slog starševstva

Introduction

Families and schools are unavoidably connected in their effort to attend to children's education (Hoover-Dempsey et al., 1987) and sociability (Vickers & Minke, 1995). This shared endeavour implies the participation of both parties, whose encounters may be characterised by communicative difficulties (Epstein & Becker, 1982; Paget, 1992). Nonetheless, a path must be found to work collaboratively and harmoniously for the good of humanity (Montessori, 2019). Different pedagogical currents, such as the Montessori Pedagogy, have focused on answering this issue. Their principles were created to facilitate child development on an individual scale (Montessori, 2019) on the basis of a joint effort from families and schools to reach a common objective: the individual development of each child.

Early childhood development is of fundamental importance because the foundations of our future are built on their achievements. Bainbridge et al. (2005) have demonstrated that attention at an early age will influence children's future educational success and their development of emotional and social competences (Kirk & Jay, 2018; Walker, 2010).

Because the Montessori Pedagogy has focused on the relationships between schools and families and on child development, the objective of this article is utilising the Structural Equation Model (SEM) to analyse how the school, the faculty, and the families understand the principles of the pedagogy itself and how they apply them in both the educational and the family environments. Analysed behaviours will be focused on the principles of environment preparation, order influence, freedom of choice, adaptation to society, guidelines of development, and the adult's role.

The relationships between the different individuals who participate in the educational stage will be specified from an eco-systemic perspective (Bronfenbrenner, 1979), and thus, so will the influences existing between the family, the school, and the child. Conversely, the synchrony of educational and parenting styles will be structured around the principles of the Montessori Pedagogy. The article will continue by presenting our selected methodology and will finish with the results, a discussion and the conclusions of the relationships established between the three agents—school, faculty and family—so as to determine the extent of shared work that is being offered in Spanish Montessori schools.

Background of the School–Faculty–Family Relationships

The origin of the school–family relationships varies considering each child individually, as well as the families, the schools and the communities they inhabit (Hoover-Dempsey et al., 1987), since all of them are active agents in the educational endeavour.

Bronfenbrenner (1979) proposed a wider ecological frame with multiple overlapping systems, which affected the course of individual development. Based on this, children develop in a variety of contexts, and in each one, multiple relationships can be analysed at different levels. The level this article will focus on is the mesosystem of family-school, which involves the interactive processes inside and between families and schools (Bronfenbrenner, 1979) and in which we will find the family-teacher sub-system.

Hoover-Dempsey et al. (1987) have shown the importance of positive, high-quality relationships between families and schools as traits that not only favour the development of the child but also maximise their education in sharing a common objective (Christenson et al., 1992; Yaya-Bryson et al., 2020), especially during the early childhood period. However, personal situations and various educational projects may facilitate or complicate the relationship between both agents.

According to Epstein and Becker (1982), family involvement in aspects of education is considerably low. From the families' perspectives, certain facts—such as lack of time, a shortage of opportunities to participate, and the antagonistic, unsympathetic attitudes displayed by the school staff—diminish their involvement in schools (Becker & Epstein, 1982). In contrast, the faculty has difficulties negotiating the academic and social dimensions that are found in the classroom (Walker, 2009), in addition to fearing the assessments made by families regarding their professional competence (Power, 1985), the lack of productive encounters with families, and the absence of outside recognition towards the good practices between families and schools (Becker & Epstein, 1982).

It is clear that education needs to find a space where dialogue between the academic dimension (formed by the school and its faculty) and the social dimension (formed by the families) takes place in order to help the individual growth of every human being (Hoover-Dempsey et al., 1987; Walker, 2009), thereby contributing to the development of society (Montessori, 2009). Benefits such as scholastic achievements, behavioural improvements, decreased school absenteeism, positive attitudes towards school and involvement in domestic chores (Hoover-Dempsey et al., 1987) appear in trusting relationships between families and schools. The children constantly perceive the influence of their immediate surroundings and their encroaching environment, whether from a physical or a social standpoint (Montessori, 2009) and because of this, positive emotions (such as passion and enthusiasm) or negative ones (such as anxiety and deception) shown by adults will impact their learning and development (Zembylas, 2007). Therefore, a quality relationship between teacher and family refers to the existence of a link between both, based on trust (Đurišić & Bunijevac, 2017), mutual insurance, affiliation, support and shared values, as well as expectations and feelings between them and towards the child (Vickers & Minke, 1995), thus creating a unified bond. This union allows them to guide the child towards his or her development through a stable path, in which early childhood education is of fundamental importance because the foundations of our future are built.

Parenting and Educational Practices

Trusting relationships, commitment, and joint work for a sole objective are features found in school-family or faculty-family relationships, as well as in parenting styles.

According to Baumrind (1991), parenting style is a bi-dimensional model of child socialisation in which multiple processes in each dimension exist. In the first dimension, we find *demandingness or control*, which implies expectations, supportive autonomy, and firm behavioural control, so as to demand maturity (Walker, 2009). In the second dimension, we find *responsiveness or nurturance*, which assumes warmth and care, providing resources, and adapting to meet individual needs. Variations between both dimensions create different parenting styles (Walker, 2010), among which we may find: authoritative (high on both dimensions), authoritarian (high demandingness and low responsiveness), permissive (low demandingness and high-moderate responsiveness), and neglectful (low levels of both) (Baumrind, 1991). Generally speaking, the authoritative parenting style is thought of as more successful than the others, since it balances the recognition of the individual's needs with their skill to adapt to expectations (Walker, 2010). Baumrind (1971) demonstrated this when he showed that children from younger ages with higher competence in autonomy, self-control or with successful social skills in school had parents that demanded appropriately from them according to their development; for example, favouring their independence when it came to homework, while at the same time commanding a mature behaviour through skills such as sensitivity, affection, and frequent, accurate communication. Simultaneously, the same sample of subjects was observed during their adolescence and revealed that teenagers who were raised with an authoritative parenting style continued a trend of success when it came to self-control, empathy, understanding of other people's perspectives and inherent motivation. In contrast, children who had authoritarian and permissive parents showed less-than-ideal academic and social results (Baumrind, 1991).

Clearly, the parenting style influences the development of the child. However, Montessori (2009) stated that children absorb everything that surrounds them without any filter during the first three years of life. For this reason, the educational style, the behaviour of the teacher and/or the environment of the classroom may have a significant impact on the individual. Patrick et al. (2005) identified three types of classroom environments: *supportive*, which consists of high expectations for the student and goodwill and respect towards the teacher; *nonsupportive*, in which the teachers emphasise extraneous motives for learning, exercise authoritarian control, and demand that students neither misbehave nor cheat; and *ambiguous*, in which the teachers offer inconsistent attention to the students and present contradictory discourses. These characteristics of classroom environments adapt to the authoritative and authoritarian parenting styles (Walker, 2010).

A perspective that reconciles the dichotomy between parenting and scholastic knowledge is possible. Recent research has shown that teachers and parents are responsible for creating ideal contexts for the development of social and academic skills that favour the command of practices built around performance while also providing individual support to the child and a receptive, appropriately demanding context (Turner et al., 2003; Walker, 2010).

These supportive school environment mechanisms and authoritative parenting styles are possible when a shared objective exists between both parties. The Montessori Pedagogy seeks this alliance through its principles from the early childhood education period, which will be presented next.

The Principles of Montessori Pedagogy

Montessori (2019) argued that the key to child development stems from the internal guidelines that lead him or her towards their highest potential, pushing them towards activities that meet their needs (Lillard, 2018). Education takes place in a prepared environment, designed to attend to children of different ages, in which class materials are created to stimulate their interests and skills through pleasant furnishings, open shelves (Berčnik & Devjak, 2017) and materials unique to specific activities (meaning that only one child can engage with each activity at a time). Kirk and Jay (2018) point out that the creation of a prepared environment is defined by its structure—the physical component—and its process—the psychological component—which belongs to social relationships. The combination and harmony of both parts allow the children to enhance their knowledge both as creative and critical individuals, freely emancipating their talent (İslamoğlu, 2017), leading them to virtuosity. Therefore, the adult in charge of the classroom assumes the role of the guide (Montessori, 2019) since he/she orients and eases the child's development without direct instruction.

The guide is the link between the children and their surroundings. Research has shown that the quality of early child-teacher relationships and the bonds they share with the school may determine their success in education (Reynolds et al., 2009). Furthermore, the behaviour of the teachers towards the creation of a positive emotional and social environment may further the social-emotional competences of young children (Heller et al., 2012; Kirk & Jay, 2018). Consequently, Montessori (2019) pays special attention to the training of adults, since they are responsible for guiding the children's development. Therein lies the interdisciplinary nature of pedagogy, since it recognises the individual learning process of the child and the educational experience of the guide (Knewstubb & Nicholas, 2017).

The classroom rewards constructive decision-making and freedom of choice within certain limits (Gross & Rutland, 2019; Lillard, 2018) in order to aid the formation of critical individuals from early childhood education. Autonomy and independence continue throughout the school day, since children participate in real-life activities, favouring the acquisition of necessary everyday skills that will help them adapt to the society in which they live. Bone (2017) postulates that the mere fact of participating in such activities will promote long-term perseverance as children have the will to take part during the first six years of life. Furthermore, autonomy is known to be instrumental in setting the basis of responsibility in an individual's actions (Devjak et al., 2021).

The environment is designed considering the concept of order, since external order can create an internal order in the minds of the children (Montessori, 2019). The sets of materials are located in specific areas, which leads to the development of skills such as consideration, theory of mind (Lillard et al., 2017), tolerance (Gross & Rutland, 2019), self-control and respect for others as well as for the natural environment (Montessori, 2019), all of which constitute elementary attitudes for humanity.

On the basis of these principles, we can observe that a supportive environment is offered for the child's development, while at the same time, the child's skills match the ones elicited from an authoritative parenting style. This union will guide our research question: to what extent is there a relationship between the opinions of the school, the faculty and the family and the application of Montessori principles in the educational and family environment?

Method

It is the purpose of this study to determine and examine the relationship between schools that work under the Montessori Pedagogy in Spain, the opinions of the faculty and the families regarding the principles of such pedagogy and the application of said principles in an educational and family environment through the use of SEM. The hypotheses are as follows:

1. Teachers with opinions closer to the Montessori principles who apply them in a stricter manner will belong to the schools with a higher degree of commitment to the Montessori Pedagogy.
2. Families that come from schools with a higher degree of commitment to the Montessori Pedagogy will have higher opinions of the method and will adapt it to their own style with more ease.
3. The schools with a higher commitment will greatly value the development of harmonisation between faculty and families, and thus their opinions and behaviours will be very truthful to the principles of the Pedagogy.

The data obtained comes from three sources: schools, which have provided information as to the degree of commitment they have towards the Montessori Pedagogy; teachers, who have provided information regarding their opinions of the Montessori principles and how they are applied in their classrooms; and families, who have provided information regarding their opinions of the Montessori principles and how they are applied in their homes.

Considering our type of analysis and the different levels that we will examine, the use of SEM is required, since it will aid in the hierarchical structuring of data in such a way that, for example, families located in Level 1 (L1) will be nested with the teachers located in Level 2 (L2) of each typology of school, thus creating the possibility of analysing relations between the variables of two levels of examination.

Participants

A total of 16 private Spanish schools that work according to the principles of the Montessori Pedagogy have participated in this research, seven of which are part of the Spanish Montessori Association (AME) and have already achieved a set standard of commitment to the Montessori Pedagogy. However, it is important to highlight the fact that the dimensions of the schools vary considerably among themselves (see Table 1), since they offer different school courses (one school offers preschool education for ages 0 to 3; seven schools offer preschool education for ages 0 to 6; one school offers preschool education for ages 3 to 6 and primary education; and seven schools offer the entire preschool and primary education cycle); therefore, the volume of subjects fluctuates.

Table 1

Families and faculty participants

School code name	Participants		
	Faculty	Families	Total
S1	59	100	159
S2	4	14	18
S3	4	19	23
S4	5	32	37
S5	8	56	64
S6	6	33	39
S7	11	53	64
S8	8	38	46
S9	4	8	12
S10	2	10	12
S11	11	27	38
S12	2	7	9
S13	2	2	4
S14	0	5	5
S15	3	10	13
S16	2	2	4
Total	**131**	**416**	**547**

A total of 547 subjects responded to the questionnaire; 17 were discarded since they neither worked at a Spanish Montessori centre nor had children studying in a Montessori school. The family sample displays that 8.17% know the Montessori principles fairly well, 68.51% say they know them well, 22.84% say they know them a little, and 0.48% say they know them very little. Regarding the academic background of the faculty, we can see that 48.85% of them have a guide's degree recognised by the Asociación Montessori Internacional

(AMI), 5.34% have a guide's degree recognised by the Instituto Montessori Internacional (IMI), 3.05% have guide certifications from various courses and associations, 0.76% have an assistant's degree from AMI, and 41.98% do not have a Montessori-related degree. Regarding faculty members, 0.76% are part of a managing team, 57.25% perform the role of guides, 27.48% perform the role of assistants, 10.69% are music, physical activity or psychology specialists, and 8.4% are or have been interns in the selected educational centres. Regarding family members, 8.41% have a secondary education, 7.21% have a high-school degree or equivalent, 52.4% have a university degree, 26.92% have a master's degree or a postgraduate degree, and 5.05% have a PhD.

In both groups, higher female participation is noticeable (81.25% of the families and 88.55% of the faculty who responded are women), as is their similar age average (41.24 years old in families, 39.35 in the faculty). The average number of children per family is 1.5, mainly between the ages of 0 and 6 years.

Instruments

The assessment of each school's commitment to the Montessori Pedagogy was obtained through the questionnaire, which was based on the items utilised by the AME when granting certifications and on the enhancement of various principles. This offered schools an opportunity to add relevant information regarding their methodology and, at the same time, allowed us to detect the degree of commitment that each school had towards their faculty and their families, since it is the objective of this research to evaluate both subjects. This instrument allows us to sort schools into three different categories: very high commitment (5 schools), high commitment (5 schools) and moderate commitment (6 schools) to the principles of the Montessori Pedagogy.

In order to determine the opinions regarding the principles of the Montessori Pedagogy and how said principles are applied according to faculty and families during early childhood, two separate questionnaires were created with an equivalent number of questions and contents, with the wording of the possible behaviours in the family or educational environment being slightly modified.

The questionnaire is composed of three blocks: specific information of the respondent, questions regarding their opinions of the Montessori principles, and questions related to the application of said principles in school or at home during early childhood. The last two blocks are scored according to the Likert scale (5, strongly agree; 4, agree; 3, neither agree nor disagree; 2, disagree; 1, strongly disagree). The respondents who showed a predisposition towards applying the Montessori principles by selecting the strongly agree or agree options were asked to elaborate on their answers so as to identify how they applied said principle, a helpful analytical tool since it provided information about predominant behaviours and attitudes. Each block is scored according to the total number of evaluated items, thus offering a maximum score of five points per item. Doing so meant that every subcategory is formed by different scores, which is an aspect that was taken into account in the final data analysis. In the opinions block (85 points), the information collected is divided into guidelines (15 points), environment preparation (25 points), order influence (10 points), freedom of choice (5 points), adaptation to society (15 points) and the adult's role (15 points). In the application block (65 points), the collected opinions concern the subject's behaviour, which is why the data is divided into respect for internal guidelines (5 points), environment characteristics (40 points), and adult characteristics (20 points).

