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Contribution to the Special Issue: "Ocean Literacy across the Mediterranean Sea region"

Tracing the occurrence of ocean sciences issues in Greek secondary education textbooks

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Abstract

This study aims to investigate the presence of ocean sciences issues in Greek secondary education (grades 7-12) science textbooks, in respect of the Ocean Literacy Framework. Content analysis was undertaken concerning both textual and pictorial materials of the Biology, Chemistry, Physics, and Geography – Geology courses. Results revealed that the textbooks under study contain limited and fragmented information with regard to the seven essential principles of the Framework, while a comparison with the Ocean Literacy Scope & Sequence evidences inconsistencies. The suggestions arising from this study could help curriculum designers, textbook authors, marine educators, and marine scientists to cooperate on a wider scale towards the inclusion of ocean literacy topics into national curricula worldwide.

Keywords: Ocean Literacy; Science textbooks; Content analysis; Secondary education.

Introduction

Over the last decades, ocean literacy (OL) has been widely introduced as a powerful approach towards the design, development, and implementation of new agendas and regulations for the degradation of the marine environment. Many international and national initiatives have called for a more ocean-literate public, i.e., ocean-literate citizens who understand the importance of the ocean, can communicate about the ocean in a meaningful way, and are able to make informed and responsible decisions regarding the ocean and its resources (Schoedinger *et al.*, 2010; National Oceanic and Atmospheric Administration–NOAA, 2013). For example, the EurOCEAN Rome Declaration (EurOCEAN, 2014, p.1) promotes a wider awareness and understanding of the importance of the seas and oceans in the everyday lives of European citizens. Moreover, the Galway Statement for Atlantic Cooperation, signed by Canada, the United States, and the European Union, supports the sustainable development of the Atlantic Ocean by promoting OL (EU-CANADA-US Research Alliance, 2013). Towards this direction, the United Nations have recently declared a Decade of Ocean Science for Sustainable Development from 2021-2030, along with the Agenda 2030, comprising seventeen Sustainable Development Goals among which is Goal 14, "Life below Water", which concerns the sustainable development of oceans, and highlights the increase in students' need for a sustainability-centred education (UNESCO, 2017). In the same context, UNESCO launched the "Ocean Literacy for All" initiative, which aims to increase worldwide awareness regarding ocean conservation (Santoro *et al.*, 2017). Additionally, several international projects such as "ResponSEAble" and "SeaChange", underline the importance of connecting Europeans with the ocean through education.

The term "ocean literacy" has been defined as "an understanding of the ocean's influence on you, and your influence on the ocean" (Cava *et al.*, 2005). The development of the Ocean Literacy Framework (OLF) was the result of an extensive process of continuous meetings in the early 2000s. It consists of a guide that identifies the essential principles of OL underpinned by a series of fundamental concepts, which all students should understand by the end of high school (NOAA, 2013) (Table 1), and a more detailed Scope and Sequence for Grades K-12 (National Marine Educators Association–NMEA, 2010), which provides guidance as to what students need to comprehend at different grade bands from kindergarten to the end of high school. This theoretical framework, developed to help implement an ocean-dedicated curriculum in the USA, is now largely accepted worldwide.

Ocean Literacy can take place in both non-formal (e.g., museums, aquariums) and formal educational settings.

Table 1. The seven Principles of the OLF and their fundamental concepts. Concepts are given in brief.

