



Assessing Knowledge, Attitudes, and Behavior of Primary School Pupils Regarding the Impact of the Global Ocean on Weather and Climate: A Case Study from Greece

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Abstract

The enormous importance of the global ocean in the existence of life and its connection to the weather and climate regulation constitute fundamental elements of the Ocean Literacy Framework through which the understanding of basic ocean sciences issues is attempted. The main aim of this study is to assess the degree to which a carefully designed and properly implemented Teaching-Learning Sequence by a university research team, regarding the third principle of the ocean literacy guide entitled “The ocean is a major influence on weather and climate” affected pupils’ awareness. For the needs of the study, a questionnaire, comprising multiple-choice knowledge questions and attitudes and behavior statements following a Likert-type scale, was administered to a class of 17 third-grade primary school pupils before (pre-test) and after (post-test) the end of the teaching intervention. The Teaching-Learning Sequence which, among others, involved lectures, hands-on activities, and the production of educational material lasted 10 hours and was realized entirely at school. Results revealed a significant increase in pupils’ knowledge regarding the interaction between the

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global ocean and the weather and climate as well as in their attitudes and behavior, which could be attributed to the success of the design and implementation of the teaching intervention.

Keywords

Ocean literacy · Climate literacy · Primary education · Pupils · Teaching-Learning Sequence · Knowledge · Attitudes · Behavior

Introduction

As all living beings are inextricably linked to the natural environment, changes in its quality affect organisms and the entire balance of nature, leading to great risks such as the loss of biodiversity (European Environment Agency 2021). Up-to-date scientific data reveal that environmental quality has an overall impact on both humans' physical and mental health, with the latter being severely affected in recent years as a result not only of the modern way of life but also of the distancing of man in general and children in particular from nature (e.g., Jančaříková et al. 2020), as well as from the consequences of environmental pollution. Accordingly, the survival of the environment itself depends directly on the activity of modern societies, as it has a catalytic effect on all its aspects (Oldfield and Dearing 2003). The rapid technological development and the increase in the production of goods and consumption, aiming at the economic growth of the modern world for many years, seem not to have considered the protection of the environment, leading to the depletion of natural resources, unambiguous degradation of ecosystems, and consequent deterioration of the quality of life, especially in the non-developed countries.

One of the most important environmental issues of our times is global climate change, also known lately as the climate crisis. The multifaceted consequences of this crisis are recognized by scientific research warning societies of the dangers that lurk not only in the long term but also in the coming years (Intergovernmental Panel on Climate Change (IPCC) 2014; National Academy of Sciences 2014). The Earth's climate throughout history shows variations related to its natural cycles of cooling and heating, with changes that alter the intensity of solar radiation received by the planet, modifications in ocean circulation affected by the movement of tectonic plates, or by massive volcanic eruptions and earthquakes, thus reflecting the complex relationships of the components that make up its systems (US Global Change Research Program 2009). Although the global climate has been relatively stable over the past 10,000 years, it has been significantly influenced by human activities during the past half of the century. Now, there are noticeable fluctuations in global climate patterns due to this human activity with serious effects on the weather and climate. The US Scientific Program on Climate Change has published findings supporting the IPCC's report on the human impact on climate change after observing patterns of temperature changes in space and time (US Global Change Research Program 2009).

Education appears to be the most important vehicle of awareness and activation regarding the environment, not only for young children but also for the entire society, as it aims to create citizens of a democratic participatory society with a critical way of thinking and the ability of decision-making based on solid knowledge. Education for sustainability, in particular, being a complex and at the same time modern pedagogical approach, confronts the problems related to the anthropogenic and natural environment relationship in a holistic and interdisciplinary way by teaching means of comprehending the environment, as well as taking informed decisions individually and also collectively. Its purpose is not only the transfer of knowledge about the natural environment but also the acquisition of skills and the strengthening of pro-environmental attitudes that could lead to environmentally responsible behaviors (e.g., Gayatri et al. 2014; UNESCO 1978).

Within the boundaries of education, new terminology has emerged, especially during the last couple of decades, attempting to describe in more detail several aspects of environmental issues and/or problems. Under the banner of the generic term “environmental literacy” that was launched in the late 1960s (e.g., Roth 1968) in parallel to environmental education, but not as widely spread during the next couple of decades as the latter one, one detects, among others, new terms in the scientific literature such as ecological literacy (e.g., Orr 1992), earth science literacy (National Science Foundation 2010), atmospheric science literacy (UCAR Center for Science Education 2008), and of course, climate and ocean literacy, the pairing of which interests the present study.