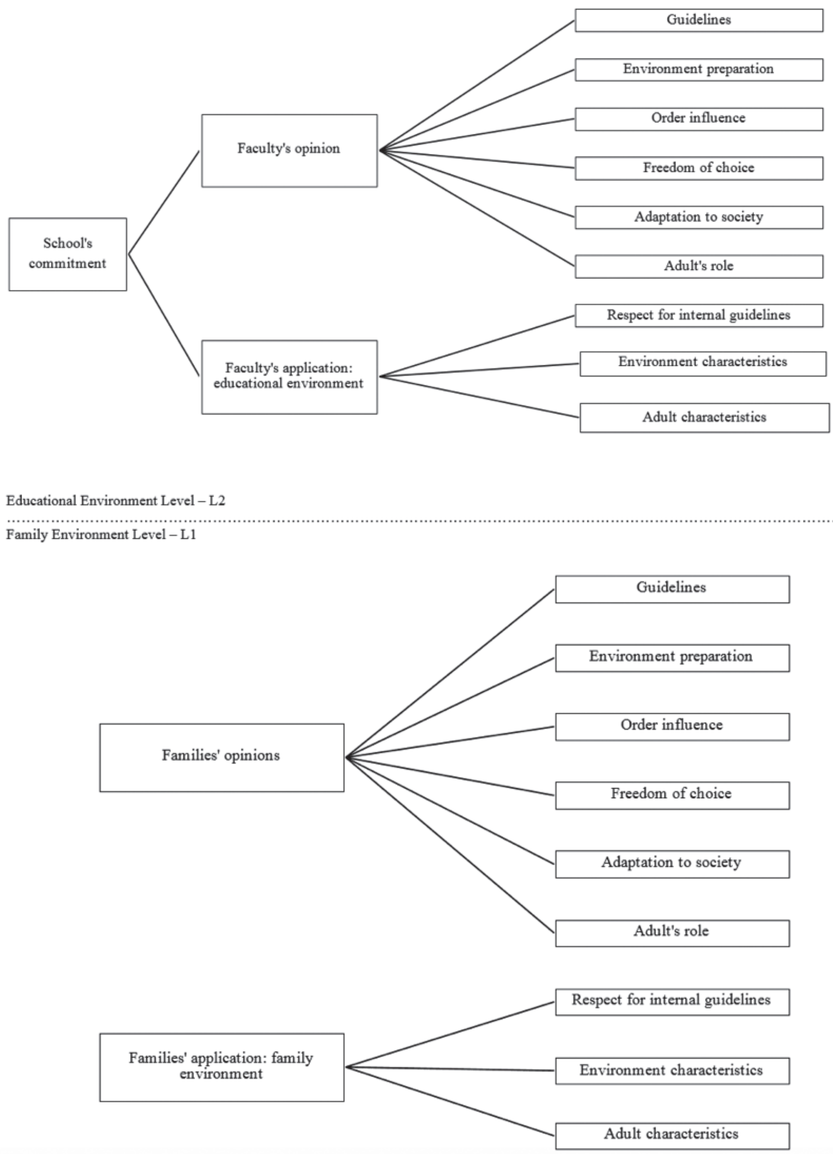
Experts have assessed the validity of the questionnaire content during its creation and administration, scoring a .823 on Cronbach's Alpha, a result that ensures high reliability.

Before the questionnaire was applied, a pilot test was performed on 20 subjects (7 Montessori teachers, 7 families with children in Montessori schools, and 6 families with children who had already finished their schooling in a Montessori centre). Assessments were made regarding the wording of certain items, and later such items were modified for easier comprehension.

The questionnaire was administered in two different contexts: the educational environment and the family environment. Doing so led us to use SEM to answer our research question. Figure 1 shows the relations considered in this model, a set of conditions that allow correlations to be found between both contexts.

Figure 1

Analysed categories between both levels



Note. The subcategories agree with the principles of the Montessori Pedagogy analysed in the conceptual framework.

Considering that the set of participant schools have been grouped according to their commitment to the principles of the Montessori Pedagogy, each situation has been examined independently in order to offer a result comparison for each one.

Results

The use of SEM enables analysing the relations established between both studied levels. However, we must consider that the schools are organised in regard to their fidelity to the Montessori Pedagogy. This dictates that the following results be organised in two ways: first, an outlook according to each analysed context in which the three possible types of schools are considered; and second, an analysis of both studied levels that presents the correlations between the variables of opinion and application according to the faculty and the families.

To determine whether statistically significant differences exist between the three types of schools, regarding the dimensions that compose the opinion and application of the principles in both faculty and families, a single factor ANOVA was performed for independent samples.

The assumption of normality and homoscedasticity was tried with the Kolmogorov, Smirnov and Levene tests, respectively, by which we were able to observe that both assumptions were not met ($p < .05$). Nonetheless, a parametric ANOVA was performed, given the fact that our sample size was statistically meaningful ($N = 547$). The Brown-Forsythe test was administered to evaluate the parity of the medians taken, since we had an uneven group size.

Faculty

Considering the dependent variable of the faculty and each independent variable composed by the evaluated subcategories, we can see statistically significant differences between schools in the following subcategories: Guidelines, Environment Preparation, Adult Preparation, Environment Characteristics, Adult Characteristics, and Respect for Internal Guidelines. Statistically significant differences can also be seen in the general categories of Opinion and Application of the Montessori Pedagogy principles (see Table 2). No statistically significant differences are found between schools regarding the subcategories of Order Influence, Adaptation to Society, and Freedom of Choice.

After applying Bonferroni's Post Hoc test, we determined that significant differences exist between groups. In the Guidelines subcategory, we can see differences between the Very high commitment group and the High and Moderate commitment groups. No significant differences can be found between the

High and Moderate commitment groups (p > .05). The same results can be seen in the Environment Preparation, Adult Preparation, Environment Characteristics, and Respect for Internal Guidelines variables.

The Adult Characteristics variable only finds significant differences between the Very high commitment and the High commitment groups, whereas the Opinion and Application totals from the faculty show significant differences between the Very high commitment group and the High commitment and Moderate commitment groups.

Table 2

Medians, standard deviations and single-factor ANOVA for the school, as per the subcategories of Opinion and Application, according to the faculty.

Variables	Very high commitment		High commitment		Moderate commitment		ANOVA	
	M	SD	M	SD	M	SD	F (df1; df2)	Post Hoc
Guidelines	13.6	.94	12.7	1.43	12.5	1.84	9.83 (2;128)	1>2.3 ***
Environment P	23.65	.85	22.12	1.28	22.50	1.57	25.07 (2;128)	1>2.3 ***
Adult P	18.75	.96	15.96	2.21	16.45	2.30	42.33 (2;128)	1>3.2 ***
Environment C	38.58	1.78	36.41	1.83	36.35	2.32	21.09 (2;128)	1>2.3***
Adult C	14.32	.68	13.41	1.17	13.80	1.10	12.24 (2;128)	1>2.3
Respect for IG	4.83	.38	4.23	.42	4.35	.48	28.62 (2;128)	1>2.3 ***
Opinion	78.86	2.79	72.92	5.11	74.15	6.01	28.63 (2;128)	1>3.2 ***
Application	57.73	2.13	54.06	2.82	54.50	3.47	29.69 (2;128)	1>3.2 ***

Note: *** p ≤ .001; *M* = median; *SD* = standard deviation; *df* = degrees of freedom. Environment P = Environment Preparation; Adult P = Adult Preparation; Environment C = Environment Characteristics; Adult C = Adult Characteristics: Respect for IG = Respect for Internal Guidelines; Opinion = Faculty Opinion; Application = Faculty Application.

Families

The relationships established between the families and the subcategories' variables indicate that statistically significant differences exist between them in relation to the following subcategories: Order Influence, Adaptation to Society, Environment Characteristics, Adult Characteristics and Respect for Internal Guidelines. Statistically significant differences can also be seen in the general category of Application (see Table 3). Conversely, no statistically significant differences can be found between families regarding the subcategories of Guidelines, Environment Preparation, Adult Preparation and Freedom of Choice.

We determined significant differences between groups after administering Bonferroni's Post Hoc test, which shows that the Order Influence subcategory displays differences between the Very high commitment group and the High and Moderate commitment groups, the first one having registered the highest median in the said variable. However, no statistically significant differences can be found between the High commitment and Moderate commitment groups (p > .05). Similar results can be observed in the Environment Characteristics variable. In the Adaptation to Society variable, significant differences can only be found between the Very high commitment and the High commitment groups, and in the Adult Characteristics variable, significant differences are found throughout all families, the Very high commitment group having registered the highest median.

Finally, in the Respect for Internal Guidelines variable, differences can be found between the Very high commitment and the High commitment groups. No significant differences were found between the rest of the groups (p > .05).

Table 3

Medians, standard deviations and single-factor ANOVA for the school, as per the subcategories of Opinion and Application according to the families

Variables	Very high commitment		High commitment		Moderate commitment		ANOVA	
	M	SD	M	SD	M	SD	F (df1; df2)	Post Hoc
Order I	9.03	1.01	8.64	1.14	8.71	1.09	6.23 (2;413)	1 >3.2 ***
A Society	13.10	1.36	12.79	1.45	12.47	1.94	4.62 (2;413)	1>2.3 ***
Environment C	33.13	3.08	31.48	3.49	31.32	3.82	13.32 (2;413)	1>2.3***
Adult C	12.94	1.23	12.16	1.41	11.64	1.46	27.71 (2;413)	1>2.3***
Respect for IG	4.22	.54	4.03	0.70	4.21	.40	4.93 (2;413)	1>3.2 ***
Application	50.29	4.05	47.68	4.54	47.16	4.86	21.15 (2;413)	1>3.2 ***

Note: *** p ≤ .001; *M* = median; *SD* = standard deviation; *df* = degrees of freedom. Order I = Order Influence; A Society = Adaptation to Society; Environment C = Environment Characteristics; Adult C = Adult Characteristics; Respect for IG = Respect for Internal Guidelines; Application = Families Application.

Studied levels

In order to prove the hypotheses related to the faculty and the families, the Pearson correlation was performed to study the opinion and application of the principles of the Montessori Pedagogy in each group of schools. According to the obtained results, a statistically significant correlation between the opinion and the application was apparent in Very high commitment schools (r = .58; p < .05), in High commitment schools (r = .32; p < .05) and in Moderate commitment schools (r = .43; p < .05). In all cases, the correlation is positive and moderate.

Considering this, the relation established between opinion and application was studied at every level (faculty and families), separated by the type of school. According to the faculty results, only one statistically significant correlation was found between the opinion and the application in the Very high commitment group ($r = .73$; $p < .05$), with the correlation being both positive and high. Nevertheless, in the High commitment and Moderate commitment groups, no relation was found between the opinion and faculty variables.

According to the families' results, statistically significant correlations were found in the three types of schools between the opinion and application variables, with all cases having positive and moderate correlations (see Figure 2).

Figure 2

Established correlations in different studied levels

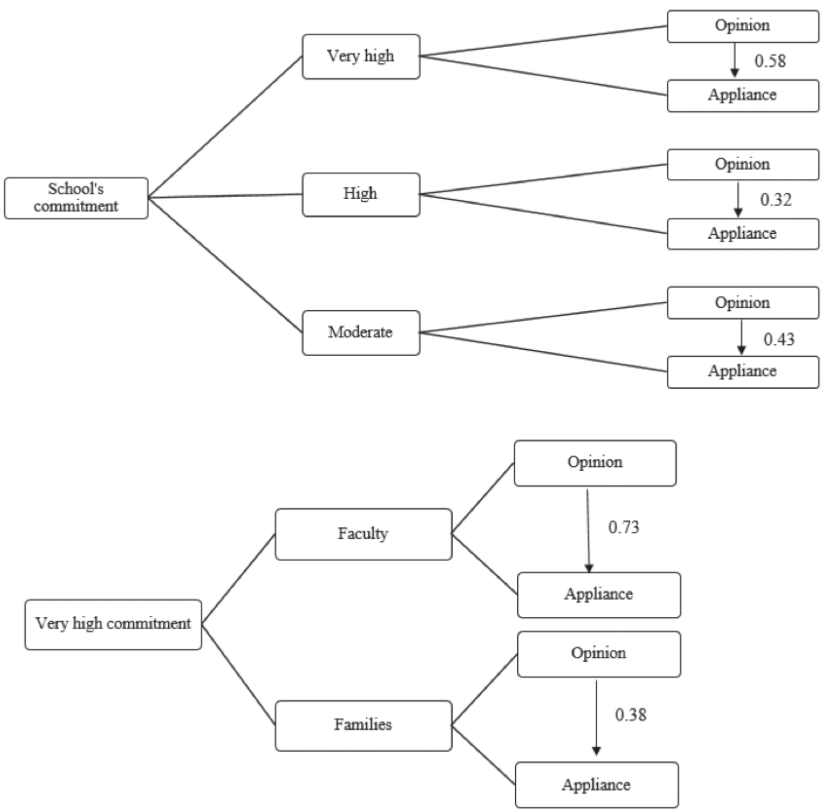
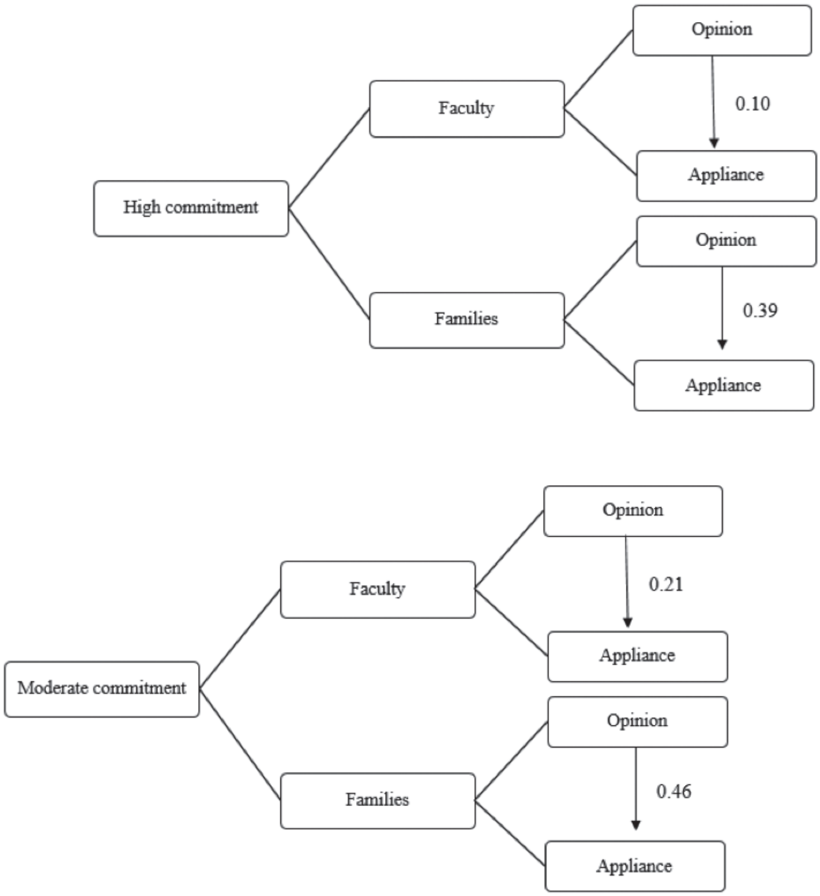


Figure 2
Continue



Discussion

The purpose of this study is to examine the relationship established between schools that apply the Montessori Pedagogy, the opinions of their faculty and their families, and the behaviour that educational and family environments display.

The three formulated hypotheses stated that a higher degree of commitment from the school, both from faculty and families, meant higher results in opinion and application of the principles of the Montessori Pedagogy during the early childhood period. Therefore, a decrease in opinions and application, both from faculty and families, would be shown in schools with a lower commitment.

The results show that this relation is not directly fulfilled. The schools with a higher faithfulness towards the Montessori Pedagogy score higher in opinion and in application in both faculty and family. However, the scores do not decrease with a lower school commitment, since both the faculty and the families of the other school types had similar results. Despite the differences between faculty and family, we can see a clear interest from both parties in applying the principles of the Montessori Pedagogy. The analysis of the qualitative data presented by the faculty and by the families shows that the principles can occur in an educational and familiar context. In the case of the families, they adopt an authoritative parenting style (Walker, 2010), where the child shows himself or herself to be an active, autonomous, and participatory agent inside the household, whereas in the case of the faculty, the principles are applied in the classroom, thus creating a supportive environment (Patrick et al., 2005). In the latter, the teacher maintains a firm demeanour, perceiving the child as an independent being who is responsible for his or her actions despite their young age. Both the supportive environment (Patrick et al., 2005) and the authoritative parenting style (Walker, 2010) place the child in the same area while the adult adopts attitudes that encourage respect and guide the child in his or her development, all of which are indispensable principles of the Montessori Pedagogy. Hence, we can see a similarity between both styles and environments, since the respondents have shown that diverse principles of the Montessori Pedagogy can appear in both contexts. The existence of this union between contexts proves that a feeling of mutual insurance and shared values exists between the educational and family environments (Vickers & Minke, 1995). However, the adult's attitude towards addressing each child individually (Montessori, 2019) must continue to be developed, since families have difficulties when it comes to attending to diverse day-to-day situations and to offering a conditioned space that meets the child's needs.

In contrast, our first hypothesis, which indicated that 'teachers with opinions closer to the Montessori principles who apply said principles in a stricter manner will belong to the schools with a higher degree of commitment to the Montessori Pedagogy', was not fulfilled. To answer this hypothesis, the categorisation of schools has not only helped their verification but also shown that the faculties of High and Moderate commitment schools have the same opinions and applications of the principles. The difference in results between both types of schools is minimal, whereas in the Very high commitment schools, the faculty (M = 78.86 in opinion) firmly believes in the Montessori principles and that their application (M = 57.73) in the classrooms is higher.

The achievement of such principles in the classroom implies an adaptation of the environment on physical and social levels (Kirk & Jay, 2018), attending to the children who inhabit it and respecting the internal guidelines (Montessori, 2019). At the same time, the faculties in every school favour participation in real-life areas, including care of the environment and of the person, freedom of opinion, of thought and of choosing the tasks to be performed (Lillard, 2018). Nonetheless, the analysis of the qualitative data presented by the faculty indicated difficulties in the understanding of the outside environment as a workspace, an aspect that may be related to the structure of each school.