Principles	Concepts
1. The Earth has one big ocean with many features	**1a.** one ocean, seven basins, 70% of planet **1b.** geological features of the seafloor **1c.** ocean circulation **1d.** sea level changes caused by tides, plate tectonics, temperature of water **1e.** properties of water **1f.** water cycle **1g.** connection of the ocean to all watersheds **1h.** large and finite ocean, limited resources
2. The ocean and life in the ocean shape the features of Earth	**2a.** earth materials originate in ocean **2b.** sea level changes shape the land surface **2c.** erosion in coastal areas **2d.** carbon cycle, dissolved carbon used by sea organisms **2e.** tectonic activity, sea level changes, force of waves influence the coast
3. The ocean is a major influence on weather and climate	**3a.** interaction of oceanic and atmospheric processes controls weather and climate **3b.** absorbs most of solar radiation **3c.** heat exchange between ocean and atmosphere, El Nino, La Nina **3d.** most rain from tropical ocean, evaporated water from warm seas, energy for hurricanes and cyclones **3e.** carbon cycle, primary productivity in ocean **3f.** ocean absorbs, stores and moves heat, carbon, water **3g.** changes in ocean-atmosphere system result in climate change
4. The ocean made Earth habitable	**4a.** most oxygen on earth from photosynthesis in ocean **4b.** ocean is the cradle of life **4c.** provides water, oxygen, nutrients
5. The ocean supports a great diversity of life and ecosystems	**5a.** ocean life ranges in size **5b.** microbes the most important primary producers **5c.** most major groups of organisms in ocean **5d.** important relationships among organisms **5e.** most of the living space in ocean, unique ecosystems **5f.** ocean life not evenly distributed due to abiotic factors **5g.** deep ecosystems independent of sunlight **5h.** vertical zonation pattern along coast and in open ocean **5i.** estuaries
6. The ocean and humans are inextricably interconnected	**6a.** affects every human life, freshwater, most oxygen, moderates climate **6b.** provides food, medicine, mineral and energy resources, transportation, jobs, national security **6c.** inspiration, recreation, discovery **6d.** humans affect ocean, laws, resource management, pollution, physical modifications, removed most large invertebrates from ocean **6e.** changes in ocean temperature and pH due to human activities **6f.** most human population in coastal areas, susceptible to natural hazards from ocean **6g.** individual and collective actions for ocean protection
7. The ocean is largely unexplored	**7a.** less than 5% of ocean explored **7b.** exploration, experimentation to better understand ocean systems **7c.** should understand ocean resources' potential **7d.** new technologies to explore ocean **7e.** develop models to understand ocean complexity **7f.** interdisciplinary scientific approach in ocean exploration

Science centres, museums, and aquaria restructure their programmes and activities to incorporate the guidelines of the OLF (e.g., Amundin & van der Meer, 2014; Källström et al., 2014; Murray, 2015; Pinto, 2016; Thompson *et al.*, 2016; Santos & Pina, 2019). Furthermore, science education standards in the U.S.A. (National Research Council, 2013) and other countries, e.g., Canada and Portugal (Escola Azul, 2020; Glithero, 2020), having adopted the principles of OL, developed new approaches adapted to their specific realities.

It is along these lines that OL should be integrated into educational practice, curricula, and textbooks (e.g., Tran *et al.*, 2010). Curricula updates in this direction have recently occurred in Korea (Park *et al.*, 2020), and similarly, micro-pedagogical "injections" of marine science into the formal curricula were viewed as a strategic and subtle way to incorporate ocean science topics into the Irish secondary science curriculum (McHugh *et al.*, 2020). Nevertheless, studies have shown that curricula in general are lacking in ocean concepts. Furthermore, there has always been a terrestrial bias in American as well as in European science education (Fauville, 2017), where ocean science does not form a substantial part of the curricula (Gotensparre *et al.*, 2017). Gough (2017) concluded that ocean and marine topics are marginalized in the national curricula in England, New Zealand, and Australia, and McPherson *et al.* (2018) revealed the limited inclusion of ocean concepts throughout the high school science curriculum in Nova Scotia, Canada. Regarding school textbooks, scientific research is evidently lacking from the relevant literature. Lal (2017) underlined the very weak representation of ocean and river literacy in the social science textbooks in Fiji, while previous research in Greece also revealed that OL principles are only partially represented and superficially introduced in primary school science textbooks (Mogias *et al.*, 2021). A similar study, regarding the presence of marine biology in Greek secondary school textbooks, revealed that although there is an attempt to present marine biology issues, it is not done in an organized way (Stasinakis, 2021) nor in alignment with the OLF.

In Greece, a country characterized by the great length of its coastline and a large number of islands, the sea has important economic benefits, as well as a recreational value. These features, taken along with an urgent need to enhance OL as a mean for achieving sustainable development of the coastal and marine environment, highlight the importance of examining the presence of the OL principles in Greek secondary education, so as to have a complete picture of the Greek science textbooks regarding OL.

The present study aims to add its weight to the international effort for the enhancement of OL by:

a. examining the presence of OL essential principles and fundamental concepts in the science textbooks of the Greek secondary education;
b. revealing the agreement of the textual and pictorial material under study with the Scope and Sequence of the OLF;
c. providing approaches for the inclusion of these principles in a revised edition of the Greek curricula.

The suggestions which arise from this study could help curriculum designers, textbook authors, marine educators, and marine scientists to cooperate on a wider scale towards the inclusion of OL topics into the curricula worldwide.