Climate literacy (CL) is the understanding of our influence on climate and climate’s influence on us and the society; a climate-literate person understands the essential principles of Earth’s climate system, knows how to assess scientifically credible climate information, communicates about climate and climate change in a meaningful way, and can make informed and responsible decisions concerning actions that may affect the climate (US Global Change Research Program 2009). The above, together with the design and communication to the public of a guide consisting of 7 basic principles (Table 1) and 39 fundamental concepts, following the accumulated experience from other preceding literacies, especially ocean literacy, were the outcome of a hard-going collaborative process among several non-governmental and US governmental agencies including the National Oceanic and Atmospheric Administration, the American Association for the Advancement of Science (AAAS), and the National Science Foundation, as well as educators from both formal and non-formal education settings. Nevertheless, this highly promising and systematic effort, which began in 2007 and was successfully released in the Spring of 2008 (Dupigny-Giroux 2010; McCaffrey and Buhr 2008; Shaffer et al. 2009), was not the first relevant attempt since its roots were found already in the middle of the twentieth century and more specifically in 1958 when the US National Academy of Science published “Planet Earth: Mystery with 100,000 Clues”; in that monumental text, the industrial civilization was accused for the first time of altering the natural greenhouse effect. During the next couple of decades, although huge attention was paid to natural science issues within formal education, the results were not the expected ones. This picture changed in the 1980s when the AAAS

Table 1 The seven essential principles of climate literacy

Principle 1	The Sun is the primary source of energy for Earth's climate system
Principle 2	Climate is regulated by complex interactions among components of the Earth system
Principle 3	Life on Earth depends on, is shaped by, and affects climate
Principle 4	Climate varies over space and time through both natural and man-made processes
Principle 5	Our understanding of the climate system is improved through observations, theoretical studies, and modeling
Principle 6	Human activities are impacting the climate system
Principle 7	Climate change will have consequences for the Earth system and human lives

established “Project 2061” and published “Science for all Americans” in 1989 and the “Benchmarks for Science Literacy” in 1993 (AAAS 1989, 1993), boosting further initiatives in the coming years, such as the publication of the “National Science Education Standards” in 1996 by the US National Research Council, thus placing science education and consequently environmental literacy in new foundations for the next millennium.

The CL guide attempts to support Climate Change Education (CCE) in the field of which scientific research has been increasing rapidly worldwide, especially during the last decade. Indeed, the attempts to bring climate issues to the attention of today's societies and correspondingly to formal and non-formal education systems across the globe were many. The first United Nations Framework Convention on Climate Change (UNFCCC) was signed by 154 countries and the European Union in 1992 in Rio, Brazil, under the threat of rising temperatures due to high greenhouse gas emissions caused by human activity (United Nations 1992). Since then, several opportunities for updating this convention have emerged; the Kyoto Protocol in 1997, the Paris Agreement in 2015, and the launching of the UN Agenda 2030 for Sustainable Development the same year, among others, were detected, with a stand-alone goal (13th goal) exclusively targeting climate. In 2016 the UNFCCC introduced the term “Action for Climate Empowerment (ACE)” (UNESCO and UNFCCC 2016), aiming to strengthen climate action by focusing on six key areas, namely, (i) education, (ii) training, (iii) awareness-raising, (iv) participation, (v) public access to information, and (vi) international cooperation. Through ACE, governments are invited to develop and implement public education and awareness programs, facilitate participation in and access to knowledge and information on climate change, and work together on these issues internationally (UNESCO and UNFCCC 2016).

According to UNESCO (2017a), the importance of education is key to societies' understanding of climate change, addressing its consequences and encouraging them to change attitudes and behaviors. For this reason, it promotes CCE which is not limited only to the teaching and learning of the phenomena of natural sciences within the school curriculum but is rather a holistic and interdisciplinary subject with many implications. It is an education field that provides the framework through which pupils and communities learn how to act in their lives (UNESCO/UNEP 2011). As

climate change is not only an environmental-scientific issue but also a deep socio-political one, CCE is also the means of communicating the urgency of climate issues so that governments on a national and global level can take measures to address it with special reference to those already vulnerable communities that will be most affected by its consequences (UNESCO/UNEP 2011).