Differences exist among the opinions and applications of the Montessori principles. Both the faculty and the families maintain a respectful attitude towards the principles when voicing their opinion but present diminishing results when translating their opinions into behaviours. The faculty of High and Moderate commitment schools had lower scores in their beliefs regarding the Montessori principles. By contrast, the faculty of Very high commitment schools exhibited a high and positive correlation ($r = .73$; $p < .05$), a result that shows that a devoted opinion towards the Montessori Pedagogy can bring about attitudes and behaviours more aligned with the pedagogy.

The qualitative analysis reveals that all faculties understand the adult's role as a guide (Montessori, 2019); however, in schools with a Very high commitment, the competences of the guide to respond to the needs of each individual and to prepare the environment are better suited. Furthermore, this type of school offers wide, varied and continuous training for its staff: an aspect that aids in their continuing to improve their early childhood educational practices. In comparison, schools with a High commitment offer specific training activities, and schools with Moderate commitment offer none. This continuous training offered by the school gives their faculty clearer, more concise opinions towards the pedagogy, which also allows them to translate their opinions into educational practices.

In the case of the families, the results in the opinions block show us that there are no statistically significant differences between them, which leads us to observe that, regardless of the degree of commitment of their schools, their opinions are the same. The analysis of qualitative data indicates that all families rely on self-preparation and are thus interested in continuously informing themselves on the aspects related to early childhood development. Schools with very High commitment offer continuous training activities for them, whereas other types of schools offer little or none. This shows that the very High commitment schools create positive, quality relationships in both contexts (Hoover-Dempsey et al., 1987). This aspect promotes a constant collective endeavour, focused on the creation of shared environments and attitudes for adults, which favours the children's development and maximises their education (Christenson et al., 1992). In working together, both environments are in sync, and the interactive processes of both schools and families (Bronfenbrenner, 1979) are equally represented before the child.

The application of the Montessori principles in the family environment decreases when the child is enrolled in a lower commitment school. According to the information provided by the families, the environment tries to respond to the needs of the children, but their involvement in day-to-day activities is focused on caring for themselves. To a smaller extent, children can participate in activities that involve cooking or caring for their environment at a young age. However, Hoover-Dempsey et al. (1987) highlighted the importance of the children's involvement in these domestic chores. They establish a bond with the schools (Vicker & Minke, 1995), since it is there they will have an opportunity to participate in activities that allow them to adapt to society (Montessori, 2019).

Based on our research, families are the subjects that establish the most positive correlations in terms of thinking and acting. When their thoughts are faithful towards the Montessori Pedagogy, so are their behaviours. Therefore, schools must offer training for them in order to present spaces that encourage dialogue and deliberation. This allows both parties to reflect on their own practices and to strengthen the bond of trust they have with the children when participating in domestic chores with accurate communication, also improving undervalued aspects of the questionnaires that favour autonomy, competence and social skills (Baumrind, 1971).

Another aspect that the faculty and the families must consider is the fact that the characteristics of their environment will be transferred to the child. The creation of an environment that responds to the needs of the child (Montessori, 2019) is apparent in both contexts, whilst grace, courtesy and social relationships between adults are some traits that need to be developed. The qualitative analysis shows deficiencies when recognising good from bad practices, both from themselves and from other adults, which is why, in order for the child's education to be front and centre, communicative adults with shared interests are a must.

When generally analysing the application of the Montessori principles block, it becomes apparent that statistically significant differences exist both in the faculty and the families' variables, something that is highly related to individual and familiar situations, and to the school settings where the teachers are. This verifies that the use of SEM in social analysis is highly valuable, since it allows us to interpret each level separately and aids our understanding of the relations established between each variable. The analysis of individual situations is configured by a myriad of variables, which SEM both establishes and relates to each other, in so revealing the comprehension of society's own hierarchies. In this case, it showed that particular situations and our own thoughts impact our behaviours and, consequently, the way we address early childhood education and sociability.

As the study shows, a mutual path between families and schools is possible, and the shared endeavour of education, especially in early childhood development, is vital to both. Bainbridge et al. (2005) indicated that attention during the early years will influence a child's future educational success and his or her development of emotional and social competences (Kirk & Jay, 2018; Walker 2010); hence, spaces for communication must exist in both contexts since they will have a direct influence on the child's development. The union of the Montessori principles both in educational and family environments will create shared values, shared objectives, and shared concerns that will guide the child with harmony, respect, and positivity, all of which are essential assets for the creation of autonomous, independent beings in society.

Limitations and Conclusions

The present study focuses on the analysis of the principles of the Montessori Pedagogy in Spain, both in families and faculty considering early childhood education. The results show that a collective work between them exists and that both care for the child's education: an education concentred on the rounded development of children, favouring their participation in day-to-day activities, allowing them to gain autonomy and independence, making them responsible for their actions and offering them the chance to express themselves and to take decisions. These characteristics are stronger in schools with a higher commitment to the principles of the Montessori Pedagogy. Nevertheless, it is the interest of all participants that the child be educated and attended to, so the preparation of the environment and of themselves is fundamental. Reflecting on their attitudes and creating spaces that respond to the needs of their children is possible as long as a collective effort exists between the schools and the families, as shown in Very high commitment schools.

Considering that the child's education is the main objective of families and schools, one limitation would be the selection of schools that exclusively apply the Montessori Pedagogy principles. In Spain, there is a great diversity of schools and family contexts; for this reason, expanding the number of schools and families that participated in this study would provide more comprehensive, varied data.

In contrast, the present research was restricted by the limited bibliography related to the usage of SEM when studying educational and family practices. This analytical method is currently receiving diverse contributions, which assist the growth of its literature and its appliance in social contexts.

Presently, the existing bibliography lacks analyses focused on the relationships established between schools, families, and children. Consequently, it would be interesting to research how the links that influence the development of the child are formed between the family and the educational contexts. Novel analytical methods, such as Multilevel Structural Equation Modelling (MSEM), could enable the analysis of each level that composes a single context, which is why it would benefit this future line of research, favouring the interpretation of the relations established between each level. This would greatly promote a higher and richer understanding, ultimately ensuring the consideration of different variables and the relations established among them.

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Biographical note

Aida Macià-Gual, PhD student on the Faculty of Education, Translation, Sport and Psychology at the University of Vic - Central University of Catalonia. She is also a Montessori guide from 0 to 6 years old in Montessori Palau Girona (Spain) and an active researcher. Her interests include family and school transitions, school adaptation, inclusion, Montessori Pedagogy and executive functions in ages between 0 to 6 years old.

Laura Domingo-Peñafiel, PhD, is a lecturer in the field of Pedagogy on the Faculty of Education, Translation, Sport and Psychology at the University of Vic - Central University of Catalonia. She is also researcher of the GREUV - Educational Research Group at the UVic-UCC. Her main areas of research interests are: training teachers, inclusion, democratic and rural schools. It is focused on multigrade and place-based teaching in a rural education framework.

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Deficits in the Socio-Educational School Inclusion Strategy for Students with Social Difficulty in Spain during the Covid-19 Pandemic

Deibe Fernández-Simo*[1], Xosé Manuel Cid-Fernández[2] and María Victoria Carrera-Fernández[2]

Students with administrative care measures have historically faced difficulties in achieving school goals. The Covid-19 pandemic forced the declaration of a lockdown, which accelerated changes in the schools' pedagogical actions. This investigation analyses the strategies used by the educational system to promote the academic inclusion of students who have an open protection file in the child welfare system within the context of Covid-19. Two different phases are compared: Phase 1) from the March lockdown to the end of the 2019/20 school year; Phase 2) The first six weeks of the beginning of the 2020/21 school year. Longitudinal follow-ups were carried out with adolescents in care with a sample of N = 10 (Phase 1) and N = 11 (Phase 2). Based on the grounded theory, information is supplemented by case studies through interviews with educational professionals, N = 14 (Phase 1) and N = 11 (Phase 2). The results indicate deficits of schools' adaptability to the situation of the students suffering social exclusion and difficulties in monitoring when students do not attend school in person and do school activities at home. It is concluded that the design of the educational policy applied in the context of the pandemic does not take the social factor into account.

Keywords: child welfare, social exclusion, disadvantaged schools, educational opportunities, Covid-19, inclusion

1 *Corresponding Author. University of Vigo, Spain; jesfernandez@uvigo.es.
2 University of Vigo, Spain.

Primanjkljaji v strategiji vključevanja socialnoizobraževalnih šol za srednješolce s socialnimi težavami v Španiji med pandemijo covida-19

Deibe Fernández-Simo, Xosé Manuel Cid-Fernández in María Victoria Carrera-Fernández

Srednješolci, deležni ukrepov administrativne oskrbe, so se že v preteklosti srečavali s težavami glede doseganja učnih ciljev. Pandemija covida-19 je povzročila razglasitev zaustavitve javnega življenja, kar je pospešilo spremembe v pedagoškem delovanju šol. Ta raziskava analizira strategije, ki so jih uporabili izobraževalni sistemi, za spodbujanje akademskega vključevanja adolescentov, ki imajo odprt status varovanja v sistemu varstva otrok znotraj konteksta covida-19. Pri tem primerjamo dve različni fazi, in sicer: fazo 1) od marčevskega zaprtja do konca šolskega leta 2019/20; fazo 2) prvih šest tednov začetka šolskega leta 2020/21. Longitudinalna nadaljnja spremljanja so bila izvedena z mladostniki v oskrbi z vzorcem $N = 10$ (faza 1) in $N = 11$ (faza 2). Upoštevajoč utemeljeno teorijo, so podatki dopolnjeni s študijami primerov, ki smo jih izvedli prek intervjujev s pedagoškimi strokovnjaki, $N = 14$ (faza 1) in $N = 11$ (faza 2). Izsledki nakazujejo primanjkljaje v zmožnosti šol po prilagajanju na položaj mladostnikov, ki trpijo za socialno izključenostjo, in na težave pri spremljanju, kdaj se ne udeležijo pouka v živo in raje opravijo zadolžitve doma. Ugotavljamo, da načrt izobraževalne politike, ki je bil uporabljen v kontekstu pandemije, ne upošteva socialnega dejavnika.

Ključne besede: varstvo otrok, socialna izključenost, prikrajšane šole, možnosti izobraževanja, covid-19, vključenost

Introduction

Due to their social vulnerability, adolescents with administrative care measures present specific difficulties that facilitate their school exclusion. These are minors for whom the public administration has to take protective measures to guarantee their right to grow up in an appropriate environment in which their personal needs are met. Their biological families do not provide the support and care that young people need. It is common for these adults to act negligently, so minors do not have the family and social support that are available to their peers. Traditionally, such minors have remained invisible in government statistics, so no official data are available on the academic evolution of vulnerable students. However, previous research has indicated that the drop-out rate of this group is a cause for concern (Sebba et al., 2015; Stott, 2013). Adolescents in care achieve a lower level of education than their contemporaries (Casas & Montserrat, 2009; Miguelena et al., 2018), presenting as greater school exclusion (Martín et al., 2008).

The NGOs responsible for the care of these adolescents warn of the worrisome situation of this group in the educational system. IGAXES (2018), an organisation responsible for the programme of transition from the protection system to adult life in Galicia, notes in its report that, in 2010–2017, 80% of the protected youth over 16 years of age did not hold the title of Secondary Education (basic education). The data presented are obtained from a large sample of 3,680 youths with an active protection dossier. The data for 2017 indicate that 43.06% were enrolled in the 3rd grade of the Certificate of Secondary Education (CSE) and showed academic delay. Repeating a course is an indicator of educational exclusion (Bolívar & López, 2009). The 'Jóvenes e Inclusión' (Youth and Inclusion Federation (2016), to which key NGOs working in socio-educational accompaniment with adolescents in care in Spain belong, notes that 75% of students with administrative protection measures do not pass their compulsory studies.

The alarming educational situation of this group may be aggravated by the emergence of the Covid-19 pandemic. During the first lockdown, adolescents in care suffered increased difficulties in the supervision of their academic activity (Fernández-Simo et al., 2020). The educational system has severe deficits in supporting the most vulnerable students. In crises, students at risk of social exclusion suffer the most significant consequences. In this context of widespread uncertainty, the public administration must develop strategies to support vulnerable students.

Over time, the educational system and specialised resources for childcare have blamed each other for the aetiology of this group's high school exclusion (Fernández-Simo & Cid, 2016). The situation indicates the appropriateness of deepening the study of the educational evolution of this group (Garcia-Molsosa et al., 2020). The pandemic has increased the urgency of making the school reality of socially challenged youth more visible. Society must know about this population's situation, so it will demand solutions from the public administration. This research was carried out to analyse the mechanisms established in Galicia to meet the needs of students in care within the context of the pandemic.

Method

In March 2020, coinciding with the lockdown, the first phase of a qualitative investigation was initiated, which aimed to analyse the educational system's performance with regard to students in administrative care. The vulnerable young people themselves and the educational teams that manage the resources and accompany the adolescents expressed their perspectives on their schools' performance. Longitudinal follow-ups were carried out using an intentional sample composed of socially vulnerable young people to analyse their situation in detail (Parrilla et al., 2010). The interest of the research during the follow-ups focused on these issues: the school's attention to the specific social difficulties of each case, the teachers' willingness to collaborate with the socio-educational teams of the protection system, the provision of means to carry out virtual activities, and working with students on digital skills.

In the first phase, an intentional sample composed of 11 young people with an average age of 18.3 years was used (Table 1). The youth participating in the study were informed by telephone of the purpose of the study and the confidentiality of the information obtained, and their verbal consent was requested. The longitudinal follow-ups were carried out over 23 days, starting on March 18, 2020, and ending on April 9, 2020. There were 42 contacts, of which 25 were by telephone and 14 were video calls with WhatsApp. The average number of contacts was 3.8.

In September 2020, a new school year began within the exceptional situation arising from the Covid-19 pandemic. Coinciding with the start of the activity of the educational system, the second phase of the study was launched. Phase 2 follow-ups began on September 14 and ended on October 23. The samples in both phases are different because, coinciding with the end of the course (end of Phase 1), some students did not continue in the educational system. Seven of the eleven young people who participated in the first phase continued in Phase 2 (Table 1). Four participants dropped out of the investigation due to changes in their personal situations that precluded their participation. Three participants (2SL12, 2SL13, and 2SL14) were added to the sample. Participants were incorporated to complement the sample and enable comparison with Phase 1. The sample modifications were made because the team are interested in continuing the investigation, assuming that they are difficulties inherent to longitudinal follow-ups. These modifications are recognised as a limitation of this research. The mean age was 18.4 years. Six are female, and four are male. A total of 26 contacts, 15 telephone calls, and 11 video calls were made; the latter were made via WhatsApp or Skype.

During the follow-ups, the interest of the research focused on the following issues: provision to students of adequate resources (tablets, Wi-Fi, PCs, etc.) for the continuity of their academic activity; teachers' contacts with the students; teacher supervision of the school activities; attention to the specific social difficulties of each case and adaptability to the circumstances; collaboration and relationship of teachers and professionals of the protection system, according to the students' viewpoint.

Table 1

Sample of young participants in the longitudinal follow-ups

Phase	Code	Studies	Gender	Age	Contacts	
					By Phone	By Video call
1	1SL1	1st MG	Female	18	2	1
	1SL2	2nd BVT	Female	20	3	1
	1SL3	2nd BVT	Male	18	2	1
	1SL4	2nd BVT	Male	18	5	0
	1SL5	3rd CSE	Female	18	4	0
	1SL6	2nd HS	Male	18	2	1
	1SL7	2nd MG	Female	19	1	3
	1SL8	3rd CSE	Male	18	1	2
	1SL9	2nd BVT	Female	18	3	0
	1SL10	4th CSE	Female	18	1	2
	1SL11	4th CSE	Male	18	1	3
2	2SL1	2nd MG	Female	19	1	1
	2SL2	1st MG	Female	20	2	1
	2SL6	1st HD	Male	18	2	2
	2SL8	4th CSE	Male	18	1	1
	2SL9	1st MG	Female	18	2	0
	2SL10	1st HS	Female	18	1	1
	2SL11	1st MG	Male	18	1	1
	2SL12	4th CSE	Female	18	1	2
	2SL13	1st MG	Male	18	2	1
	2SL14	2nd HS	Female	19	2	1

Note. Certificate of Secondary Education = CSE; Middle Grade = MG; Higher Degree = HD; Basic Vocational Training = BVT; High school = HS.

The information obtained in the follow-ups was complemented by case studies carried out by the professionals. The research analysed the schools' performance concerning school inclusion through the testimonies of vulnerable students and professionals outside the educational system. Disciplinary barriers are overcome when examining the schools' procedure from the outside. It is not the teachers but, instead, other actors who analyse the educational system's performance. We highlight the desirability of studying the educational phenomenon from the perspective of the other actors involved (Susinos & Parrilla, 2013). The methodological design, typical of the grounded theory, facilitates the performance of semi-structured interviews built on the information obtained in the follow-ups. Two professionals specialised in vulnerable adolescence and external to the research team supervised the categories obtained, both in the follow-ups and the interviews with the educational teams, at each stage of the study, ensuring the reliability of the data analysis.