Materials and Methods

The corpus of the study

The corpus under study comprised five series of reading books, namely (i) *Geology-Geography*, (ii) *Biology*, (iii) *Physics*, (iv) *Chemistry*, and (v) *Technology*, all corresponding to compulsory courses in grades 7-12, while another textbook (*Geology & Management of Natural Resources*) was offered to 10th graders as an optional course (Table 2). Apart from the reading books, workbooks which are used as complementary material to help students revise their learning (Liu & Treagust, 2013) were also taken into consideration in the analyses, wherever these existed.

Table 2. Secondary education textbooks (grades 7-12) comprising the corpus under study.

Grades	Students' age	Course
7	12/13	Technology
		Geology - Geography
		Biology
		Physics
8	13/14	Technology
		Geology - Geography
		Biology
		Chemistry
		Physics
9	14/15	Biology
		Chemistry
		Physics
10	15/16	Geology & Management of Natural Resources
		Biology
		Chemistry
		Physics
11	16/17	Biology
		Chemistry
		Physics
12	17/18	Biology

Publisher: Computer Technology Institute & Press "Diophantus"

The framework of the study and statistical treatment of data

It has been stated (Tracana *et al.*, 2008) that textbook analysis constitutes a significant parameter in terms of the implementation of educational goals at the school level. Towards this direction, content analysis was selected as the method best fitted to undertake studies concerning both textual and pictorial material of the corresponding school manuals, to evaluate (a) the presence of ocean sciences issues according to the OLF (NOAA, 2013), and (b) their alignment to the OL Scope and Sequence (NMEA, 2010).

With regard to the presence of ocean sciences issues, it was only the manifest content that was examined, which describes only the visible or obvious components and not the latent one which concerns the underlying meaning of each passage of the text (Downe-Wamboldt, 1992; Potter & Levine-Donnerstein, 1999), as our main focus remained on what textbooks can explicitly provide to the students, without considering the extent to which teachers can influence or drive the respective contents. The unit of analysis and the construction of categories, which define content analysis procedure, were also considered. More specifically, concerning the unit of analysis, the "theme" was chosen, referring to clusters of words or categories with different meanings or connotations that taken together pertain to a single theme or issue (Weber, 1990), as according to Krippendorff (2004) thematic excerpts are rich in information and preferable to other kinds of distinctions; in terms of the construction of categories, a deductive coding scheme (Stemler, 2001) was followed in the present study, as the 7 essential principles and 45 fundamental concepts of the OLF already in existence constituted the categorical context for the respective analyses. In addition to the above, validity and reliability were also ensured. Regarding validity, the system of categories was created during a long process of consultation by experts (Downe-Wamboldt, 1992) relating to marine and education sciences, while as far as reliability is concerned, both stability and reproducibility methods were applied; concerning the former, the same text was analyzed and reanalyzed after a while (test-retest design) (Binns, 2013), and as for the latter, Krippendorf's alpha index was used as it can be applied with any number of coders, with or without missing data (Hays & Krippendorff, 2007). In our case, after the training of the authors on the coding system, they were randomly assigned a total of 100 pages from all textbooks, and inter-coder reliability statistics were calculated using the Krippendorf's alpha index to assess the agreement level, revealing high value (α=0,75); thereafter, the first author completed the analysis.

In terms of the agreement of the textual and pictorial material under study with the Scope and Sequence of the OLF, three levels of alignment were adopted following the general pattern of NMEA (2010), namely (a) no mention of concepts, (b) superficial mention of concepts and (c) concepts addressed in depth; regarding in-depth alignment, the explicit inclusion of every single element of each fundamental concept was considered as such.

Finally, as the data analyses remained strictly descriptive, frequency tables and graphs were performed to portray the presence of the OL principles and the corresponding concepts in the respective secondary school textbooks.

Results

General considerations

With regard to the textual material, ocean sciences issues were identified in 201 out of 2,810 pages (7.2%) of the reading books which were examined and 17 out of 404 (4.2%) of the corresponding workbooks; while as regards pictorial material (i.e., images, graphics), there were 178 out of 5,230 (3.4%) relevant illustrations in the reading books, and 24 out of 677 (3.5%) in the workbooks (Tables 3 and 4). Among the textbooks examined, *Geology-Geography* (offered in grades 7-8) and *Geology and Management of Natural Resources* (grade 10) displayed the highest frequencies of issues referring to ocean sciences, while *Technology* (grades 7-8) revealed no presence whatsoever (Tables 3 and 4). Whereas the number of OL principles fluctuated in middle school textbooks (grades 7-9), showing the highest value in grade 8 with all seven principles, the corresponding number of concepts revealed a gradual decrease from 23 to 15 concepts (Table 3). On the contrary, both principles and concepts decreased progressively from 6 to 3 principles and from 22 to 4 concepts respectively in high school textbooks (grades 10-12) (Table 4).