Due to its scientific perspective, CCE often falls within the offered courses of the school curriculum, thus providing significant advantages for the inclusion of climate change in formal education and an opportunity for holistic and interdisciplinary teaching (National Research Council 1996). There are, however, some difficulties regarding the pressures associated with teaching about climate change that affect teachers, as they face pressure not only to eliminate or weaken the science of climate change but also to introduce non-scientific ideas (e.g., Branch 2013; Branch et al. 2016; Johnson 2011; National Earth Science Teachers Association 2011). These pressures promote the teaching of non-scientific ideas that make it difficult for pupils to be properly informed, facilitate favoring misconceptions, and increase confusion about climate issues. Another difficulty in the implementation of CCE is the lack of teachers' scientific training. Research on what affects how climate change is presented in science courses in public high schools in the USA showed that both individual and community factors play an important role and that the most effective way to improve CCE is to improve teacher training in the field of climate science (Busch 2021). In any case, it seems that climate issues are directly influenced and dependent on both local and national perceptions and practices for teaching and learning. At present, however, most governments do not seem to recognize the importance of CCE in their education action plans. Only a few countries have integrated climate education into their official curricula, and therefore governments should urgently step up efforts to provide quality climate education for all pupils (Kwauk 2021).

A very interesting case of integrating knowledge related to climate change both into formal and non-formal education settings is the use of another modern aspect of environmental literacy, namely, ocean literacy (OL) (National Oceanic and Atmospheric Administration 2013), referring to the understanding of the ocean's influence on us and our influence on the ocean (e.g., Cava et al. 2005). It is a fundamental tool not only for enhancing ocean knowledge but also for providing incentives for citizens and stakeholders to have an active role in the implementation of sustainable actions toward the marine environment. A healthy and accessible ocean, in which all nations and citizens can have access to data, information, and technologies, is one of the expected results of the UN Decade of Ocean Science for Sustainable Development 2021–2030 (UNESCO-IOC 2021), as a basic attempt to meet the requirements of the Sustainable Development Goal 14 of the Agenda 2030 (UNESCO 2017b). OL was the first field where several scientists, educators, policymakers, and agencies experimented with the sense of a guide that includes several basic principles and fundamental concepts underpinning these principles and which citizens should comprehend in order to be called ocean literate. Therefore, after a long period of consultation which started in the late 1990s and was completed in 2004, the OL guide including 7 principles (Table 2) and 44 concepts was published; a second

Table 2 The seven essential principles of ocean literacy

Principle 1	The Earth has one big ocean with many features
Principle 2	The ocean and life in the ocean shape the features of Earth
Principle 3	The ocean is a major influence on weather and climate
Principle 4	The ocean made Earth habitable
Principle 5	The ocean supports a great diversity of life and ecosystems
Principle 6	The ocean and humans are inextricably interconnected
Principle 7	The ocean is largely unexplored

version of the guide, launched in March 2013, appeared with the addition of one more concept, thus bringing the total number to 45 fundamental concepts. OL principle 3 concerns the weather and climate supported by seven concepts due to its importance. These concepts roughly refer to the interaction of oceanic and atmospheric processes which (i) controls weather and climate by dominating the Earth's energy and carbon systems, (ii) moderates global weather and climate by absorbing most of the solar radiation reaching Earth and affecting global and regional weather phenomena, (iii) functions as the main system of the water cycle, and (iv) drives to dramatical physical, chemical, biological, economic, and social consequences (National Oceanic and Atmospheric Administration 2013).

Taking into consideration the few years of existence of the above two aspects of environmental literacy, namely, the ocean and the more recent climate literacy, the recorded scientific research is still far from adequate. This becomes even more limited when one refers to the combination of the two literacies. Maybe the most characteristic study belongs to Boaventura et al. (2021) who evaluated the effectiveness of primary school pupils' participation in school and citizen science activities to enhance their scientific knowledge and skills on OL in the context of climate change. The strategies applied in this study allowed pupils to actively engage themselves through hands-on activities and authentic learning, revealing a significant increase in their knowledge and skills of climate change effects on species distribution on rocky coasts.