In Phase 1, the cases were studied with a convenience sample of 14 professionals who had been active in the protection system for a minimum of 12 months (Table 2). The educators accompanied a total of 76 students who were studying during the pandemic: 29 in basic vocational training; 30 in secondary education; 13 in middle grade; 3 in high school; 1 in a higher degree. The average age of the professionals was 35.3 years. Their average specialised working experience was 68.9 months. The interviews were conducted via the Skype computer app between April 13 and 24, 2020. Previously, telephone contact was made, requesting the students' collaboration, informing them about the issues of interest for the investigation and the necessary data.

A sample of 11 professionals was used in the second phase. Three educational professionals who participated in the first phase could not continue the study. The average work experience was 67.5 months. Seven professionals worked in residential resources and four in communities. They accompanied a total of 45 adolescents enrolled in secondary or post-compulsory studies (Table 2). An in-depth interview was conducted via Skype with each professional between October 27 and November 2, 2020.

Table 2

Sample of professionals in the case study

Phases	Resource typology	Code	Students		Age	Gender	Months of work experience
1	Residential	1E1	1	BVT	28	Female	31
			2	CSE			
			1	MD			
		1E2	1	HS	35	Female	63
			1	CSE			
			2	BVT			
		1E3	3	CSE	32	Male	49
		1E4	1	MD	29	Female	86
			1	BVT			
		1E5	3	CSE	34	Female	101
		1E6	2	BVT	42	Male	142
			1	CSE			
		1E7	3	BVT	46	Female	165
			1	MD			
		1E8	3	BVT	41	Female	57
			1	HS			
			2	MD			
		1E9	4	CSE	40	Female	42
			2	BVT			
	Community	1E10	3	BVT	25	Female	15
			1	CSE			
		1E11	1	MD	31	Female	21
			4	BVT			
		1E12	1	HD	39	Male	72
			1	HS			
			3	MD			
			4	CSE			
		1E13	5	BVT	33	Female	95
			6	CSE			
			3	MD			
		1E14	1	MD	39	Female	26
			5	CSE			
			3	BVT			

Phases	Resource typology	Code	Students		Age	Gender	Months of work experience
2	Residential	2E1	1	BVT	28	Female	31
			2	CSE			
		2E2	1	HS	35	Female	63
			2	SEC			
			3	BVT			
		2E3	2	CSE	32	Male	49
		2E5	3	CSE	34	Female	101
		2E6	1	BVT	42	Male	142
			1	CSE			
		2E7	3	BVT	46	Female	165
			1	HD			
			1	MG			
		2E8	2	BVT	41	Female	57
			1	HS			
			1	MD			
			1	HD			
	Community	2E10	3	BVT	25	Female	15
			1	CSE			
		2E11	1	MD	31	Female	21
			4	BVT			
		2E12	1	HD	39	Male	72
			1	HS			
			2	CSE			
		2E14	2	MD	39	Female	26
			3	CSE			
			1	BVT			

Note. Certificate of Secondary Education = CSE; Middle Degree = MD; Higher Degree = HD; Basic Vocational Training = BVT; High School = HS.

The purpose of the interviews with the professionals was to delve into the following issues: the school's mechanisms to address the social factor in school inclusion processes; which collaboration spaces are available to work in coordination with the teachers; changes in the school dynamics during the start of the course following the situation derived from Covid-19; which activities in digital skills were being carried out with the students and which technical means were provided.

Results

The school does not possess mechanisms of action in the social factor. This deficit made it more likely for students to suffer school exclusion during the lockdown in March, with the same situation continuing in the first few weeks of the start of the new school year. The results indicate that the educational system did not have the resources to meet the demands of students arising from situations of social vulnerability. One professional argued that 'The schools act as if social difficulties have nothing to do with them, and I think that this is even more serious in a situation like the current one' (2E14). 'The youths' social issues are usually not addressed' (2E2), said one educator. »No one asked us if we had any personal problems or if there were any problems in our live […] the course started normally' (2SL8), said one student. 'I told the history teacher that I didn't have a laptop, and he replied that nowadays everyone has a computer, just like there are mobiles' (1SL8), said a CSE student. In situations like these, the lack of adaptability of the educational system to the diversity of social situations leads to an increase in educational inequalities. Child protection resources seek to remedy the school deficiencies. 'In the centres, we manage with the means that we have, but the students who went home have a more complicated situation' (1E5), said one professional.

Part of the faculty tried to meet the demands of the vulnerable students in the absence of institutional response. A variety of situations conditioned by the teachers' individual predispositions was detected. One young man enrolled in basic vocational training said, 'The teacher helped me get data for the phone, so I could see what is uploaded... When I cannot download things, she calls me, and we do them by phone' (1SL3). One professional of the child welfare system stated that 'Some teachers are flexible and try to adapt to the reality of the students' (1E3). This indicates the presence of teachers' proactive and resolute attitudes when facing their students' situations of social difficulty. In other cases, passive attitudes are detected that foment difficulties in the school integration of the most disadvantaged students. One educator, who works in open media, stated that 'A girl's tutor told me literally that she could not do any more with a teacher who asked for everything to be sent by computer and did not answer the phone.... I don't understand how situations like this are allowed, knowing that the girl doesn't have a computer at home' (1E14).

The collaboration between teachers and professionals of specialised resources is mostly improvised. 'There are no established protocols for doing a conjoint job, so collaboration depends on the teacher's will' (2E1), said one educator. Another professional argued that 'Some teachers do get involved, but they do so on an individual basis, they frequently do not assume the social problems as their business, and that means that the meetings with us are only to collect information but not to work together' (2E7). The results indicate that collaboration dynamics are limited to punctual information-exchange contacts. In some cases, it is related to the pre-declaration of the lockdown. 'My educator talks to my tutor from time to time and so they know at the centre how I'm doing in class' (1SL10) said a CSE student. 'Before all this, I would talk every so often with the boys' teachers' (1E7), said a professional. The follow-ups indicated that difficulties in establishing a fluid channel of communication with teachers are common. 'I told my educator to talk to the teachers to see how we were doing… they only communicate by email and there are some things we don't understand in the homework' (1SL9), said a basic vocational training student.

The results indicated the absence of an institutional government strategy to support socially challenged students in the context of Covid-19. Adaptability actions respond to specific actions of certain schools or by the faculty. A young student of basic vocational training stated that 'The tutor helps a lot to resolve my doubts by telephone' (1SL2). Another student, from a different school, argued otherwise. 'No one contacts me, and when I call, I can only talk to the principal who tells me to do what they tell me by email' (1SL9), she said. The perspective of neglect of personal needs was confirmed by another participant, commenting, 'No one asked me why I still have received no material whether if I need anything' (2SL8).

Contacts with students in distance-learning periods varied, depending on the teacher's involvement. 'The relationship with the youths depends directly on the teacher. You find some very involved teachers who are very attentive and others who only send instructions' (1E11), stated an educator. 'Some teachers are very sensitive to the youths' needs, but there is no regulated form of acting; instead, it depends on each person and, in our case, most youths were not asked whether they needed anything' (2E10), said another educator. 'The tutor asked me if I needed anything or if I had any problems and is attentive' (2SL13), one student reported.

Table 3
School Inclusion Deficits in Students in Protection within the Context of Covid-19

Category	Course start (Phase 2) Frequencies		First lockdown (Phase 1) Frequencies	
	Follow-ups	Case studies	Follow-ups	Cases studies
Deficits in pedagogical practice related to the social factor	7	8	9	11
Deficit in collaboration between school and protection system	7	8	10	13
Deficits in support and supervision of academic tasks in distance-learning periods resulting from personal and/or collective confinements	7	8	6	10
Absence of training actions aimed at promoting students' digital competencies.	7	9	10	10
No use of virtual teaching platforms with confined students	6	7	10	10
Non-provision of technical means for conducting school activities during distance-learning periods	5	6	4	6

The improvisation prevailing during the first lockdown continued at the start of the new school year. Students' digital skills were not addressed, and no diagnosis was made of the students' performance level in the new technologies. No mechanisms were established to facilitate technological means to supervise distance-learning teaching. The results indicate an absence of planning of the educational system in a context of uncertainty in which confinements at home were recurring. Vulnerable students had the least social support and were, therefore, the most affected by school deficits. 'The problem we have is that the youths know how to use the mobile well to relate, but managing programmes like Word or knowing how to use platforms on the internet is something else' (2E5), said one educator. 'No one asked us anything about our computer usage level or offered to give us courses' (2SL11), recalled one student.

The provision of technological means varied by school. 'The teacher called me and asked if I had problems with the internet connection. He told me that if I needed help, he would help me' (1SL6), said a young male high school student. Another student, in this case, a secondary student, stated that 'The teachers upload what you have to do but they don't tell the ones who don't have laptops at home what to do' (1SL11). 'I'm not going to the institute now because a classmate tested positive, and they told part of the class not to go as a precaution... they didn't give us anything and I have to use the laptop lent to me by the educators' (2SL12), explained a young woman. 'I am very angry that the Consellería de Educación makes press announcements saying that no one is going to be left behind, but then, in practice, nothing is done, the supports are focused on some NGO that facilitates things' (1E13), asserted an educator.

The results indicated that virtual platforms were not operational for distance-learning teaching at the start of the course. In several cases, schools intended to combine class attendance periods with virtual teaching. This situation particularly affected schools where classrooms could not accommodate all the students, ensuring mandatory distancing and safety measures during the pandemic. 'It's a shame that they send the kids home for a week with the idea of giving them virtual lessons and they don't even receive a single hour all day,' (2E3), said one educator. Another professional stated that 'In the first three weeks, they did not teach the youths who were at home and now, some professors do and others do not' (2E8). During the first few days of class, the digital platforms did not work. In the third week after the start of the course, a virtual teaching application was activated for the entire educational system. The results indicate that, at the time of completion of the data collection, some teachers did not teach students who were in the virtual mode.

Discussion

The study results indicate that the educational system did not design effective strategies to improve the adaptability of teaching activity to the students' social situation derived from Covid-19. No dynamics were established to promote school inclusion of socially vulnerable students. In the opinion of the authors of the present paper, school inclusion is a process that ensures that all students, without discrimination due to their social situation, have access to a quality school education. To make school inclusion real, the government must establish support mechanisms. The specific needs of the collective do not obtain institutional attention because of inadequate adaptability to their specific reality (Fernández-Simo & Cid, 2018). In the socio-educational accompaniment of vulnerable adolescence, it is necessary to consider the contextual factors (De Valenzuela et al., 2018; Santana-Vega et al., 2018). Social conditions affect each adolescent's opportunities, even determining how much time they have to achieve their goals (De-Juanas et al., 2020), including those of the academic itinerary.

Coordination between schools and resources of the child welfare system is essential to minimise the consequences of Covid-19, which increase the difficulties of school inclusion of students in care (Fuentes et al., 2020). The social and family circumstances of this group of young people hinder the application of remote teaching methodologies. Socially disadvantaged students do not have the environmental conditions in their homes that make distance-learning teaching feasible (Murillo & Duk, 2020). The results indicate deficits in the availability of technical means as well as in the management of digital skills. Students have the technology (mainly smartphones) but do not have the necessary means to follow a distance-learning academic activity (Rodicio-García et al., 2020). Vulnerable adolescents are used to using internet and telephone services as a relational medium (Álvarez-Sigüenza, 2019; Cobo & Narodowski, 2020), but they lack abilities in the management of programmes, files, or printing (Jiménez et al., 2016). The training aimed at increasing students' digital competence, which is carried out during the first weeks of the course, is anecdotal or punctual. There is no comprehensive training strategy that is applied throughout the educational system. The difficulty of managing the technological media, detected during the unexpected confinement of March 2020, was not addressed when starting the new school year.

The results indicate that the administration leaves it up to the schools to provide laptops and tablets, which reflects different situations depending on the reality of each school. The government does not guarantee that all students will have the same opportunities. The possibilities of each centre affect the options given to students during periods of non-virtual teaching. Severe deficits are detected in the supervision of the virtual educational activity of students in care. The findings coincide with recent reports on the increase in school exclusion due to the social factor in the context of the pandemic (Consejo Escolar del Estado (State School Council), 2020; Save the Children, 2020).

The possibility of a new lockdown and the lack of information increase participants' uncertainty about which strategies educational administration will follow to overcome its improvisation during the first lockdown. The absence of action mechanisms hinders the school inclusion of students with greater social vulnerability, as the ineffectiveness of the educational institution conditions this group's academic evolution (Portela et al., 2019). Professionals in the protection system emphasise that the opportunity for shared socio-educational action is in the hands of each teacher's voluntarism. Whether or not a student is accompanied by teachers who are sensitive to the social dimension is a question of luck. The right to equitable education is not addressed from a system perspective.

The results indicate that the school is passive toward socio-educational needs. Achieving school inclusion requires the schools to implement proactive dynamics. The school's commitment to the social dimension facilitates overcoming contextual difficulties. A school involved in the socio-educational dimension will promote the most vulnerable students' achievement of goals. The pandemic has increased school inclusion difficulties arising from the social factor. The situation is particularly worrisome in periods of non-present teaching in which teachers have trouble maintaining communication with vulnerable students (Bermello, 2020). Crises affect socially challenged groups more harshly due to the historical absence of a socio-educational perspective in school.

The educational system should activate mechanisms for intervention in social issues in order to provide a more effective response when ensuring a fair model. These needs were already present before the onset of Covid-19. School strategies to support socially challenged families, which are exacerbated by the pandemic, continue to be implemented (Reimers & Schleicher, 2020). During the lockdown, no support resources were established for families to manage family difficulties and dynamics effectively (Orte et al., 2020). Implementing socio-educational accompaniment would alleviate situations of vulnerability (Amorós-Martí et al., 2016).

Conclusions

The education system has deficits in its attention to the needs of students cared for by the child welfare system. The lack of mechanisms to meet students' needs makes it difficult to reduce the indicators of school exclusion in this group. The situation is exacerbated in crisis contexts resulting from the emergence of Covid-19. Students in care suffer from the lack of mechanisms from the school responding to their specific needs. The public administration should support an educational model that assumes equity as a preferred objective. Passing academic goals is essential for students without support in their natural context. These young people need to reach training levels that facilitate their future working lives. Without work, they will not achieve the essential economic resources for independent living. If school inclusion is not facilitated, they will not be able to overcome the social exclusion situation that gave rise to the protection file.

The school should assume its social responsibility for students from the child welfare system. It plays a key role in the path of social justice. The permanence of school practices that perpetuate the students' situation of social exclusion is currently being tolerated. Activating strategies to respond to the social dimension will help to reduce the processes of exclusion of students in care. The outstanding challenge is to apply, in the coming courses, socio-educational perspectives for the management of the educational system. The public administration cannot continue to refuse to assume the need for a change in the educational model. All students have the right to receive the same opportunities to advance in their educational itinerary.

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Biographical note

Deibe Fernández-Simo, PhD, is an assistant professor in the field of Theory and History of Education of the University of Vigo, Spain. Her research interests include social exclusion, vulnerable youth and social education.

Xosé Manuel Cid-Fernández, PhD, is a full professor in the field of Theory and History of Education of the University of Vigo, Spain. Her research interests include history of social education, social exclusion and education for peace.

María Victoria Carrera-Fernández, PhD, is an assistant professor in the field of Theory and History of Education of the University of Vigo, Spain. Her research focuses on bullying as a gendered practice of heteronormative and ethnocentric control.

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Determining Pre-Service Teachers' Astronomy-Related Self-Efficacy Belief Levels

Ebru Ezberci Cevik*[1] and Oktay Bektas[2]

This study aims to reveal the astronomy-related self-efficacy beliefs of pre-service teachers studying science education, primary school education, and social studies education programmes. The study is conducted using the survey design, a quantitative research method. The study sample consists of 322 pre-service teachers in their third or fourth year of a science education, primary school education, or social studies education programme at a university in Turkey's Central Anatolia Region during the 2016 fall semester. The Astronomy Teaching Self-Efficacy Belief Scale developed by Güneş was used as the data collection tool. SPSS 22 was used to analyse the data, and the analyses benefited from descriptive and inferential statistics. Based on the findings, the pre-service teachers' total scores for astronomy self-efficacy showed no significant difference in terms of certain variables (i.e., gender, age, year, and having taken a previous astronomy course). However, significant differences were found regarding self-efficacy scores in terms of the programme and having taken part in astronomy and sky-gazing activity. Concerning the obtained results, the following suggestions can be made: pre-service teachers should be actively involved during the astronomy course, and their classroom management experiences should be promoted to improve their astronomy self-efficacy belief levels.