Presence of ocean sciences issues

Content analysis of both textual and pictorial material revealed that many elements of several OL concepts are missing, although all seven OL principles are recorded in the Greek secondary education textbooks. In general, principles 1 and 6 are the ones best represented followed by principle 5, while principle 7 is almost absent.

Considered on a grade basis, we discovered that middle school textbooks (Fig. 1) covered more concepts and presented a far higher number of thematic quotations than the respective high school ones (Fig. 2). More specifically, regarding middle school manuals, grade 7 covered most concepts (23), while grade 8 presented the highest occurrence of excerpts (Fig. 1). No reference to the 7th principle was detected in grades 7 and 9, as well as to the 4th principle in grade 9. Regarding high school manuals, grade 10 dominated by far both in number of concepts and quotations, due exclusively to the presence of the optional course *Geology and Management of Natural Resources*, (Fig. 2).

To consider the materials in textbooks, *Geology-Geography* and *Geology and Management of Natural Re-*

Table 3. Frequency of pages in the textual material and illustrations related to ocean sciences issues, and number of ocean literacy principles and concepts per course in middle school textbooks (grades 7-9).

		Reading book		Workbook		OL principles	OL concepts
		Textual material	Pictorial material	Textual material	Pictorial material		
Grade 7	Technology	0.0% (0/73)	0.0% (0/168)				
	Geology-Geography	17.2% (23/134)	5.2% (17/330)	2.7% (2/73)	1.0% (1/98)	6	21
	Biology	7.4% (10/135)	7.6% (38/502)	2.7% (2/73)	8.9% (15/169)	2	3
	Physics	3.4% (2/58)	2.2% (3/134)			4	7
	TOTAL	**8.8% (35/400)**	**5.1% (58/1134)**	**2.7% (4/146)**	**6.0% (16/267)**	**6**	**23**
Grade 8	Technology	0.0% (0/86)	0.0% (0/223)				
	Geology-Geography	25.3% (41/162)	8.9% (27/304)	11.5% (6/52)	5.9% (5/85)	4	10
	Biology	3.7% (5/136)	4.0% (15/374)	1.6% (1/63)	1.3% (1/80)	3	8
	Physics	11.9% (19/159)	2.7% (11/404)			6	11
	Chemistry	4.3% (4/92)	3.0% (8/264)	6.7% (4/60)	0.0% (0/59)	4	9
	TOTAL	**10.9% (69/635)**	**3.9% (61/1569)**	**6.3% (11/175)**	**2.7% (6/224)**	**7**	**19**
Grade 9	Biology	3.7% (5/136)	4.0% (15/374)	1.6% (1/63)	1.3% (1/80)	3	8
	Physics	2.9% (5/172)	2.6% (11/427)	0.0% (0/33)	0.0% (0/29)	4	6
	Chemistry	5.1% (5/98)	0.8% (2/241)	4.0% (2/50)	1.3% (2/157)	5	8
	TOTAL	**3.7% (15/406)**	**2.7% (28/1042)**	**2.1% (3/146)**	**1.1% (3/266)**	**5**	**15**

sources are the two basic manuals which have the richest content in terms of ocean sciences issues, as together they cover 22 out of 45 concepts in total and present a high occurrence of quotations (Fig. S1). The former manual includes information about almost all principles except for principle 7, focusing mainly on the 1st and 6th principle, while the latter, focusing mainly on principles 1, 5, and 6, does not cover principle 2 at all. A few elements, mainly from OL principle 5 as expected, were identified in the *Biology* textbooks, with no mention of issues related to principles 2, 3, and 7; it is interesting however that relevant issues are almost absent in high school grades 10 and 11 (Fig. S2). In Figs. S3 and S4, the results from the *Chemistry* and *Physics* textbooks are presented, revealing a rather inadequate treatment of concepts and a low presence of relevant references, especially in high school grades; between the two courses, *Physics* seems to dominate in both levels, i.e., covering more concepts and presenting more quotations.