The main aim of the present study is to assess (i) the knowledge, attitudes, and behavior of third-grade primary school pupils regarding the influence of the global ocean on weather and climate and (ii) the degree to which a carefully designed and properly implemented Teaching-Learning Sequence (TLS, teaching intervention) by university researchers regarding the third OL principle could affect pupils' awareness of the marine environment and its interaction with weather and climate.

Methodology

This research constitutes a case study since it serves as a specific scientific example created to imprint a more general situation (e.g., Cohen et al. 2007). The research population was Greek third-grade primary school pupils (8–9 years old), while a convenience sample from one school class with 17 pupils was employed.

For assessing the knowledge, attitudes, and behavior of pupils regarding the impact of the global ocean on weather and climate and therefore the teaching intervention, a questionnaire was designed, constructed, and administered to the class before (pre-test) and immediately after (post-test) the intervention. The questionnaire consisted of three parts. The first one included demographic questions (gender, age, participation in environmental education programs related to the sea, parents' educational level, and sources of information about the natural environment). The second part included ten multiple-choice knowledge questions selected to adequately cover the concepts of the third OL principle and aligned with the corresponding grade level. The last part of the questionnaire included ten attitude and behavior statements in which pupils were asked to document their level of agreement on a 5-point Likert scale from 1 (totally disagree) to 5 (totally agree).

The Teaching-Learning Sequence (TLS) (teaching intervention), specially designed and applied for the needs of this study, lasted ten teaching hours and was spread over 2.5 months. Rich audiovisual material was systematically used, mainly videos and photographs of the oceanic environment, weather phenomena, climate conditions, and natural disasters in different parts of the world in general and in Greece in particular. Throughout the intervention, a variety of educational tools were used, such as group discussions, brainstorming, use of information and communication technologies, art (e.g., drawings, dramatization, children's literature, comic book creation, role-playing games, poster creating, music), experiments, and communication with scientists. Moral dilemmas about the problematic relationship between man and the marine environment were quite often posed to the pupils, related to specific issues of the third OL principle.

For the needs of the data analysis, both descriptive (mean values, standard deviations (SD), and frequencies) and inferential statistics were used. Especially for the latter, as this was a case study and only one class with a small number of pupils was involved, the non-parametric statistical criteria Mann-Whitney-U and Kruskal-Wallis-H tests were selected, and therefore the reader should interpret conservatively the results of this analysis. The significance level was set at $\alpha = 0.05$.

Results

The total number of pupils in this study was 17, most of whom (58.8%) were female pupils. As in early school grades, even a few months seem to play an important role in pupils' performance, most of them (70.6%) were 9 years old and the rest 8 years old. Exhibiting the same percentage (70.6%), most of them had no experience of any environmental program related to the sea during their limited attendance at school, while regarding parents' educational level, their statements revealed mainly higher (university) education. They were also asked to document their degree of agreement with several sources from which they acquired information about environmental issues (Table 3). The same question was pre-decided to be repeated in the post-test as well in case something might have changed as a result of the teaching intervention. Their answers highlighted some interesting differences since after the intervention

the increasing values of teachers’ important role, as well as that of out-of-school textbooks, could be easily detected; on the contrary, the family impact was highly reduced after the intervention (Table 3).

Figure 1 presents pupils’ performance on the knowledge scale during the two time periods of administering the tool. It can be seen that their mean knowledge score appeared to be particularly low before the intervention (0.94) with the maximum score being 10 corresponding to the total number of questions, while it increased significantly ($p \leq 0.001$), reaching a mean score of 8.0, immediately after the intervention (Fig. 1).

The percentage of correct answers per knowledge question of the pre- and post-tests is given in Table 4. The slightly easier questions before the intervention turned out to be the fourth question (*Heat exchange between the ocean and the atmosphere can lead to dramatic global and local weather events, such as severe storms, heavy rainfall, and severe drought*) with a percentage of 23.5%, the first (*The global ocean regulates the weather and climate of our entire planet*), with a percentage of 17.6%, as well as the ninth (*The ocean has a significant impact on climate change*) with the same percentage of correct answers. The hardest items of the questionnaire that the pupils were unable to answer were the fifth (*Most of the rain that falls in the area we live comes from the evaporation of water in the distant tropical ocean*), the sixth (*The process of photosynthesis takes place all over the ocean surface as it is done on*