Keywords: astronomy education, astronomy self-efficacy belief, pre-service teacher

1 *Corresponding Author. Faculty of Education, University of Erciyes, Turkey; ezbercicevik@erciyes.edu.tr.

2 Faculty of Education, University of Erciyes, Turkey.

Ravni prepričanja o samoučinkovitosti v povezavi s poznavanjem astronomije pri študentih pedagoških smeri

Ebru Ezberci Cevik in Oktay Bektas

Raziskava skuša predstaviti prepričanja o samoučinkovitosti glede znanja astronomije pri študentih pedagoških smeri naravoslovja, osnovnošolskega poučevanja in družboslovnih programov. Študija je bila izvedena z uporabo ankete, pri čemer se je poslužila kvantitativne raziskovalne paradigme. Vzorec sestoji iz 322 študentov pedagoških smeri naravoslovja v njihovem tretjem ali četrtem letniku, osnovnošolskega poučevanja ali družboslovja na univerzi osrednje turške pokrajine Anatolije v jesenskem semestru leta 2016. Kot pripomoček za zbiranje podatkov je bila uporabljena lestvica prepričanj o samoučinkovitost glede znanja astronomije, ki jo je razvil Günes. SPSS 22 je bil uporabljen za analizo podatkov, pri čemer ta obsega opisno in vzorčno statistiko. Na podlagi ugotovitev se rezultati statistično pomembno ne razlikujejo glede na spremenljivke spola, starosti, letnika in predhodnega obiskovanja predmeta astronomije, pomembne razlike pa so dokazane glede na študijski program in sodelovanje pri astronomiji ter pri opazovanju neba. Dobljeni izsledki dopuščajo naslednje sklepe: študentje pedagoških smeri bi morali aktivno sodelovati pri predmetu astronomije, v nadaljevanju pa bi se jih moralo spodbujati pri upravljanju razreda, da se izboljša tudi njihova prepričanja o samoučinkovitosti glede znanja astronomije.

Ključne besede: poučevanje astronomije, prepričanje o samoučinkovitosti glede znanja astronomije, študentje pedagoških smeri

Introduction

The process of learning science involves a combination of observations and interpretations that enable students' meaningful learning (Pundak et al., 2017). As a result, astronomy has become included in this combination. Therefore, having individuals who have been interested in the sky since an early age continue these interests using the knowledge they gain from scientifically reliable sources by observing and interpreting is considered necessary.

From an international point of view, the debate on how to teach astronomy within the curricula has been chiefly about whether it should be taught as a separate course or as a part of other fields. In both cases, the topics planned to be taught include the formation of day and night, the seasons, the phases of the moon, eclipses, tides, planets, and stars (Taşcan & Ünal, 2015). Each country expresses the importance they attach to astronomy education in their education system. For instance, Serbia requires 33 seminars over three years on various topics in astronomy every second Tuesday throughout the academic year at the Department of Astronomy and 33 seminars held at the Astronomical Observatory (Atanackovic & Arbutina, 2021). In Thailand, new topics such as the celestial sphere, astronomical coordinate systems, and the sun's apparent motion had been introduced within astronomy to all science classes, as of 2008 (Jansri & Ketpichainarong, 2020).

Turkey has drawn attention to the topics addressed in teaching astronomy. When viewed nationally, it is seen to give relatively high importance to astronomy topics in its primary and secondary school curricula. The Ministry of National Education (MoNE) has started including astronomy topics (e.g., Let's Get to Know Our Planet; The Earth's Crust and the Motion of Our Planet; The Sun, Earth, and Moon; The Solar System and Eclipses; The Solar System and Beyond; Seasons and Climate) starting in the third-grade science curriculum (2018a). Unlike in previous curricula, the subject areas of the world and the universe have also been included in the first units with the aim of developing students' sense of curiosity about astronomy and of developing their interest in science. In this respect, having education regarding basic concepts in astronomy be effectively presented by increasing observation and critical thinking in schools will make an essential contribution to individuals' meaningful learning and interest in astronomy (Oğuz et al., 2012). In other words, having students take an active role in teaching topics on astronomy is very important in being able to create learning environments that will contribute to meaningful learning and to help students' critical thinking and discussions of processes in terms of conceptualising knowledge on astronomy (Akimkhanova et al., 2020; Güneş, 2010). Teachers who display such an approach attach importance to students' ideas and show they trust the students so as to increase the value of this importance. As in many other subjects, this aspect allows students to trust themselves in astronomy. Meanwhile, teachers' self-confidence in performing their duties and competencies in influencing the performance of their students relate directly to their self-efficacy beliefs (Bandura, 1994; Gusken & Passaro, 1994).

Self-efficacy belief is based on social learning theory and is expressed as individuals' ability to take charge of the events that affect their lives (Bandura, 1977). According to Bandura (1997), four main factors affect the perception of self-efficacy in individuals: direct experiences of success, indirect experiences based on observation, verbal persuasion, and psychological and physiological situations. Çakıroğlu et al. (2005) stated that one of the most important topics in teacher training programmes regarding the goal of teaching qualified and effective teachers was providing them with self-efficacy. Meanwhile, Tschannen-Moran and Woolfolk Hoy (2001) argued that teachers and academics (lecturers) should have self-efficacy beliefs and that these beliefs should be integrated into teaching strategies. At the same time, they argued that teacher-student communications should be increased and that lessons may become more productive due to this integration.

As seen above, instructors have a great responsibility in developing self-efficacy beliefs. The question that comes to mind is whether instructors have the necessary knowledge and skills for improving self-efficacy beliefs. Pajares (1992) stated that individuals' self-efficacy beliefs were related to their level of knowledge and skills specific to the subject. From this point of view, instructors who lack knowledge and skills in any subject obviously will have difficulty developing their learners' self-efficacy levels. Similarly, pre-service teachers should have the necessary knowledge and skills to meaningfully and self-confidently teach students subjects (Bağdiken & Akgündüz, 2018). Thus, similar to what Pajares (1992) found in his study, pre-service teachers with sufficient knowledge and skills in astronomy can be considered to have an adequate level of self-efficacy beliefs. In contrast, teachers and pre-service teachers with sufficient self-efficacy beliefs can transfer their knowledge and skills on astronomy to those who have learned meaningfully (Demirci, 2017; Güneş, 2010). In this context, self-efficacy belief can be said to be the key to realising astronomy-related studies.

Although developing self-efficacy beliefs in astronomy is vital for meaningful learning, studies on the field of self-efficacy in the literature have primarily involved mathematics self-efficacy (Gülten et al., 2012; İskenderoğlu et al., 2016; Pajares, 1996), science self-efficacy (Akbaş & Çelikkaleli, 2006; Kaya, 2013; Riggs & Enochs, 1990), and academic self-efficacy (Choi, 2005; Ekici, 2012; Høigaard et al., 2014; Oğuz, 2012; Yağcı & Aksoy, 2015). In this sense, although studies are found on self-efficacy in science, studies on the field of astronomy are generally related, especially in the context of the current study, to the conceptual meanings students have regarding topics in astronomy (Baloğlu Uğurlu, 2005; Bülbül et al., 2013; Cin, 2007; Durukan & Sağlam Arslan, 2013; Göncü & Korur, 2012; Küçüközer, 2007; Şensoy, 2012) and students' knowledge levels (Bostan, 2008; Kanlı, 2014; Kaplan & Çifçi Tekinarslan, 2013; Taşcan, 2013); the number of studies on astronomy self-efficacy is relatively low (Carter, 2005; Güneş, 2010). Of these, a limited number is found on the self-efficacy of pre-service teachers. For example, only Durukan and Sağlam Arslan (2013), Küçüközer (2007), and Şensoy (2012) have studied conceptual interpretation; Bostan (2008) and Kanlı (2014) studied knowledge levels, İyibil and Saglam Arslan (2010) studied mental models, and Carter (2005) and Güneş (2010) studied astronomy self-efficacy. Other studies have been directed toward students and teachers.

In light of the presented literature, the lack of self-efficacy studies on pre-service teachers is noteworthy. When considering that students encounter many concepts related to astronomy during their learning process and are introduced to these concepts primarily through their teachers, determining pre-service teachers' self-efficacy related to these concepts and subjects that will occur in the teaching profession is vital. In this way, the conceptual comprehension studies related to astronomy in the literature (Baloğlu Uğurlu, 2005; Küçüközer et al., 2010; Plummer, 2006; Trundle et al., 2006; Trundle & Troland, 2005) can be guided by investigating the reasons behind the subject in relation to self-efficacy beliefs on astronomy.

Different studies in the literature have obtained various results regarding self-efficacy scores in terms of gender. Akbaş and Çelikkaleli (2006) stated that teacher candidates' self-efficacy beliefs on science teaching do not vary according to gender, while Cassidy and Eachus (2002) found men to have higher self-efficacy beliefs than women did. In view of these differences in the literature, the current study aims to examine how self-efficacy scores vary with regard to gender. Studies in the relevant literature have used age and grade level as other variables. Özenoğlu-Kiremit's (2006) study evaluated science teacher candidates' biology-related self-efficacy beliefs according to age and determined that such beliefs regarding biology teaching increase with age. Similarly, pre-service teachers' levels of self-efficacy beliefs toward biology teaching also increased with higher grade levels (i.e., freshman, sophomore, junior, senior). In this context, the variables of age and grade are considered important in determining self-efficacy beliefs. Differentiating between pre-service teachers' self-efficacy scores based on age and grade will provide significant opportunities for teacher training institutions that consider this.

Self-efficacy beliefs are fundamental in individuals' behaviour and are said to be related to the above-mentioned variables based on four sources (Ekici, 2009): first-hand experience of similar behaviour, the opportunity from others to follow the same kind of behaviour, being convinced by an authority, and self-awareness of physiological and emotional states. First-hand experience plays a vital role in self-efficacy (Woolfolk Hoy, 2000), because when people gain work-related experience, they feel more qualified to finish or perform the work (Bandura, 1977). In this sense, the study aims to determine the effect pre-service teachers' previous astronomy courses and previous experience with astronomy and sky observations have on their self-efficacy beliefs on astronomy.

Purpose of the research

Pre-service teachers' self-efficacy regarding their confidence in and expectations from astronomy is a crucial element in teaching astronomy subjects to students (Demirci, 2017). In particular, this situation becomes more prominent in science, classroom education, and social sciences involving topics on astronomy. For example, one of the aims of the social studies curriculum is to recognise the general geographical characteristics of the environment and world in which students live (MoNE, 2018). The publications on teacher qualifications prepared by the School-Based Professional Development Unit of Turkey's Ministry of National Education state that classroom teachers should have competence in providing information about scientific developments (MoNE, 2008) and, in this sense, emphasise that students should gain the ability to recognise the antecedents of scientific concepts such as the basic concepts in astronomy (MoNE, 2009). Similarly, this is essential in science education (e.g., physics, chemistry, biology) because of its relationship to the universe, the world, and nature (Göncü & Korur, 2012). Meanwhile, other natural science departments, such as mathematics, are interested in the calculations in astronomy rather than the topics or concepts in the subject.

The current study will discuss the need for science and social science teachers to have experience in terms of having an effective astronomy education (Güneş, 2010), the importance of topics on astronomy in science, classroom education, and social sciences departments, and how these pre-service teachers will teach this course. Self-efficacy is very important in guiding individuals' behaviours, attitudes, and taking action. In this sense, unlike the studies on determining attitudes towards astronomy that are frequently carried out in the literature, this current study will complement the other studies by determining pre-service teachers' ability to use the knowledge and skills necessary for their students to learn in the future. Obtaining information about pre-service teachers' levels of self-efficacy beliefs will shed light on their future teaching. Studies have proven teacher efficacy to be strongly related to many meaningful educational outcomes (Vlah et al., 2021). Teachers' self-efficacy beliefs about the subject are thought to affect students' conceptual learning or academic achievement (Nie et al., 2013; Şirin & Metin Peten, 2020). Even if pre-service teachers' self-efficacy levels cannot be identified at the desired level, the suggestions this study makes can firmly guide new teachers. This is because new teachers can be more productive in their future teaching lives by considering the current study results and the suggestions presented to learn what they need to do to develop their self-efficacy beliefs toward astronomy. In this context, this study aims to reveal the astronomy self-efficacy of prospective teachers studying science education, classroom education, and social studies education programmes.

The research questions are as follows:

1. Does a statistically significant difference exist between male and female pre-service teachers' self-efficacy total and factor scores?
2. Does a statistically significant difference exist between the self-efficacy total and factor scores of pre-service teachers of different ages?
3. Does a statistically significant difference exist between the astronomy self-efficacy total and factor scores of pre-service teachers in terms of whether or not they have taken an astronomy course?
4. Does a statistically significant difference exist between the astronomy self-efficacy total and factor scores of pre-service teachers in terms of whether they have engaged in astronomy and sky-watching activities?
5. Does a statistically significant difference exist between the astronomy self-efficacy total and factor scores of 3^{rd}- and 4^{th}-year teacher candidates?
6. Does a statistically significant difference exist between the self-efficacy total and factor scores of teacher candidates in different programmes?

Method

Research design

The research was carried out as a survey study (i.e., a quantitative research design). Survey studies aim to determine participants' characteristics, such as their opinions, interests, abilities, and attitudes; these studies differ from other studies using larger samples (Fraenkel & Wallen, 2006; McMillan & Schumacher, 2006). Studies with larger samples are concerned with how participants' views are distributed over the sample rather than why they have particular views (Fraenkel & Wallen, 2006).

The primary purpose of survey studies is to describe a current situation (Çepni, 2012). Therefore, the study has used the survey model to determine pre-service teachers' self-efficacy beliefs about astronomy. In addition, this design is appropriate for studying self-efficacy beliefs with respect to different variables.

Participants

The research sample consists of 3rd- and 4th-year pre-service teachers studying science, classroom education, and social studies education programmes in Turkey's Kayseri Province in the 2016 fall semester. The sample consists of 322 pre-service teachers (122 in the science education programme, 110 in the classroom education programme, and 90 in the social studies education programme). Some departments (e.g. teaching mathematics) have not been included in the study, and the simple random sampling method has been preferred in selecting the sample. Designated pre-service teachers were included in the study on a volunteer basis. Moreover, the participants were informed that the study results would be presented in scientific publications. In such cases, they were also told that their identity would be kept strictly secret, and their approval was obtained. Table 1 shows the frequency distribution of the pre-service teachers in the different programmes with respect to their demographic characteristics (e.g., age, gender, grade level, and whether or not they had taken an astronomy course or taken part in astronomy/sky-gazing activities).

Table 1

Demographic Characteristics of the Participants

Variable	Category	Science Education	Classroom Education	Social Studies Education
Age	19–21 years old	79	77	48
	22 years or older	43	33	42
Gender	Female	103	92	45
	Male	19	18	45
Grade level	3rd	59	47	46
	4th	63	63	44
Took a previous astronomy course	Yes	19	12	6
	No	103	98	84
Participated in an astronomy/sky-watching activity	Yes	15	10	16
	No	107	100	74
	Total	**122**	**110**	**90**

When examining Table 1, participants in the 19–21-year age group are the most common among the pre-service teachers studying for all three programmes in terms of age. In terms of gender, the science education and classroom education programmes have more females than males, while the social studies education programme has equal numbers of males and females. In terms of grade level, more 4th-year students were in the science education programme, while 3rd-year students were more frequently in the classroom and social studies education programmes. The number of pre-service teachers who answered 'no' in terms of having taken astronomy courses was relatively high in all three programmes; similarly, those who answered 'no' in terms of participating in an astronomy/sky-gazing activity comprise an even more significant majority in all three programmes.

Data collection tool

The Astronomy Teaching Self-Efficacy Belief Scale was used as the data collection tool. It was developed by Riggs and Enochs (1990) and adapted into Turkish by Özkan et al. (2002) as the Science Teaching Self-Efficacy Scale. This version of the scale consists of two factors: Personal Science Teaching Efficacy Belief and Science Teaching Outcome Expectancy. Güneş (2010) adapted the scale in his study to examine the relationship between astronomy knowledge with the nature of science and the astronomy self-efficacy belief of pre-service teachers from science and technology and the social studies departments. This version of the scale was also used in the current study. The scale consists of two factors: Personal Self-efficacy in Astronomy Teaching (PSAT) and Expected Results in Astronomy Teaching (ERAT). The scale has 23 items: 13 for PSAT and 10 for ERAT. It is a five-point Likert-type scale (1 = Strongly Disagree and 5 = Strongly Agree). The items on the scale are intended to measure self-efficacy for general astronomy teaching and are not based on any specific concept in astronomy. 'I think I will always find better ways to teach astronomy' can be stated as an example item. Güneş (2010) calculated Cronbach's alpha of reliability for the scale as .80, for the factor of PSAT as .87, and for the ERAT factor as .78. Within the scope of the present study, the items were re-analysed, and the decision was made to subtract six items due to their difficulty and differentiation. Validity and reliability analyses have been performed over a total of 17 items.