Alignment with Scope and Sequence

Table 5 presents the level of agreement between the textbooks under study and the Scope and Sequence of the OLF, focusing on the respective grade bands for Greek middle and high school education (grades 7-8 and 9-12, respectively). In the first grade band, we identified elements of 29 fundamental concepts of the suggested 42 (69.0%), while from the 34 proposed concepts to be examined in depth, only 8 (1a,b, 2e, 3b, 6a,b,d,f), corresponding to 23.5%, seemed to be following the framework; on the contrary, 3 other concepts (1f, 3d, 6c) appeared to be addressed in depth in the examined textbooks. In grade band 9-12, elements of 31 of the proposed 40 concepts (77.5%) were identified in the textbooks, from which only 6b and 6d were found to be in line with the Framework to be considered in depth, while the present study revealed 5 new ones (1f,h, 2d, 5i, 6c) to be addressed in depth (Table 5).

Table 4. Frequency of pages in the textual material and illustrations related to ocean sciences issues, and number of ocean literacy principles and concepts per course in high school textbooks (grades 10-12).

		Reading book			
		Textual material	Pictorial material	OL principles	OL Concepts
Grade 10	Geology & Management of Natural Resources	30.5% (72/236)	14.5% (27/186)	6	22
	Biology	0.0% (0/224)	0.4% (1/228)	1	1
	Physics	0.9% (2/216)	1.4% (5/350)	3	4
	Chemistry	1.6% (3/192)	0.5% (1/205)	2	2
	TOTAL	**8.9% (77/868)**	**3.5% (34/969)**	**6**	**22**
Grade 11	Biology	2.1% (3/145)	0.5% (1/185)	2	4
	Physics	0.0% (0/196)	0.3% (1/314)	1	1
	Chemistry	1.3% (2/153)	0.5% (1/182)	3	3
	TOTAL	**1.0% (5/494)**	**0.4% (3/681)**	**4**	**7**
Grade 12	Biology	3.5% (5/143)	4.3% (9/209)	3	4
	TOTAL	**3.5% (5/143)**	**4.3% (9/209)**	**3**	**4**