Table 3 Mean values and standard deviation of information sources before (pre-test) and after (post-test) the teaching intervention

Sources	Pre-test		Post-test	
	Mean	SD	Mean	SD
Teachers	4.35	0.931	4.71	0.470
School textbooks	3.82	1.380	3.71	1.105
Out-of-school textbooks	3.12	1.453	4.18	1.131
Internet	3.35	1.656	3.65	1.539
TV	3.53	1.419	3.53	1.419
Family	4.18	1.468	3.65	1.539
Friends	3.24	1.522	3.47	1.546

Fig. 1 Pupils’ knowledge scores before (pre-test) and after (post-test) the teaching intervention and significance level

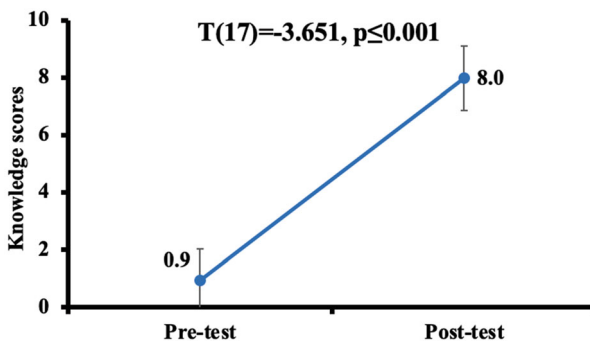


Table 4 Frequencies (%) of pupils' correct answers regarding knowledge scale before (pre-test) and after (post-test) the teaching intervention (bold letters indicate correct answers)

	Knowledge questions	Pre-test	Post-test
1.	The global ocean <i>regulates the weather and climate of our entire planet</i>	17.6	88.2
2.	The ocean moderates the weather and climate on a global scale because <i>it absorbs most of the solar radiation reaching the earth</i>	5.9	70.6
3.	If it were not for the sea, the climate of the coastal areas would be <i>characterized by warmer summers and colder winters</i>	11.8	64.7
4.	Heat exchange between the ocean and the atmosphere <i>can lead to dramatic global and local weather events, such as severe storms, heavy rainfall, and severe drought</i>	23.5	88.2
5.	Most of the rain that falls in the area we live comes from <i>the evaporation of water in the distant tropical ocean</i>	0.0	64.7
6.	The process of photosynthesis <i>takes place all over the ocean surface as it is done on land</i>	0.0	76.5
7.	Because photosynthesis takes place in the ocean, <i>oxygen is produced and carbon dioxide is absorbed</i>	0.0	76.5
8.	The ocean absorbs <i>about 40%</i> of the atmospheric carbon dioxide	5.9	94.1
9.	The ocean <i>has a significant impact on climate change</i>	17.6	94.1
10.	Alterations caused in the ocean by climate change <i>have an impact on nature, economy, society, and all life on the planet</i>	11.8	82.4

land), and the seventh question (*Because photosynthesis takes place in the ocean, oxygen is produced, and carbon dioxide is absorbed*) (Table 4).

As it can be easily observed in Table 4, after the end of the intervention, the correct answers increased dramatically and fluctuated between 64.7% and 94.1%. More specifically, the eight question regarding the amount of carbon dioxide absorbed by the ocean, along with the ninth one referring to the effect of the ocean on climate change, showed the highest values (94.1%), followed by questions 1 and 4 with a percentage of 88.2%, which concerned regulation of weather and climate by the global ocean and the impact of heat exchange between ocean and the atmosphere on global and local weather phenomena, as well as question 10 referring to the impact on nature, economy, society, and life on the planet by alterations caused in the ocean due to climate change (82.4%) (Table 4). The relatively lower percentages of correct answers are found in questions 3 and 5 (64.7%) which concerned the influence of the ocean on the climate of coastal areas and the rain that falls somewhere on the planet as a result of water evaporation in the distant tropical ocean (Table 4).

Figure 2 presents the level of pupils' pro-environmental attitudes and behavior. It is clear to the reader that pupils, despite their limited knowledge level, featured a satisfactory level of positive attitudes and behavior toward the ocean from the beginning, revealing a mean value of 4.07 (± 0.455) on the 5-point Likert scale, while after the intervention it increased even further (4.58 ± 0.190), with the difference between the two values being statistically significant ($p \leq 0.05$) (Fig. 2).