Within the scope of the content validity study, all the items on the scale were examined by five experts in terms of scientific appropriateness, representational power of the property to be measured, comprehensibility and clarity, and representation of the target group. Three of these experts are faculty members in science education, one is a faculty member in classroom education working in the field of astronomy, and one is a faculty member in the department of measurement and evaluation who conducts doctoral studies on measurement and science education programmes and also has studies on astronomy. The appropriate changes as proposed by the experts were made to the scale.

- *Item 8 (Pre-Adjustment):*
  I generally think I cannot teach astronomy lessons effectively.
- *Item 8 (Post-Adjustment):*
  I think I cannot teach astronomy effectively.

Similar to the example above, the expression 'astronomy' has been changed to 'topics in astronomy', and the modified sentences were clarified. The experts deemed the addition of the words 'topics in' to be appropriate in order to be able to adopt an education-oriented approach. After making these corrections, the scale was prepared for application.

In terms of criterion validity, the first developed form of the scale had been applied to 3^{rd}- and 4^{th}-year undergraduate pre-service teachers in science and social studies education programmes. Similarly, the current study applies the scale to 3^{rd}- and 4^{th}-year pre-service teachers in science, classroom, and social studies education programmes. The variables of age, gender, education programme, grade level, having taken an astronomy class, and having participated in an astronomy/sky-watching activity are considered to be related to the self-efficacy beliefs of pre-service teachers. The first form of the scale is compatible with the study in terms of department and gender. In both studies, similar stages were followed in the data collection stage. In terms of criterion validity, the results from both scales could not be correlated because the scale in the previous study could not be applied to this sample.

Factor analysis was used to determine the construct validity of the scale. The original scale has the two factors of PSAT and ERAT. As a result of the exploratory factor analysis conducted in the present study, the scale was also determined to consist of the same two factors (PSAT and ERAT). In order to test the accuracy of the two-factor structure determined by the exploratory factor analysis, confirmatory factor analysis was applied using LISREL software. Hu and Bentler (1999) specified the critical values for the criteria used in the model fit of the items as $CFI > .90$, $RMSEA < .05$, and $NFI > .90$. As a result of the analysis of the current study, all values were found to have perfect fit limit values, and thus the models of the scale items were found to be appropriate.

In order to determine the reliability of the scores obtained from the scale, Cronbach's alpha of reliability was determined using the SPSS 22 software. As a result of the analysis of Factor 1, Cronbach's alpha was calculated as .794 and as.667 for Factor 2. Cronbach's alpha for the 17 items was calculated as .752. As this value is acceptable (Pallant, 2007), the scores participants obtain from the self-efficacy scale can be said to be reliable.

Data collection process

The data collection tool was applied to pre-service teachers in the 2016 fall semester. They participated in the study voluntarily and signed the Social and Humanities Informed Consent Form. The participants were also told that the results of the study would be presented in a scientific publication. As such, they were also told that their identity would be kept strictly confidential, and then their approval was obtained. The pre-service teachers were first asked to fill out the descriptive information (e.g., gender, age, grade level) that was considered helpful in analysing the research on the scale and then to carefully read the statements about teaching astronomy and mark the option indicating their agreement with each statement. The pre-service teachers were given 30 minutes to answer the scale. The scale was applied to everyone in the sample group within 15 days.

Before the statistical analysis, the scales were examined to see if the pre-service teachers had completely filled out the scales, and an analysis was carried out over the 322 scales that were found to be missing no data.

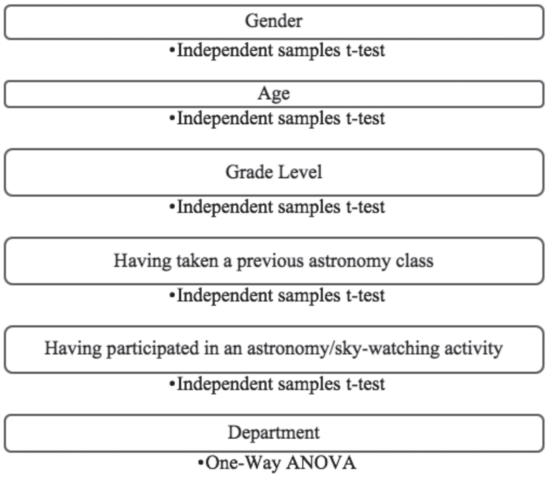
The study has observed all the rules in the Higher Education Institutions Scientific Research and Publication Ethics Directive, and no action in conflict with the Actions Against Scientific Research and Publication Ethics was performed in the second part of the implementation.

Data analysis

SPSS 22 was used to analyse the data. Descriptive statistics have been made primarily for the identified sub-problems, and whether the assumptions related to appropriate analysis had been achieved were verified. Inferential statistics have been used for different variables. The descriptive statistics and inferential statistics tables are explained in the Results. Figure 1 displays the independent variables and statistics.

Figure 1

Inferential statistics used for the variables



Results

This section presents the statistical analysis findings from the Astronomy Teaching Self-Efficacy Belief Scale applied to pre-service teachers studying in different programmes in terms of the various variables. The findings are presented according to the respective categorical variables.

Investigating Pre-Service Teachers' Self-Efficacy Beliefs According to Gender

The descriptive statistics on pre-service teachers' self-efficacy scores according to gender are presented in Table 2.

Table 2

Descriptive Statistics of Pre-Service Teachers' Self-Efficacy Scores According to Gender

		n	x	*SD*	Skewness	Kurtosis	Min	Max
PSAT	Female	240	12.50	4.10	-.22	-.48	0	20
	Male	82	12.33	4.93	-.28	-.47	0	20
ERAT	Female	240	9.61	3.05	-.42	-.53	1	14
	Male	82	9.84	3.17	-.49	-.64	2	14
Total	Female	240	22.12	5.32	-.12	-.49	7	34
	Male	82	22.17	6.59	-.56	.62	2	34

According to Table 2, the number of individuals in each gender group should be greater than 15 (Pallant, 2007). In addition, a normal distribution is considered to have been achieved as the kurtosis and skewness values are between +2 and -2. Finally, the Levene test results are examined for the homogeneity of variance (see Table 3).

Table 3

Levene Test Results

Levene Statistic	Sig.		
	PSAT	ERAT	Total
	.08	.75	.11

According to Table 3, the Levene test regarding the equality of variances shows the variance for all factors and the scale to be equal ($p > .05$) for the analysis of astronomy self-efficacy scores. The results from the independent samples t-test for the data obtained from the pre-service teachers regarding gender are presented in Table 4.

Table 4

Independent Samples t-Test Results of Pre-Service Teachers' Self-Efficacy Scores According to Gender

		x	t	*df*	*p**
PSAT	Female	12.50	.32	320	.75
	Male	12.33			
ERAT	Female	9.61	-.58	320	.56
	Male	9.84			
Total	Female	22.12	-.08	320	.94
	Male	22.17			

Note. *$p < .05$

When examining Table 4, the pre-service teachers' scores for the PSAT and ERAT sub-scales and total scores were determined to show no significant difference according to gender ($p > .05$). Moreover, when considering the averages, the female and male pre-service teachers both have low mean scores.

Investigating Pre-Service Teachers' Self-Efficacy Beliefs According to Age

The descriptive statistics on the self-efficacy scores of the pre-service teachers according to age are presented in Table 5.

Table 5

Descriptive Statistics of Pre-Service Teachers' Self-Efficacy Scores According to Age

	Age (yrs)	*n*	x	*SD*	Skewness	Kurtosis	Min	Max
PSAT	19-21	204	12.57	4.33	-.29	-.40	0	20
	22+	118	12.27	4.31	-.20	-.39	0	20
ERAT	19-21	204	9.68	3.12	-.40	-.64	1	14
	22+	118	9.65	3.01	-.50	-.41	2	14
Total	19-21	204	22.25	5.61	-.25	-.09	6	34
	22+	118	21.92	5.76	-.37	.37	2	34

According to Table 5, the number of individuals in each age group is greater than 15, and the kurtosis and skewness values are between +2 and -2, which shows the normal distribution. The Levene test results have been examined for homogeneity of variance (see Table 6).

Table 6

Levene Test Results

Levene Statistic	Sig.		
	PSAT	ERAT	Total
	.93	.42	.72

According to Table 6, the Levene test for the equality of variances shows the variance for the sub-factors and the whole scale to be considered equal for analysing astronomy self-efficacy scores in terms of age ($p > .05$). The independent samples t-test for the data obtained from the pre-service teachers in terms of age is given in Table 7.

Table 7

Independent Samples t-Test Results of Pre-Service Teachers' Self-Efficacy Scores According to Age

	Age (yrs)	*n*	x	*SD*	t	*df*	*p**
PSAT	19-21	204	12.57	4.33	.60	320	.55
	22+	118	12.27	4.31			
ERAT	19-21	204	9.68	3.12	.08	320	.94
	22+	118	9.65	3.01			
Total	19-21	204	22.25	5.61	.50	320	.62
	22+	118	21.92	5.76			

Note. $*p < .05$

When examining Table 7, no significant difference has been determined to exist between pre-service teachers' self-efficacy scale sub-factors or total scores with respect to age ($p > .05$).

Investigating Pre-Service Teachers' Self-Efficacy Beliefs According to Having Taken a Previous Astronomy Class or Participated in an Astronomy/Sky-Watching Activity

The descriptive statistics regarding the pre-service teachers' self-efficacy scores with respect to having taken a previous astronomy class or participated in an astronomy/sky-watching activity are shown in Table 8.

Table 8

Descriptive Statistics of Pre-Service Teachers' Self-Efficacy Scores According to Having Taken a Previous Astronomy Class or Participated in an Astronomy/ Sky-Watching Activity

		n	x	*SD*	Skewness	Kurtosis	Min	Max
Astronomy Course	Yes	37	23.78	5.81	-.13	-.90	12	33
	No	285	21.92	5.62	-.33	.19	2	34
Astronomy and Sky Activity	Yes	41	23.95	5.50	-.46	-.63	12	32
	No	281	21.87	5.65	-.28	.20	2	34

According to Table 8, the number of individuals in each group is seen to be greater than 15, and the kurtosis and skewness values to be between +2 and -2. In this context, the group shows normal distribution. The Levene test results have been examined for the homogeneity of variance (see Table 9).

Table 9

Levene Test Results

Levene Statistic	Sig.	
	Astronomy course	Astronomy/sky-gazing activity
	.64	.85

According to Table 9, the Levene test for the equality of variance shows the variance for both factors and the whole scale to be able to be accepted as equal for the analysis of astronomy self-efficacy scores related to having taken a previous astronomy class or been involved in an astronomy/sky-gazing activity ($p > .05$).

The independent samples t-test for the data obtained from pre-service teachers regarding having taken a previous astronomy class or participated in an astronomy/sky-gazing activity is given below.

Table 10

Independent Samples t-Test Results of Pre-Service Teachers' Self-Efficacy Scores According to Having Taken a Previous Astronomy Class or Been Involved in an Astronomy/Sky-gazing Activity

		n	x	*SD*	t	*df*	*p**
Astronomy Course	Yes	37	23.78	5.81	1.90	320	.06
	No	285	21.92	5.62			
Astronomy and Sky Activity	Yes	41	23.95	5.50	2.22	320	.03*
	No	281	21.87	5.65			

Note. * $p < .05$

When examining Table 10, the pre-service teachers' scores obtained from the self-efficacy scale were found to show no significant difference with respect to whether or not they had taken an astronomy class ($p > .05$); however, a significant difference was determined with respect to whether or not they participated in an astronomy/sky-gazing activity ($p < .05$).

Investigating Pre-Service Teachers' Self-Efficacy Beliefs According to Grade Level

The descriptive statistics regarding pre-service teachers' self-efficacy scores according to grade-level variables are presented in Table 11.

Table 11

Descriptive Statistics of Pre-Service Teachers' Self-Efficacy Scores According to Grade Level

	Grade	*n*	x	*SD*	Skewness	Kurtosis	Min	Max
PSAT	3rd year	152	12.59	4.02	-.22	-.41	1	20
	4th year	170	12.35	4.58	-.26	-.48	0	20
ERAT	3rd year	152	9.55	9.55	-.38	-.68	2	14
	4th year	170	9.78	9.78	-.49	-.49	1	14
Total	3rd year	152	22.13	5.17	-.18	-.38	6	32
	4th year	170	22.13	6.09	-.35	-.19	2	34

According to Table 11, the number of individuals in each group with regard to grade level is seen to be greater than 15, and the kurtosis and skewness values to be between +2 and -2. In this sense, the group shows normal distribution. The Levene test results have been examined for the homogeneity of variances (see Table 12).

Table 12

Levene Test Results

Levene Statistic	Sig.		
	PSAT	ERAT	Total
	.06	.33	.09

According to Table 12, the Levene test for the equality of variances shows the variance for the sub-factors and the whole scale to be able to be considered equal for the analysis of astronomy self-efficacy scores with respect to grade level ($p > .05$). The independent samples t-test for the data obtained from the pre-service teachers regarding grade level is given in Table 13.

Table 13

Independent Samples t-Test Results of Pre-Service Teachers' Self-Efficacy Scores According to Grade Level

	Grade	*n*	x	*SD*	t	*df*	*p**
PSAT	3rd year	152	12.59	4.02	.49	320	.62
	4th year	170	12.35	4.58			
ERAT	3rd year	152	9.55	9.55	-.69	320	.49
	4th year	170	9.78	9.78			
Total	3rd year	152	22.13	5.17	.00	320	.99
	4th year	170	22.13	6.09			

Note. $^*p < .05$

When examining Table 13, no significant difference has been determined to exist between pre-service teachers' sub-factors and total scores with respect to grade level ($p > .05$).

Investigating Pre-Service Teachers' Self-Efficacy Beliefs According to Department

The descriptive statistics regarding pre-service teachers' self-efficacy scores according to their department are presented in Table 14.

Table 14

Descriptive Statistics of Pre-Service Teachers' Self-Efficacy Scores According to Programme

	Programme	*n*	x	*SD*	Skewness	Kurtosis	Min	Max
PSAT	Science	122	14.20	4.10	-.40	-.62	3	20
	Classroom	110	11.40	4.17	-.23	-.40	0	19
	Social Studies	90	11.40	4.07	-.30	-.01	0	20
ERAT	Science	122	9.64	2.85	-.47	-.29	2	14
	Classroom	110	10.19	3.12	-.59	-.37	1	14
	Social Studies	90	9.08	3.23	-.24	-.90	2	14
Total	Science	122	23.84	5.53	-.36	-.23	7	34
	Classroom	110	21.59	6.18	-.19	-.09	6	31
	Social Studies	90	20.48	5.84	-.36	.59	2	34

When examining Table 14, the highest mean among the total score averages is among the pre-service science teachers (x = 23.84), and the lowest average belongs to the pre-service social science teachers (x = 20.48). In general, the mean scores of the pre-service teachers' astronomy self-efficacy are low. The number of individuals in each group with respect to programme/department is also e greater than 15, and the kurtosis and skewness values are between +2 and -2. In this sense, the group shows a normal distribution. The Levene test results have been examined for the homogeneity of variance (see Table 15).

Table 15

Levene Test Results

Levene Statistic	Sig.		
	PSAT	ERAT	Total
	.44	.30	.17

According to Table 15, the Levene test for the equality of variances shows the variance for the sub-factors and the whole scale to be equal for the analysis of astronomy self-efficacy scores with respect to programme ($p > .05$). One-way ANOVA results are shown in Table 16.

Table 16

One-Way ANOVA Results for Pre-Service Teachers' Astronomy Self-Efficacy Scores According to Their Department

		Sum of Squares	*df*	Mean Square	*F*	*p**
PSAT	Between Groups	592.70	2	296.35	17.52	.00*
	Within Groups	5397.28	319	16.92		
	Total	5989.98	321			
ERAT	Between Groups	61.53	2	30.76	3.30	.04*
	Within Groups	2975.58	319	9.33		
	Total	3037.11	321			
Total	Between Groups	632.75	2	316.38	10.45	.00*
	Within Groups	9657.77	319	30.28		
	Total	10290.52	321			

Note. $^*p < .05$

Table 16 shows the output from the one-way ANOVA analysis and whether a statistically significant difference exists between the groups' means. As seen from this table, t significant mean differences are found between groups for the dependent variable of programme/department ($F_{(2, 319)} = 10.450$, $p < .05$;

$F_{(2, 319)} = 17.515$, $p < .05$; $F_{(2, 319)} = 3.298$, $p < .05$). When calculating the effect size for the total score, the result is .06. In other words, the pre-service teachers' department accounts for approximately 6% of the variance in their self-efficacy scores. The results from the Bonferroni posthoc test, which was conducted to determine the differences among the groups, are given in Table 17.