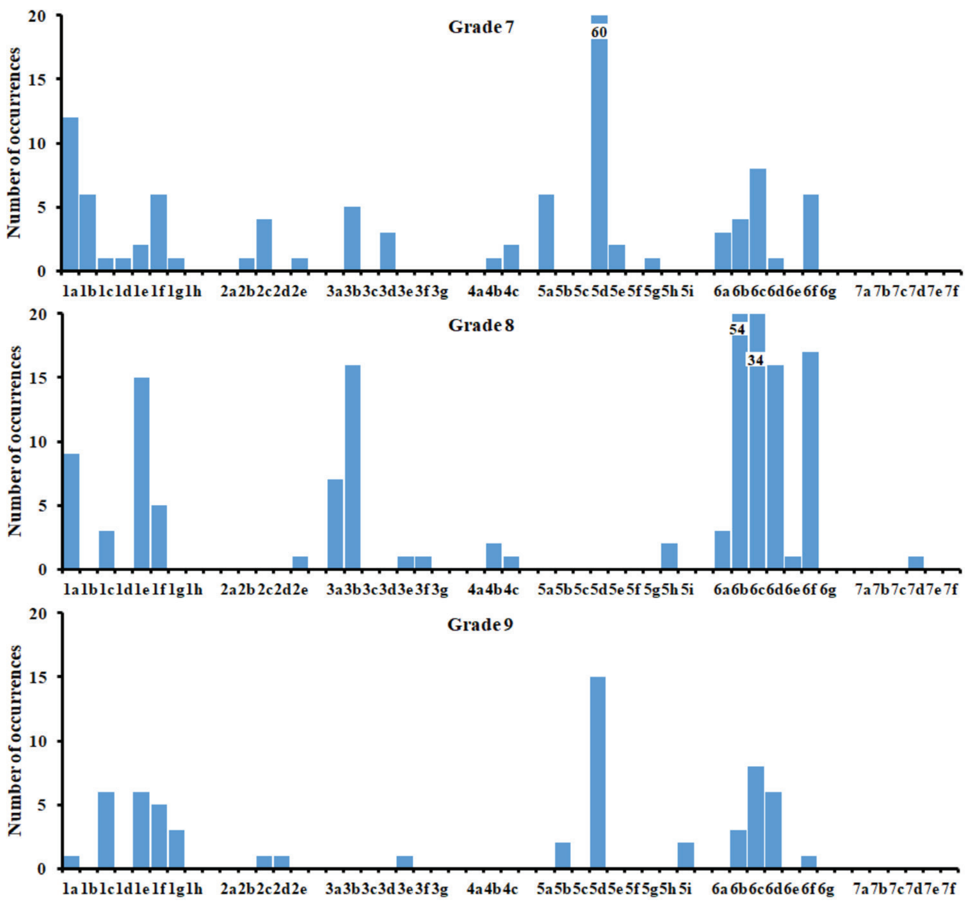

Fig. 1: Presence of ocean sciences issues per OL principle and concept in middle school (grades 7-9) science textbooks (all courses).

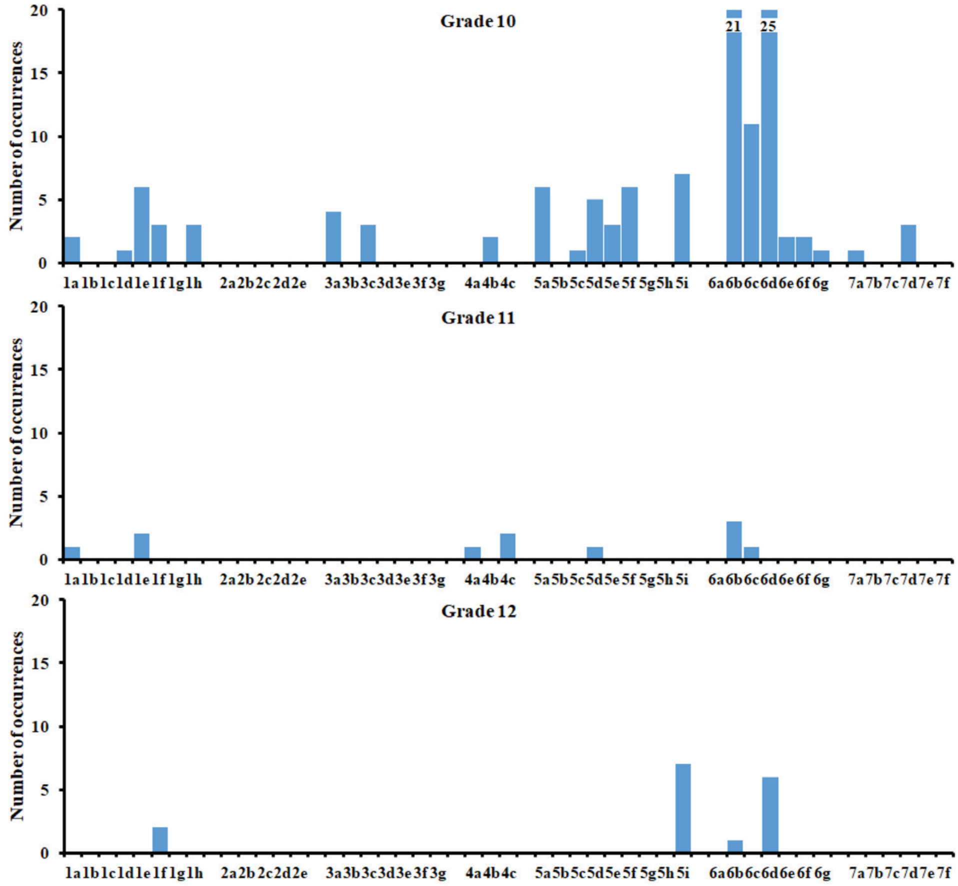

Fig. 2: Presence of ocean sciences issues per OL principle and concept in high school (grades 10-12) science textbooks (all courses).

For both grade bands, the common concepts addressed in-depth pertained to the water cycle and the connectedness of all Earth's water reservoirs (1f); the fact that the ocean is a food, medical, and resources provider supporting jobs, national economies, serving as transportation means of goods and people (6b); a source of inspiration, recreation, discovery, an important element in the heritage of many cultures (6c); humans' multilevel influence on the ocean (6d).

Contrary to the above, there are 5 concepts (2a, 3g, 7b,c,f) proposed in the Scope and Sequence for both grade bands, but to which we found no reference in our study. These are related to materials and biogeochemical cycles originating in the ocean, the ocean-atmosphere interactions resulting in changes to the climate, and the need for interdisciplinary collaborations towards exploration, experimentation and discovery issues, and the sustainable use of ocean resources.