Fig. 2 Pupils' attitude and behavior mean values before (pre-test) and after (post-test) the teaching intervention and significance level

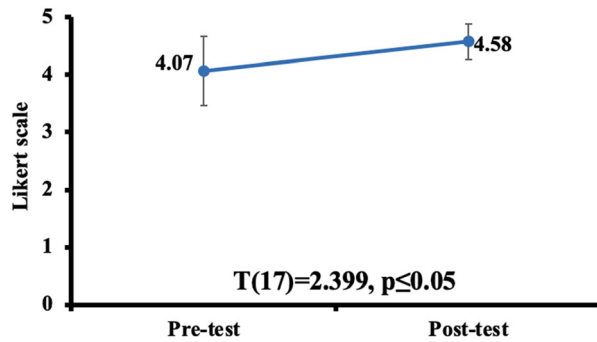


Table 5 Mean values and standard deviation of attitudes and behavior scale before (pre-test) and after (post-test) the teaching intervention

	Statements	Pre-test		Post-test	
		Mean	SD	Mean	SD
1	The ocean is important to me	4.76	0.562	4.82	0.728
2	The ocean is important to our planet	4.71	0.588	4.94	0.243
3	Marine organisms are at risk from humans	3.41	1.372	4.47	0.717
4	I am concerned about the pollution of the ocean coming from people	4.06	1.088	4.71	0.686
5	People are at risk of ocean pollution	3.47	1.546	4.47	0.800
6	My actions can help protect the ocean	4.35	1.057	4.47	0.874
7	I do things to help protect the ocean	4.12	1.111	4.53	0.943
8	The pollution we cause in the ocean affects the global climate	3.82	1.015	4.41	0.618
9	The ocean has an impact on climate change	3.88	1.453	4.59	0.507
10	Photosynthesis taking place in the ocean affects the weather and climate	4.06	1.088	4.35	0.786

More specifically mean values ranged between 3.41 and 4.76 in the pre-test, with the highest one (4.76 ± 0.562) found in the first statement (*The ocean is important to me*), the second statement (*The ocean is important to our planet*) (4.71 ± 0.588), the sixth statement (*My actions can help protect the ocean*) (4.35 ± 1.057), and the seventh one (*I do things to help protect the ocean*) (4.12 ± 1.111) (Table 5). On the contrary, the lowest mean values were found in the third statement (*Marine organisms are at risk from humans*) (3.41 ± 1.372), the fifth statement (*People are at risk of ocean pollution*) (3.47 ± 1.546), and the eighth statement (*The pollution we cause at the ocean affects the global climate*) (3.82 ± 1.015) (Table 5).

After the teaching intervention, an increase was observed in all statements with the mean values varying between 4.34 and 4.94 (Table 5). More specifically, once again the first two statements (the importance of the ocean to me and the planet) remained at the top of pupils' preferences with a mean value of 4.82 (± 0.728) for the first and 4.94 (± 0.243) for the second one, respectively, while the tenth statement

(*Photosynthesis taking place in the ocean affects the weather and climate*) and the eight statement (*The pollution we cause at the ocean affects the global climate*) presented the lowest values (4.35 ± 0.786 and 4.41 ± 0.618 , respectively) (Table 5). Finally, a possible effect of pupils' gender and participation in environmental education programs related to the sea was also investigated before and after the teaching intervention, without revealing any statistically significant difference ($p \geq 0.05$).

More specifically, once again the first two statements (the importance of the ocean to me and the planet) remained at the top of pupils' preferences with a mean value of $4.82 (\pm 0.728)$ for the first and $4.94 (\pm 0.243)$ for the second one, respectively, while the tenth statement (*Photosynthesis taking place in the ocean affects the weather and climate*) and the eight statement (*The pollution we cause at the ocean affects the global climate*) presented the lowest values (4.35 ± 0.786 and 4.41 ± 0.618 , respectively) (Table 5). Finally, a possible effect of pupils' gender and participation in environmental education programs related to the sea was also investigated before and after the teaching intervention, without revealing any statistically significant difference ($p \geq 0.05$).