Table 17

Post-Hoc Test Results

Dependent Variable	(I) programme	(J) programme	Mean Difference (I-J)	Std. Error	Sig.	Bonferroni
PSAT	Science	Classroom	2.25*	.72	.01	Science > Classroom Science > Social Studies
		Social Studies	3.36*	.76	.00	
	Classroom	Science	-2.25*	.72	.01	
		Social Studies	1.11	.78	.47	
	Social Studies	Science	-3.36*	.76	.00	
		Classroom	-1.11	.78	.47	
ERAT	Science	Classroom	2.80*	.54	.00	Classroom > Science Science > Social Studies
		Social Studies	2.80*	.57	.00	
	Classroom	Science	-2.80*	.54	.00	
		Social Studies	.00	.58	1.00	
	Social Studies	Science	-2.80*	.57	.00	
		Classroom	.00	.58	1.00	
Total	Science	Classroom	-.55	.40	.51	Classroom > Social Studies
		Social Studies	.56	.42	.56	
	Classroom	Science	.55	.40	.51	
		Social Studies	1.11*	.43	.03	
	Social Studies	Science	-.56	.42	.56	
		Classroom	-1.11*	.43	.03	

As a result of the Bonferroni posthoc test performed in Table 17; departmental differences were found between the science and classroom (in favour of science) and between the science and social studies (in favour of science) for PSAT, between the science and classroom (in favour of classroom) and between the science and social studies (in favour of science) for ERAT.

When considering the averages in general, the pre-service teachers studying in the various departments have low levels of self-efficacy with regard to astronomy. Noteworthily, the lowest levels occur among the pre-service teachers in all three department types for the ERAT factor in particular.

Conclusion, Discussion and Recommendations

This study has been conducted to examine the status of self-efficacy beliefs regarding astronomy teaching for teachers enrolled in science education, classroom education, and social studies education programmes. The results were evaluated according to different variables (gender, age, programme, grade level, whether or not they had taken an astronomy course, and whether or not they had participated in an astronomy/sky-gazing activity). The study took the variable of gender into consideration for the first sub-problem and has concluded no significant difference to be present in terms of total astronomy self-efficacy scores between the female and male pre-service teachers. Other studies in the literature have also stated that no significant difference exists for self-efficacy beliefs in terms of gender (Akbaş & Çelikkaleli, 2006; Çakıroğlu et al., 2005). As Akbaş and Çelikkaleli (2006) asserted, the reason for no variance in the self-efficacy beliefs of pre-service teachers in terms of gender can be said to result from the increasing success of women's roles in society and, therefore, no limitation occurs between women and men. However, Anderman and Young (1994) and Britner and Pajares (2006) reported finding a difference between males' and females' self-efficacy levels.

Similarly, Formanek et al. (2019) examined the relationship between students' motivation and course participation in an open online course on astronomy and found males to show higher self-efficacy levels. According to Bandura (2002), the reason for obtaining different findings in studies may be intercultural differentiation, because self-efficacy beliefs according to gender may differ between cultures. The current study is limited to a conclusion about whether there is a difference in terms of gender only, and the cultural dimension can be investigated in future studies.

The current study concludes that the astronomy self-efficacy beliefs of pre-service teachers do not differ according to age. Considering the studies conducted with different age groups on the relationship between self-efficacy and age, Seferoğlu and Akbıyık (2005) also found no significant difference according to age in terms of computer self-efficacy perceptions; their reason for this was that participants may be close in age. When considering the same situations, the pre-service teachers of the current study have also been determined to be very close in age, and thus their astronomy self-efficacy levels are thought to resemble one another.

In contrast, it was determined that there was no significant difference in the science self-efficacy beliefs of primary school teachers according to the age variable, while there was a significant difference between those younger than

25 years old and other groups in the sub-factors of efficacy belief and outcome expectation. It has been determined that this difference is in favour of teachers who are older than 25 for efficacy belief and in favour of those younger than 25 for outcome expectation according to the study conducted by Bozkurt Uluçay and Akıllı (2021). Yıldırım and Karataş (2020) stated that students' self-efficacy levels decrease as age increases. Research needs to be increased to explain the relationship between self-efficacy and age in the literature better.

Similarly, while the current study is limited to the fact that there is no significant difference between the astronomy self-efficacy of pre-service teachers who had taken astronomy classes, it is recommended to determine the reasons for this situation for future studies. Because, when considering that individuals gain experience from work and will feel more able to finish or perform work they had previously done, those who had experience with an astronomy/sky-gazing activity will inevitably have higher self-efficacy beliefs. Those who had previously taken a course in astronomy were similarly expected to have higher self-efficacy; however, this study found no difference. In this regard, Bandura (1977) states that the knowledge, skills, and learned strategies will not be functional unless the person can use them under appropriate conditions. According to Pasachoff and Percy (2005), the most effective methods for learning astronomy are based on direct experience and observations. This situation may result from different variables, such as the difference in course content or teaching process, and thus in student academic achievement. Güneş' (2010) study on pre-service teachers showed a statistically significant relationship between academic achievement and self-efficacy belief in teaching astronomy. Moreover, Susman and Pavlin (2020) stated that in-service teachers expounded on how they felt uncomfortable teaching astronomy topics during the teacher training despite having worked on models of the solar system, moon phases, and eclipses. This result also supports the results from the current study.

When considering that students' self-efficacy beliefs are sensitive to changes in their lifelong learning experiences (Oğuz, 2012), differentiating by one grade level may not be enough to show variations in their self-efficacy beliefs. In addition, the introduction of similar courses in the field of education that have topics on astronomy in the 3rd and 4th years of schooling may be another reason for the similarity of self-efficacy beliefs toward astronomy teaching in these grades. Unlike the current study, Şenler (2017) studied the self-efficacy beliefs of science teacher candidates regarding science teaching and examined their views on scientific inquiry; it was found that pre-service teachers' self-efficacy beliefs decrease after their second year as their grade level increases (i.e., from sophomore year to junior year and from junior year to senior year). The reason for this was explained as students' self-confidence increasing in their sophomore year through their education and field courses, while the more intense lessons in their junior and senior years and increased exam anxiety had caused lower self-efficacy. Bailey et al. (2017) stated physiological and affective states also possibly impact self-efficacy. In this case, they stated any change in self-efficacy to be related not only to the existence of a source but also to how the individual internalises the information arising from that source. A difference was observed to occur among the pre-service teacher groups with regard to programme/department for both sub-factors and the total score. This generally was in favour of the pre-service science teachers for all scores (sub-factors and total). When considering that students who developed academic skills regarding science since elementary school are also able to develop competencies such as expectations and self-perception, this is thought to have a greater effect on their self-efficacy development when compared to pre-service classroom or social studies teachers. Demirtaş et al. (2011) reached a different result in their study in terms of total scores obtained from the self-efficacy scale, with pre-service teachers studying in the Turkish, social studies, music, and painting education departments perceiving themselves to be better qualified, compared to pre-service teachers studying in the classroom, preschool, science, or elementary mathematics teaching departments. Demirtaş et al. stated the reason for self-efficacy scores being higher is due to those lessons (e.g., music and painting) being more popular with students. In this sense, saying that studies in the literature on self-efficacy conducted over certain variables such as programme/department have achieved consistent results would be difficult.

Ashton (1984) claimed no other teacher trait to show as consistent and close a relationship with student achievement as teachers' self-efficacy. The importance of this situation was also stated in Walan and Chang Rundgren's (2014) study. In this context, the importance of determining self-efficacy beliefs in relation to teaching topics on astronomy has been emphasised through the present study's results. In terms of developing self-efficacy in this sense, self-efficacy beliefs regarding astronomy teaching are important (Bailey et al., 2017) and organising activities and projects where pre-service teachers can gain experience is recommended so that their self-confidence may increase. In this sense, activities suitable for the constructivist approach may be beneficial. For example, increasing student participation when teaching topics on astronomy and focusing on class management are thought to increase teachers' self-efficacy. In this sense, it can be said that the importance of practical applications will be remarkable, because the factor that has the strongest effect on the development of individuals' self-efficacy perceptions is direct experiences (Bandura, 1977).

Thus, the results of these applications can be analysed in future studies.

The current research has used the survey study design for determining the participants' statuses. The change in pretest-posttest practices of pre-service teachers' self-efficacy beliefs regarding astronomy can also be examined by considering different variables. Different studies may also be carried out using qualitative-based research methods to investigate the reasons for their lack of self-efficacy.

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Biographical note

Ebru Ezberci Cevik, PhD, is an associate professor in the field of science education at the Faculty of Education, University of Erciyes, Turkey. Her research interests include astronomy education, model and modeling, grounded mental model theory. She has published articles and papers on related topics. She took part in national research projects on science education. Her current research focus is augmented reality, teacher education and high-level thinking skills.

Oktay Bektas, PhD, is a professor in the field of science education at the Faculty of Education, University of Erciyes, Turkey. His main areas of research are chemistry education, teacher education, nature of science, pedagogical content knowledge, test development, and epistemology. Oktay BEKTAS has nearly 200 articles and papers. Seven of them were published in SSCI indexed journals, and many of them were published in indexed journals such as ESCI and ERIC. He is a chapter writer in two books and an editor in one book. As a project, he took part in 25 projects.

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Xana Sá-Pinto, Anna Beniermann, Tom Børsen, Martha Georgiou, Alex Jeffries, Patrícia Pessoa, Bruno Sousa and Dana L. Zeidler (Eds.), *Learning Evolution Through Socioscientific Issues*, UA Editora, 2022; 219 pp.: ISBN: 978-972-789-822-0

Reviewed by Bento Cavadas[1]

Learning Evolution through Socioscientific Issues is a vital contribution to how evolution can be mobilised through complex, open-ended and controversial issues that embed science content and practices to inform solutions to the social issues in which they occur (Kinslow et al., 2019). The book resulted from the collaborative effort of an international team of experts that included teachers, science museum practitioners, evolutionary biologists, and science education researchers. The editors and chapter authors have succeeded in presenting a comprehensive collection of testimonies that is very useful for educators, evolutionary biologists, science education researchers, science communicators, policymakers, and other professionals interested in the connections between socio-scientific issues (SSI) and evolution. The book explores a broad range of issues and highlights the connections between evolution and SSI in formal and non-formal educational contexts, scientific literacy, and sustainable development. The book also abundantly presents key factors of evolution teaching and valuable suggestions for educators.

Connections between evolution & SSI in formal education practices

The word cloud of the keywords of the book's chapters shows that the most common word used is education, closely followed by evolution (Figure 1).

1 Polytechnic Institute of Santarém; Lusófona University, CeiED - Interdisciplinary Research Centre for Education and Development, Portugal; bento.cavadas@ese.ipsantarem.pt.

Figure 1

Word cloud of the keywords of the book chapters

The central place of education in this book is not surprising because most of the authors of the chapter have a strong educational background, which is reflected in their approach to evolutionary issues from an SSI perspective. In fact, evolution education is a challenging issue that has long attracted educators' and researchers' attention. One ongoing concern is what educational strategies are effective for promoting students' scientific literacy on evolution. From my perspective as a science educator, teaching it through SSI is a relevant approach to achieving that purpose. Although not limiting itself to formal education, the book has great relevance for educators in formal settings.

Connections between evolution & SSI in formal contexts

Educators interested in practice descriptions to explore SSI and evolution will find them in six complementary chapters that cover an array of specific topics. For example, in Chapter 8, *Evolving cooperation and sustainability for common pool resources*, Hanisch, Eirdosh, and Morgan present a detailed practice description organised in a unit with five lessons, targeting 15- to 18-year-old students, on how people can cooperate and sustainably manage their shared resources. Starting from the presentation of case studies or models based on agent-based computer simulations, students must predict the outcomes of the situation presented. The unit concludes with a project in which students are asked to mobilise their understanding of the complexity of social-ecological systems to analyse a specific SSI. The final task is the communication of results to stakeholders, which is a strategy to promote the project's outreach and develop the students' communication skills.

Also targeting 15- to 18-year-old students, in Chapter 11, *The impacts of solar radiation on our health*, Ponce, Carneiro, Rodrigues, and Topçu present a practice description that explores how the differences in solar radiation across the globe impact the health of individuals with variations in skin colour differently and historically influenced the evolution of human populations. Based on this knowledge, the authors promote the students' discussion of the use of ethnic information to communicate about health issues using an SSI approach. Throughout four sessions, students learn about the evolution of skin colour, skin colour distribution, and the impacts of solar radiation on human health and reflect on a set of questions related to medical and ethical issues. In addition, educators will find questions outlined by the chapter's authors to foster discussion about the previous issues, as well as valuable tips on how to manage the sessions.

In this comprehensive book, high school teachers also can find activities specifically created to explore human evolution with high school students. For example, in Chapter 7, *Opportunities to deal with human evolution*, Siani and Yarden use lactose tolerance, celiac disease, and starch consumption affecting diabetes as topics to explore human evolution. The related activities were created within the framework of four specific design principles and implemented in an online context. The authors argue that discussing genetic evidence with students is one possible way to enhance their knowledge and evolution acceptance. A rationale for this is that, by comparing the DNA sequences of different species, similarities between them can be observed and represented through a numerical score. The activities were also designed to prevent students from putting forward teleological explanations and to promote their understanding of the nature of science. Siani and Yarden also present valuable suggestions for teaching practices, arguing that the use of human evolution examples is a powerful evolution education strategy. For example, the lactose tolerance activity exposed the students to the fact that humans are the product of evolution and are still evolving, just like every other organism.

If the educator is interested in an SSI approach to genetic engineering for 12- to 18-year-old students, Chapter 12, *Are we allowed to tinker with (human) DNA? Addressing socioscientific issues through philosophical dialogue - the case of genetic engineerin*g, provides an interesting activity. In this chapter, De Schrijver, Blancke, Comelissen, Sermeus, and Dunlop propose philosophical inquiry as a relevant approach to address SSI related to genetic engineering. In this approach, students are asked to look for answers to challenging philosophical questions. Specific examples of philosophical questions that do or do not work in philosophical dialogue and philosophical follow-up questions are presented. Furthermore, the tips for practice presented by the authors concerning the questions that the facilitator can ask students for clarity, arguments, alternative perspectives, implications, consequences, and meta-reflections, help to clarify the management of the philosophical dialogue. Dialogue examples are also presented in the description of the educational practice, and they also prove to be of high value for those educators who are looking for specific examples of how to manage philosophical questions in a genetic engineering context.

If your students are younger, look at the activity in Chapter 10, *Why are pollinators declining?*, proposed by Lewis, Bell and Kent for 11–14-year-olds. Pollinator decline is a major global risk for society because it harms ecosystems services and impacts food production and other aspects of human well-being (Dicks et al., 2021). The authors propose that students act as farmers and reflect on how to balance pollinators' conservation with the unpredictable impacts of environmental and socio-economic factors on the farmers' profits, using a gamification strategy. Throughout the game, students can explore evolutionary biology concepts, such as specialisms in plants and pollinators, co-evolution, or the differential disease resistance between species. Finally, the activity concludes with discussion points to facilitate students' understanding of the complexity of SSI from a societal perspective.

College teachers can also find detailed practice descriptions targeting higher education students in this book. For example, in Chapter 9, *Considering evolution as a socioscientific issue: an activity for higher education*, Cebesoy describes an educational practice about natural selection within the context of antibiotic-resistant bacteria, a major worldwide socio-scientific problem (Centers for Disease Control and Prevention, n.d.; European Centre for Disease Prevention and Control, n.d.). Organised in three lessons, this chapter offers educators valuable suggestions for engaging higher education students with collaborative work around the core ideas of natural selection and its transposition to antibiotic resistance. Furthermore, in the appendix, the author presents the reading materials and additional sources used in the lesson, which are very good starting points for anyone who wants to address this topic.

Connections between evolution & SSI in non-formal contexts

Those interested in exploring the connections between evolution and SSI in non-formal contexts, such as museums, will find relevant insights in Chapter 4, *SSI approach out of schools - How can these approaches be used in science museums and other non-formal education contexts?* Through a case study approach of three natural history and science museums, Georgiou, Fonseca, Fortin, Turpin, and Roux-Goupille present the reader with interesting examples of how to explore biodiversity, SSI and citizen science in non-formal educational contexts. The relationship between SSI and biodiversity is explored by the Natural History and Science Museum of the University of Porto through hypercubic displays. These displays provide the setting in which the aesthetic, ethical, economic and scientific principles are explored. The theme of biodiversity is also at the core of one activity proposed by the Zoological Museum of the Biology Department of the University of Athens. Presenting to the participants different (endemic and non-endemic) animal species living in Greece, their risk categories and the causes that lead to the extinction of endangered species are the starting points to question the place of humans among other living organisms in order to emphasise that human beings are just one of them. The French National Museum of Natural History focused its SSI approach on a citizen science project, fostering the participation of primary, middle or high school teachers and students in the science project 'Vigie-Nature École' (VNE). By monitoring wildlife, participants engage in decision-making processes related to the conservation of biodiversity in a local context. Using a simple, albeit effective and accurate protocol, participants are invited to make bird observations in urban areas and express the results using a digital tool. This out-of-school activity, although starting from a non-formal context, could be transferred to formal educational contexts. The authors of the chapter discuss that, by experiencing the natural world and becoming immersed in nature, people scaffold their emotional and affective responses towards the SSI issue, which can trigger individual and collective action.