Discussion

The results of the study revealed that all OL principles are presented in the textbooks but with only a few of the supporting fundamental concepts, most of which are absent for most of the principles. Furthermore, ocean sciences issues in Greek secondary education textbooks are mostly present in middle school and much less in high school texts. This diminishing presence is probably due to the fact that in the last two grades, school textbooks serve the need for preparing students for university entrance examinations. Therefore, there is a greater focus on content knowledge about specific topics, which students are about to be examined on, while broader academic knowledge and knowledge concerning the environment and its protection in particular are neglected. This absence sends a strong message that this kind of knowledge is probably viewed as unimportant.

More specifically, the fact that the elements of most of the concepts of OL principles 6 and 1 are represented adequately, is consistent with the findings concerning Greek primary education (Mogias *et al.*, 2021), as well as McPherson *et al*. (2018) results. Moreover, Lal (2017) also noted that principle 6 is the only one well represented in all grades in Fiji's textbooks. This finding indicates how important the relationship between the ocean and humans is considered. Additionally, the ocean features which are included in OL principle 1 are possibly the first which come to mind when talking about knowledge of the ocean and they are considered as important items of knowledge of oceanography. Within this context, this type of information consists of the introductory chapters in most of the relevant books (e.g., Segar, 1998; Thurman & Trujillo, 2004; Moran, 2011; Marrero & Schuster, 2012), as well as the first OL principle.

Concepts of principle 5, which concerns ocean biodiversity, are expected to have a high presence since humans and especially youth are interested in animal life

Table 5. Alignment of the textual and pictorial material of secondary education textbooks (grades 7-12) to the Ocean Literacy Scope and Sequence (blank: no alignment; x: mentions concepts; XX: addresses concepts in depth) (OLP, stands for Ocean Literacy Principle).

		Grades 7-8		Grades 9-12	
	Concepts	**Scope & Sequence**	**Greek Textbooks**	**Scope & Sequence**	**Greek Textbooks**
OLP 1	**a**	XX	XX	XX	x
	b	XX	XX	XX	
	c	XX	x	XX	x
	d	x	x	XX	x
	e	XX	x	XX	x
	f	x	XX		XX
	g	XX	x		x
	h			x	XX
OLP 2	**a**	XX		XX	
	b	XX	x	x	
	c	XX	x	XX	x
	d	XX		x	XX
	e	XX	XX	XX	
OLP 3	**a**	XX	x	XX	x
	b	XX	XX		
	c	XX		XX	x
	d	x	XX	x	
	e	XX	x	XX	x
	f	XX	x	XX	
	g	x		XX	
OLP 4	**a**	XX		XX	x
	b	XX	x	XX	x
	c*		x		x
OLP 5	**a**	XX	x	XX	x
	b	XX		XX	x
	c	XX		XX	x
	d	XX	x	XX	x
	e	x	x	x	x
	f	XX		XX	x
	g	x	x	x	
	h	XX	x	XX	
	i	x		x	XX
OLP 6	**a**	XX	XX	x	x
	b	XX	XX	XX	XX
	c	x	XX	x	XX
	d	XX	XX	XX	XX
	e	XX	x	XX	x
	f	XX	XX	XX	x
	g	XX		XX	x
OLP 7	**a**	XX		XX	x
	b	XX		XX	
	c	XX			
	d	XX	x	XX	x
	e			XX	
	f	XX		XX	

* The Scope and Sequence of the Ocean Literacy Framework, still comprises 44 concepts (4c is excluded), and therefore not yet aligned with the two revised versions (March 2013 and May 2021) of ocean literacy fundamental concepts

and biodiversity (Marrero, 2010). However, Stasinakis (2021), who studied those Greek secondary textbooks which focus on marine biology issues, concluded that there is some attempt to present these issues, but not in an organized way, and usually, these are not observed through a matter of central choice but as an exception or an extension of other topics. Moreover, the fact that information on deep-ocean ecosystems, e.g., hydrothermal vents and methane cold seeps, is missing, probably suggests that there is a certain prioritization in the selection of the concepts included in the curricula, which might, among other factors, derive from their frequency of occurrence and the human accessibility to them. These findings are consistent with those in Greek primary school textbooks (Mogias *et al.*, 2021).