Discussion

Based on the results of the present study, it becomes clear that a thoroughly structured and carefully designed and implemented Teaching-Learning Sequence (TLS), adapted to the developmental level of 3rd-grade primary school pupils, can increase content knowledge and pro-environmental attitudes and behavior towards a field such as marine science that is not common in education, and therefore no sufficient preexisting knowledge and/or experience is expected to be recorded. In the beginning, the participating pupils in this research presented minimal knowledge regarding the fundamental concepts of the 3rd OL principle entitled "***The ocean is a major influence on weather and climate***", revealing the greatest difficulty around the origin of rain on the planet and the process of photosynthesis in the ocean. After the completion of the 10-hour teaching intervention, however, the level of their knowledge increased significantly. As the level of pupils' pro-environmental attitudes and behavior was already quite high from the very beginning, a further increase in their values was achieved. Even pupils' choices on the sources of information about environmental issues were influenced by the TLS, showing henceforth an undisputed preference for the work done at school mainly by their teachers with the assistance of out-of-school textbooks, and not the family, as was the case before the intervention. Gender and pupils' participation in Environmental Education programmes related to the sea did not seem to play a significant role either in their cognitive performance or in the level of their environmental attitudes and behavior.

Research regarding ocean sciences issues, in general, reveals mostly limited knowledge and a series of misconceptions in several populations, such as primary and secondary education pupils, pre- and in-service teachers, and the public at large

(e.g., Ballantyne 2004; Brody 1996; Boubonari et al. 2013; Çakir et al. 2010; Chang 1999; Fortner and Mayer 1989; Gopal et al. 2004; Guest et al. 2015; Koulouri et al. 2022b; Lambert 2006; Linsky 2017; Markos et al. 2015; Mogias et al. 2015, 2019; Péer et al. 2007; Stir 2006; Summers et al. 2001). Similar findings are reflected in the present research, with pupils showing limited knowledge in subjects specifically related to the third OL principle, which changed significantly after the teaching intervention. According to the literature, very few studies focus on specific principles of the OL guide, while research involving teaching interventions appears to be even more limited (e.g., Boaventura et al. 2021; Costa et al. 2022; Cummins and Snively 2000, Hallar et al. 2011; Lambert 2006; Payne and Zimmermann 2010; Realdon et al. 2019; Stepath 2007) and in line, to a greater or lesser extent, with the results of our study.

Our results comply with other research attempts regarding misconceptions related to ocean sciences issues and more specifically the third OL principle, such as the fact that almost half of the atmospheric oxygen is produced in the global ocean and not only in the land forests (Cook 2018; Koulouri et al. 2022b; Mogias et al. 2019; Phillips 1991) and that rain falling in every part of the world originates from the distant tropical ocean (Cardak 2009; Koulouri et al. 2022b; Mogias et al. 2019). Another common finding with other studies (e.g., Cummins and Snively 2000; Greely 2008; Realdon et al. 2019) is the inherent interest that pupils present toward the natural environment in general and the sea in particular, with the consequent desire to participate in relevant environmental activities. This positive attitude is an element that can and should necessarily be utilized by education policymakers in the context of both formal and non-formal education.

Another interesting finding that emerged from this research, which is in full compliance with the literature (e.g., Dublickas and Ilich 2017; Jose et al. 2017; Kelly et al. 2022; Owens 2018), is the use of experiential teaching and learning, especially when it comes to unfamiliar scientific subjects. Through the use of a variety of holistic, interdisciplinary, and participatory methodological approaches, it becomes feasible to deconstruct difficult scientific concepts to comprehend them more thoroughly and, at the same time, increase pupils' motivation for more active and responsible involvement. Within the context of the present study, the methodological approaches followed throughout the TLS were many, in some cases repetitive, and based on current research. Regarding weather reports on the radio and television, for example, an activity repeatedly used in our case is considered, according to Wagenaar et al. (1985), a useful means of receiving information due to the use of images and/or animations. Children's literature was also used throughout the TLS to introduce issues that were not familiar to the pupils. Literature reading is a pleasant activity for pupils from a very early age since they come into contact with it mainly through fairy tales and in the next few years through magazines, books, and other publications. Comics, a universally understandable language, belong to this category; as Burton (1955) pointed out many decades ago, they challenge the senses of the participant, transform the abstract into the concrete, and elevate the imagination, while according to Gardner and Hatch (1989), they further support teaching based on the theory of multiple intelligence.