Key factors of evolution teaching

A valuable chapter for all teachers and other educators who wish to address evolution effectively is Chapter 6, *Evolution education and outreach: important things to know about how to teach about evolution*. The authors, Nehm and Kampourakis, alert teachers to the fact that language misunderstandings can compromise learners' comprehension of evolution. To overcome this difficulty, the authors present and discuss common and problematic terms that must be explicitly addressed prior to and during outreach and evolution education. For example, terms such as 'fitness' and 'adaptation' can have different meanings in everyday language and in scientific contexts, and teachers must be aware that some students do not have sufficient content knowledge to apply those terms to evolution contexts properly. Furthermore, the authors also describe a set of cognitive biases and misconceptions that teachers and science communicators must be aware of when addressing students or the general public. These misconceptions can impact the learners' reasoning and ability to learn about evolutionary phenomena. To overcome those biases and misconceptions, Nehm and Kampourakis offer valuable didactic suggestions, such as a focus on disciplinary core ideas, cross-cutting concepts and science practices. For example, the authors suggest that presenting cross-case comparisons, and aligning the cases presented with the students' interests, could foster their motivation to learn about evolution. A set of pedagogical and assessment approaches that could help teachers evaluate the effectiveness of their evolution education practices and communication is also discussed.

Using 'hooks' to foster and maintain the participants' interest in evolution is a theme addressed in Chapter 5, *How is evolution impacting our lives*, by Jeffries, who presents a point of view focused on the exploration of real-life evolution contexts which impact human life, to engage learners in the topic. The relationship between evolution and ethics, cancer, biodiversity change and Covid-19 are presented as powerful examples of real-life evolution contexts that can act as drivers for evolution understanding by enhancing students' involvement with this topic.

Relationship between evolution, SSI and scientific literacy

As highlighted in the editorial, the chapters discuss, from a variety of angles, the mobilisation of SSI as a valuable pedagogical strategy to develop scientific literacy. According to the National Academies of Sciences, Engineering, and Medicine (2016), one of the common aspects of individual science literacy is the cultural understanding of science. This dimension acknowledges the 'interrelationships of science and society and science and the humanities and recognises science as a major human achievement' (NASEM, 2016, p. 33). These interrelationships of science and society were approached by the authors of Chapter 2, *Using socioscientific issue approach to promote students' scientific literacy*. Sankaya and Topçu outline the connections between two models that can support educators with the development of SSI-Based instruction, the socio-scientific instructional model, first described by Friedrichsen et al. (2016), and the 5E teaching model, developed by Bybbe et al. (2006). The argument is that starting from this framework, educators can explore different visions of scientific literacy and mobilise them to develop competencies in their students.

Connections between evolution, SSI, and sustainable development

The relationship between evolutionary biology and sustainable development is a theme that crosses many chapters of this book but is more explicitly addressed in Chapter 3, *Evolution education through SSI for sustainable development*. Through a systematic literature review, Pessoa, Lopes, Pinto, and Sá-Pinto analyse which evolution key concepts are explored in studies that use SSI approaches to promote evolution education and which competences in sustainability these most often address. In the chapter's Table 2, the authors provide a list of papers addressing specific dimensions of evolution education (history of life, evidence of evolution, mechanism of evolution, and studying evolution) that might be especially interesting for educators looking for inspiration to explore specific dimensions of evolution education in an SSI context. The authors state that, although approaches addressing SSI from an evolutionary perspective are still scarce and not very diverse, they show great potential to foster students' key competencies in sustainability and to empower them to become active promotors of sustainable development. The authors stress the need to diversify and increase the number of approaches that promote evolution education through SSI to develop students' key competencies in sustainability. They also highlight the importance of enhancing the engagement of schools and students with external stakeholders related to diverse SSI and the promotion of collaborative work among the students.

The book *Learning evolution through socioscientific issues* sheds light on the connections between the SSI approach and evolution education. Giving voice to many different experts in this field, the editors were proficient in presenting a wide range of educational strategies to improve the understanding of evolution and the development of socio-scientific reasoning. The cross-disciplinary approach used is remarkable and constitutes a valuable tool for educators that want to address evolution in interdisciplinary settings and different contexts. Although the book presents a comprehensive approach to the issues discussed, it also leaves room for further analysis and reflection. The authors put forward many pressing and valuable questions relating to further studies to better understand the full potential of evolution and SSI.

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Reviewed by Jerneja Pavlin[1]

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Recently, much attention has been paid to scientific literacy, which can be defined in several ways. Roughly speaking, scientific literacy is defined as the knowledge and understanding of scientific concepts and procedures necessary to make personal decisions in civil, cultural, and economic matters (OECD, 2018). It is an essential outcome of school science. However, the fundamental goal of science education research is to understand and improve the learning and teaching of science to develop scientific literacy. Understanding how science concepts are learned is necessary so that teaching can be adapted to students' needs and effective learning can occur. To explore this, the increasing use of modern technologies in educational research (e.g., recording students' eye movements) has opened up new research areas in science education. With it, researchers can use various methods to collect learning data, which are relatively more objective than observations, interviews, questionnaires, and similar methods (Devetak & Ferk Savec, 2020; Docktor & Mestre, 2014; Torkar et al., 2018; Tóthová et al., 2021). However, the interpretation of psychophysiological data should be carefully considered.

The book *Applying Bio-Measurements Methodologies in Science Education Research* considers the above point and presents several chapters on the application of specific bio-measurement methods, focusing on eye-tracking

1 Faculty of Education, University of Ljubljana, Slovenia; jerneja.pavlin@pef.uni-lj.si.

technology that can be used in education. As written in the book's preface, teachers who examine students' oral or written responses typically have no insight into how students solved specific problems and how they arrived at their correct or incorrect solutions. Therefore, with the methods used in physiology, data can be obtained by scanning the central nervous system (brain). Solving mental tasks is accompanied by physiological responses. These not only indicate a stressful situation but are probably related to the cognitive load during the problem-solving process. Therefore, another group of devices collects data from specific parts of the human body's activities that originate in autonomic nervous system dynamics, such as measurements of heart rate, heart rate variability, blood pressure, skin conductance, skin temperature, facial thermogram, respiratory rate and amplitude, pupil dilatation, and eye movements.

The book was edited by Iztok Devetak, PhD, and Saša Aleksij Glažar, PhD, professors of chemistry education at the Faculty of Education, University of Ljubljana, Slovenia. Glažar is also a professor emeritus of chemistry education at the same university. The preface, which includes the importance of science education and a brief overview of the content, is followed by 15 chapters written by 37 authors from 8 countries (Croatia, Finland, Germany, Poland, Slovenia, Taiwan, Turkey, USA). The book starts with three general chapters describing cognitive processes and how these processes are measured using eye-tracking methods and other psychophysiological parameters, as well as motivation. This is followed by chapters presenting studies in specific scientific areas of chemistry (4 chapters), biology (2 chapters), physics (5 chapters), and geology (1 chapter). A brief description of all 15 chapters follows.

The first chapter by Anja Podlesek, Manja Veldin, Cirila Peklaj, and Matija Svetina, titled *Cognitive Processes and Eye-Tracking Methodology*, discusses psychological aspects of eye-tracking approaches in cognitive research, focusing on cases from science education. They present the case study of two 7^{th}-grade students exhibiting individual eye movement differences.

Chapter 2, *The Interplay of Motivation and Cognition: Challenges for Science Education Research and Practice*, authored by Mojca Juriševič and Tanja Črne, examines two internal variables-student motivation and visual attention-and how they affect learning processes. The authors present in detail motivation in learning, challenges in learning and teaching science, including examples of potential problems in learning motivation and the development of visual attention.

The third chapter, *Predicting Task Difficulty Through Psychophysiology*, prepared by Junoš Lukan and Gregor Geršak, argues that mental task solving is accompanied by physiological responses. An attempt to predict the difficulty of the task perceived by the subject on the basis of physiology is described. To answer the question of how best to predict the perceived difficulty of a task based on physiological responses, it was first necessary to select a measure of each physiological process. It was found that skin temperature, respiratory rate, heart rate, and skin conductance best predicted task difficulty.

Chapters 4 through 7 present the research work from the field of chemistry education.

In Chapter 4, *The Role of the Explanatory Key in Solving Tasks Based on Submicroscopic Representations,* Vesna Ferk Savec and Špela Hrast present the analysis of Slovenian chemistry textbooks with a focus on the sub-microscopic representations that were integrated into the textbooks to illustrate the particle nature of chemical concepts and processes and to facilitate learning chemistry with understanding. To facilitate students' learning of chemistry in a meaningful way, the representations must be properly understood by students, and the explanatory key accompanying them can play an essential role in this process. The role of the explanatory key in processing sub-microscopic representations in solving chemistry problems was investigated. Attention was given to the use of pictorial and textual explanatory keys accompanying the representations, which were investigated using eye-tracking and interviews with students.

In the fifth chapter, *Investigating the Role of Conceptual Understanding on How Students Watch an Experimental Video Using Eye-Tracking*, Sevil Akaygun and Emine Adadan explore how eye-tracking technology can be used to explore the role of students' (preservice science or chemistry teachers) conceptual understanding of how they navigate tasks to be solved while watching an experimental video of a redox reaction. Eye-tracking technology can be used to investigate how different levels of understanding can induce students to follow different aspects of an experimental video. Students' levels of understanding of redox reactions played a role in the patterns of their eye movements as they looked where they needed to look, remained focused, and ignored other details as they were more mentally engaged.

In the sixth chapter, entitled *Using an Eye-Tracker to Study Students' Attention Allocation when Solving a Context-Based Problem on the Sublimation of Water*, Miha Slapničar, Valerija Tompa, Iztok Devetak, Saša A. Glažar, and Jerneja Pavlin present the importance of 3D-dynamic sub-microscopic representations for solving specific chemical tasks. The students' attention allocation on the areas of interest in solving context-based tasks involving macroscopic and sub-microscopic levels of sublimation of water representations was investigated. The research objective was to identify differences between successful and unsuccessful students in overall fixation duration, visit count, and average pupil size. The research results provide an insight into the learning process (cognitive load) specific to the information processing of 3D-dynamic sub-microscopic representations.

Iztok Devetak prepared Chapter 7, entitled *Using an Eye-Tracking Approach to Explain Students' Achievements in Solving a Task about Combustion by Applying the Chemistry Triplet*. The author examined the chemistry triplet, including macroscopic, sub-microscopic, and symbolic levels of chemical concepts representations, as an essential part of teaching and learning chemistry and stressed that it is important to understand how students cognitively move between these representations when solving specific context-based task or problems. The significance of this research is in understanding how important the different levels of the chemistry triplet are to students in solving specific problems (in this study, the chemical reaction of burning) and how teachers can predict which levels should be more emphasised in chemistry lessons, depending on the level of chemical knowledge and skills of other students.

Two chapters (8^{th} and 9^{th}) presenting studies from the fields of biology and medical education follow.

The eighth chapter, *Pre-Service Teachers' Determination of Butterflies with Identification Key: Studying Their Eye Movements,* written by Tanja Gnidovec and Gregor Torkar, examines the ability of pre-service teachers (biology and primary school) to determine butterfly species with a simplified dichotomous identification key that includes illustrations, photographs, and a written description, using the eye-tracking method (determining students' visual attention). Analysis of eye movements showed that students preferred illustrations over photographs of butterflies in the identification process. Students mostly looked at both images (photographs and illustrations) in the process.

Chapter 9, *Case Processing in the Development of Expertise in Life Sciences-What Can Eye Movements Reveal?,* prepared by Ilona Södervik and Henna Vilppu, presents future experts in the life sciences with innovative forms of reasoning and the ability to use knowledge and skills adaptively in unforeseen and adverse contexts. The authors synthesise two studies (Study 1 about examining the effect of the level of expertise on case processing and Study 2 about students' processing of a non-routine case and its relationship to the level of their basic biological knowledge) using the eye-tracking method, in which routine and non-routine text-based case tasks were used to investigate processing and problem-solving by medical personnel with different levels and types of expertise. Eye-tracking provides interesting insights into knowledge integration and problem-solving through medical case processing.

Physics education studies are presented in the next five chapters (10 to 14).

Chapter 10, *Analysis of Aspects of Visual Attention when Solving Multiple-Choice Science Problems*, authored by Miroslava Sajka and Roman Rosiek, presents the aspects of visual attention when solving multiple-choice science problems involving mathematics or physics concepts; they were analysed using eye-tracking technology. The authors also examined how problem-solving strategies affected learners' visual attention. They emphasised that the methodology used in this study may be useful in determining the cognitive load of solving multiple-choice tasks during the decision-making process.

Jerneja Pavlin and Miha Slapničar, in Chapter 11, *The Impact of Students' Educational Background, Formal Reasoning, Visualisation Abilities, and Perception of Difficulty on Eye-Tracking Measures when Solving a Context-Based Problem with Sub-microscopic Representation*, emphasise the importance of several independent variables that can influence solving context-based tasks at the macroscopic and sub-microscopic levels. The exercise addresses the phenomenon of gas released when a bottle of sparkling water is opened. Their study aimed to find out how educational level, formal reasoning, and visualisation abilities influence the way students solve these tasks. Eye-tracker measurements (total fixation duration, visit count, average pupil dilatation) were taken while solving the task.

Chapter 12, prepared by Pascal Klein, Stefan Küchemann, Ana Susac, Alpay Karabulut, Andreja Bubic, Maja Planinic, Marijan Palmovic, and Jochen Kuhn, entitled *Students' Understanding of Diagrams in Different Contexts: Comparison of Eye Movements Between Physicists and Non-Physicists Using Eye-Tracking*, examines the understanding of line charts as a skill necessary for understanding information in science and everyday life. They compare physics and non-physics students on their understanding of graph slope and area under the graph in the context of physics and finance in two datasets from Germany and Croatia. Eye-tracking technology was used to investigate students' competencies in solving problems related to the slope and area under the graph.

Chapter 13, entitled *Task-Evoked Pupillary Responses in Context of Exact Science Education*, written by Roman Rosiek and Miroslawa Sajka, also addresses the importance of graphs in physics and mathematics. The results of eye-tracking research, in which changes in pupil diameter are observed and analysed when solving tasks related to graphs, are evaluated to determine if there are significant differences in the physiological response of individuals. Analysis of relevant changes in pupil diameter may be an indicator of subjective assessment of task difficulty and an indicator of motivation.

Chapter 14, the last chapter in the series of physics education papers, entitled *An Investigation of Visual and Manual Behaviors Involved in Interactions Between Users and Physics Simulation Interfaces*' and written by Guo-Li Chiou, Chung-Yuan Hsu, and Meng-Jung Tsai, illustrates the importance of computer simulation in physics education. Although computer simulations have been shown to have a positive impact on improving science learning, little is known about how users interact with simulation interfaces. The authors address the question of whether students with different learning performances distribute their visual attention while manipulating the simulations and whether students with different learning performances have different visual and manual behaviour patterns.

The final chapter, Chapter 15, of the book titled *Visualising Student Navigation of Geologic Block Diagrams* was written by Karen S. McNeal, Rachel Atkins, and Elijah T. Johnson. It relates to the problems of 3D visualisation in geosciences. The exploratory eye-tracking study provided unique insights not yet available to the geoscience education research community about how students with spatial skills navigate geological block diagrams, a 2D visualisation tool used in the geological sciences to represent conditions within a 3D geological formation. Eye-tracking was used as an exploratory method to investigate students' visual navigation approaches to spatial problems, particularly geological block diagrams used in the geological sciences. Spatial and temporal information about students' gaze patterns was collected and analysed using the different facets of the block diagrams as prominent locations, and the relationship between spatial abilities and visual patterns in problem-solving was investigated.

The book brings expertise and views from science education research to the discourse on broadening horizons in understanding learning processes when eye-trackers are incorporated into research in science education and in general. The book attempts to fully frame the topic and refers to a complex study on the topic of integrating eye-tracking measurements into science education research and lists interesting further research opportunities to understand learning even more comprehensively.

The book is aimed at science teachers and science education researchers, both in terms of the topic chosen and the way it is written. It contains some presentations of eye-tracking studies on concrete topics that can be elaborated at different educational levels. It also encourages science educators to include them in their didactics courses for pre-service and in-service teachers.

In summary, the book *Applying Bio-Measurements Methodologies in Science Education Research* provides a comprehensive overview of the use of eye-tracking in science education and its potential to explore and fully understand the learning process of students with different abilities. It provides a deeper understanding of the learning process and offers several guidelines for designing lesson plans with the goals of scientific literacy in mind.

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