The fact that principle 2 appeared mostly with information referring to erosion issues (concept 2c) and the influence of the coastal physical structure from tectonic activity, sea level changes and waves (2e), and that principle 3 pertaining to the ocean's influence and moderation on global weather and climate (3a,b) also occur in Greek primary school textbooks (Mogias *et al.*, 2021), suggests that these concepts are probably considered as the most important and/or easier for young students to understand. On the other hand, important information is missing in the respective textbooks, regarding several elements of the concepts such as biogeochemical processes and cycles (e.g., carbon cycle), which constitutes essential knowledge for understanding the earth systems and their connection. This type of knowledge requires systems thinking and, therefore, is rather challenging (Assaraf & Orion, 2005).

Our findings that OL principles 4 and 7 are almost absent in the secondary textbooks under study are also consistent with the findings of McPherson *et al.* (2018), as well as Mogias *et al.* (2021). Principle 4 concerns knowledge of complex biogeochemical processes, as well as the theory of evolution, which are concepts difficult to understand. Indeed, it has been found in various countries that the teaching of evolution in secondary education can be beset with difficulties (e.g., Kim & Nehm, 2011). The limited presence of OL principle 7 is probably due to the fact that its concepts concern perspectives about the development of ocean exploration and not pure ocean scientific knowledge. However, young people in coastal countries ought to know about the new and innovative technologies for marine exploration, as well as the job opportunities and careers in the maritime sector (McPherson *et al.*, 2018). This kind of information is not even provided through the *Technology* textbooks which present no reference to any concept of principle 7.

The finding that *Geology-Geography* and *Geology and Management of Natural Resources* are the two basic manuals with the richest content in terms of ocean sciences issues is aligned with the Mogias *et al.* (2021) finding that *Geography* primary textbooks display the highest percentage of presence of ocean sciences, confirming their suggestion that the OLF could be successfully embraced in the *Geography* curriculum.

The limited and irregular alignment of the existing ocean sciences concepts found in the textbooks under study with the OL Scope & Sequence (NMEA, 2010) suggests that the content information about ocean sciences issues is very fragmented and there is no coherent progression with grades, a fact that potentially creates a seriously inadequate level of knowledge and/or misconceptions. Furthermore, the fact that most concepts proposed from the OL Scope & Sequence (NMEA, 2010) to be addressed in depth for the grade band 9-12, are either absent from the textbooks or only a few quotations about them are included, probably strengthens the aforementioned assumption that during the last school grades, knowledge and skills concerning the environment and its protection receive little or no attention.

Conclusions

In conclusion, the study revealed that although all OL principles are presented in the school textbooks, many of their supporting concepts are lacking, while the existing ones are not sufficiently addressed according to the OLF, especially in the last grades of high school, probably leaving young citizens and future voters without the appropriate knowledge and skills needed for the protection of the marine environment.

Thus, to address the sustainability of the marine environment, we need to improve education concerning OL. Since school textbooks are extensively utilized for teaching and learning, it is critical to proceed with a revision based on the OLF. However, curricula should not be overstressed with additional content, but rather ingrained with interdisciplinary additions concerning OL. Moreover, one possible solution in this direction could be to provide easily accessible available supplementary resources. Supplementary resources could include background information for teachers, lesson plans, and hands-on activities. This material would be very helpful for teachers, who admit their lack of knowledge about or access to teaching resources devoted to ocean education, while indicating at the same time that resources connected to the curriculum in a meaningful way would impact the inclusion of ocean education into the science course (McPherson *et al.*, 2020). Marine educators and marine scientists could cooperate for the production of such educational material in the light of the OLF. These materials, after being revised and approved by an international scientific community, could be diffused worldwide and adapted to the curricula of each country. This approach could potentially lead to students' improved knowledge about the marine environment and the enhancement of their OL and responsible environmental behaviour concerning ocean conservation.

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Supplementary Data

The following supplementary information is available online for the article:

Fig. S1: Presence of ocean sciences issues per OL principle and concept in *Geology-Geography* textbooks (grades 7, 8, and 10).
Fig. S2: Presence of ocean sciences issues per OL principle and concept in *Biology* textbooks (grades 7, 9, 10-12).
Fig. S3: Presence of ocean sciences issues per OL principle and concept in *Chemistry* textbooks (grades 8-11).
Fig. S4: Presence of ocean sciences issues per OL principle and concept in *Physics* textbooks (grades 7-11).