Furthermore, several art forms were frequently used, such as making collages of the photosynthesis process in the ocean, drawings, posters, and badges inspired by several sources such as *The Great Wave off Kanagawa* by the well-known Japanese artist Hokusai. As it is beautifully portrayed in the literature, artworks can contribute greatly to the teaching and learning practice, as they cover a wide range of objectives, such as the development of critical reflection, creativity, self-knowledge, and confidence (e.g., Farrington et al. 2019; Nilson et al. 2013).

However, during the implementation of this study, some difficulties arose, mainly regarding the limited time of the intervention and to a much lesser degree the restrictions of the COVID-19 pandemic. Although the pupils' interest in participating and conducting several activities exceeded our expectations, the always crowded school curriculum did not allow for a more in-depth engagement of the pupils who kept asking to spend more time on the project. That, combined with the safety restrictions of the unprecedented experience of the pandemic, did not permit the planning of any visit outside the school, resulting in all actions taking place in the classroom and the schoolyard. To minimize the effect of this situation, rich audio-visual material, hosting scientists online, and a variety of educational tools were systematically used throughout the teaching intervention.

As this paper concerns a case study due to the involvement of only one class, our conclusions cannot be generalized to the total pupil population. Future research is needed, using a larger sample with different demographic characteristics to draw more reliable conclusions. Another point that did not meet the scope of this pilot study, but is found lately in OL research and could be applied to CL as well, is the evaluation of other significant parameters, apart from knowledge, attitudes, and behavior, such as awareness, communication, and activism (McKinley and Burdon 2020).

Finally, it is necessary to highlight a gap that, to our knowledge, exists in CL despite the rapidly evolving research in this field. This gap refers to the lack of validated assessment tools for mapping the cognitive level of several groups, such as primary and secondary school pupils, university students, pre- and in-service teachers, and the public at large, based on the CL guide as has already been documented in OL research (e.g., Boubonari et al. 2013; Cheimonopoulou et al. 2022; Fauville et al. 2018; Greely 2008; Koulouri et al. 2022a,b; Mogias et al. 2015, 2019; Markos et al. 2015; Realdon et al. 2019). Such studies, often being cross-cultural and cross-aged, allow us to record cognitive benefits and deficits, difficulties in understanding, and most importantly misconceptions; therefore, they provide the expertise to implement the CL guide in the best possible way depending on students' age, cognitive level, interests, and possible obstacles in terms of school curricula and textbooks.

Conclusion

The present study constitutes an effort to portray the significance of a short-term project within the context of formal education and to contribute to the limited literature appearing in the combining fields of marine and climate education. It

reveals that a thoroughly designed and carefully implemented teaching intervention can successfully increase content knowledge and empower pro-environmental attitudes and behavior, especially toward non-familiar scientific fields such as marine issues for both pupils and teachers. The need for a meaningful education regarding ocean sciences issues is imperative nowadays, mainly because the vast marine environment can function as an excellent context through which many scientific topics, especially the rather hard ones, can be highlighted from a pedagogical perspective. One of these topics is certainly related to climate change and/or climate crisis. Therefore, the development and implementation of these two guides, namely, the OL and the CL guide, constitute an important tool to use in formal and non-formal education settings. As far as the first is concerned (formal education), the corresponding training of pre-service teachers should be a priority to the respective university departments, as well as the training of in-service teachers within the context of lifelong learning. These trainings should aim both at content knowledge increase, especially in scientific fields such as marine and climate sciences, and pedagogical content knowledge improvement since it is argued that current methodological approaches and resources that could address cognitive deficiencies and misconceptions are rarely used in everyday school practice due to unfamiliarity to many education professionals. These approaches tend to reveal their strength, especially concerning the introduction of unknown topics into education. In terms of the school curricula, there appears to be an urgent need for reform in this direction, followed by the revision of school science textbooks hosting environmental topics, so that they can adequately support teaching and learning of such issues. It is also considered equally important to include environmental education programs in schools focusing on relevant issues. As far as non-formal education is concerned, the collaboration of schools with non-formal settings such as zoos, aquaria, museums, scientific institutes, environmental education centers, and the local community is considered of paramount importance.

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