

Contributions from Biology Education Research

Olivier Morin
Catherine Bruguière
Marcus Hammann *Editors*

Challenges of a Changing World in Biology Education

Selected Papers from the ERIDOB 2024
Conference



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Chapter 4

Students' Knowledge of Ocean Acidification and Its Impact on Marine Organisms



Theodora Boubonari  and Athanasios Mogias

4.1 Introduction

The increased atmospheric carbon dioxide (CO₂) levels due to human fossil fuel combustion and deforestation, which is mitigated by increased oceanic uptake (Moran, 2011), brings about pH reductions and alterations in fundamental chemical balances commonly called ocean acidification (Moran, 2011). According to the global framework for ocean sustainability (UNESCO, 2017), one of the future targets is to minimize and address the impacts of ocean acidification. Furthermore, considering that citizens through their everyday lives contribute to the increased CO₂ emissions, they have a responsibility to make informed lifestyle choices to minimize this impact. To do so, citizens need to have a solid understanding of this complex environmental issue and hold certain attitudes that shape their behaviour, to contribute to its amelioration. However, the dearth of research concerning either the public's or students' knowledge of ocean acidification or the carbon cycle has articulated participants' low awareness of these subjects (e.g. Danielson & Tanner, 2015; Düsing et al., 2019; Hartley et al., 2011; Spence et al., 2018; Zangori et al., 2017), while, to our knowledge, there are no relevant studies concerning primary students' knowledge of these issues.

School is one of the leading institutions responsible for communicating environmental knowledge and shaping attitudes to students, who are regarded as future decision-makers. The development of their knowledge, attitudes, and pro-environmental behavior would, therefore, have a significant effect on sustainable development. To the best of our knowledge, there are no relevant studies concerning the teaching of ocean acidification to primary students. According to Ocean Literacy

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Framework (National Oceanic & Atmospheric Administration, 2013) and Scope and Sequence for Ocean Literacy (National Marine Educators Association, 2010), ocean acidification could be taught to 11-12 year-old primary students.

A preliminary survey of all the Greek formal educational material for the primary level revealed that there is no material or program specifically concerning the carbon cycle and/or the ocean acidification. In the textbooks, there are fragmented concepts concerning the carbon cycle namely photosynthesis, respiration, fossil fuels, acids and bases, the flow of energy, the cycling of matter, and food chains (Hellenic Pedagogical Institute, 2003), and, thus, a sixth grader is expected to know about them.

Concerning these concepts, previous studies noted that primary students at least partially know what is made during photosynthesis, but they believe that the main purpose of photosynthesis is the formation of oxygen, followed by the formation of glucose (e.g., Dimec & Strgar, 2017; Lin & Hu, 2003). Respiration is often confused with breathing, and one of its major products, energy, is quite vague for younger pupils, probably due to their poor understanding of the cycling of matter and flow of energy (e.g., Lin & Hu, 2003). Decomposition and the role of micro-organisms in the cycling of matter are the most commonly misunderstood concepts (Byrne et al., 2009). Decomposition is seen as a process during which matter disappears over time and dead organisms are converted into minerals or soil without involving other organisms and without acknowledging physiological processes (Hellden, 1992; Özkan et al., 2004; Sequeira & Freitas, 1986; Smith & Anderson, 1986). Additionally, students do not recognise the trophic level of decomposers (Leach et al., 1996). On top of all this, it should be mentioned that the carbon cycle is highly complex because these carbon-compound transforming processes need to be integrated, which is problematic, since primary school students lack knowledge about the chemical aspects of them. Thus, it is unlikely to teach subject matter about each process and integrate it at the very beginning of learning about complex environmental problems, such as ocean acidification.

Given the lack of research on primary students' knowledge of the carbon cycle and of ocean acidification, the purpose of this study is to investigate the impact of a teaching intervention, based on the carbon cycle, on elementary school students' construction of knowledge on ocean acidification. The main focus of the study is students to achieve a basic understanding of the following concepts of the carbon cycle: (a) carbon is a chemical element found in the atmosphere as carbon dioxide (CO₂), as well as in all living things and fossil fuels, (b) the carbon cycle is a natural process where carbon moves through the environment via photosynthesis, respiration and decomposition; in photosynthesis, plants take in carbon dioxide from the air to make food and release oxygen, in respiration animals breathe in oxygen and exhale carbon dioxide back into the atmosphere, and during decomposition decomposers break down dead plants and animals, returning carbon to the soil and atmosphere, (c) the sources and sinks of carbon, (d) human activities like burning fossil fuels and deforestation can increase carbon levels in the atmosphere, contributing to ocean acidification, (e) ocean acidification is the process where the ocean becomes more acidic due to increased levels of carbon dioxide, harming sea creatures, especially

those with shells or skeletons made of calcium carbonate, and (f) the importance of reducing emissions of carbon dioxide for a healthy ocean. These concepts were the content of the teaching intervention, without focusing on the chemical aspects of the processes.

For the needs of this study, we used a mixed-method approach with qualitative and quantitative research tools. In the qualitative approach, students were asked to draw the carbon cycle including ocean acidification, before and after the intervention (Boubonari et al., 2023). In their post-drawings, students included in their post-drawings all four earth systems in the carbon cycle, increased the number and variety of the processes and improved their ability to identify dynamic relationships among the components and the processes. However, although they understood the input of carbon, they still had difficulties to understand and include in their post-pictures the output mechanisms of the carbon cycle, mostly respiration and less decomposition. Also, students achieved to understand and integrate ocean acidification into the carbon cycle. They highlighted human's impact on the carbon cycle, which indicates that they realized that humans' everyday actions concerning CO₂ emissions may affect ocean acidification and, consequently, the ocean's health.

In the present study, we focus on the quantitative research tools, addressing the following research questions:

- 1 To what extent did the intervention lead to an increase in students' knowledge of the carbon cycle including ocean acidification from pre-test to post-test?
- 2 To what extent did students' self-assessments of knowledge about the terms and concepts of the carbon cycle change from pre-test to post-test?

4.2 Methodology

4.2.1 Sample

The study was conducted during the school year 2018 with a convenient sample of 85 sixth-grade students (11–12 years-old) of 5 classes from 2 public primary schools located in a coastal provincial town, in Greece. Both schools are considered regular ones representing the vast majority of Greek primary schools in relation to both students and teachers.

4.2.2 Research Design

The authors developed a teaching intervention for the age group of the present study taking into account (a) the Ocean Literacy Guide (National Oceanic & Atmospheric Administration, 2013), especially the fundamental concepts which concern the domination of the ocean on the carbon cycle and the balance of pH (Principle 1, concept

E; Principle 2, concept D; Principle 3, concepts A, E, F); (b) the Ocean Literacy Scope and Sequence for the corresponding age (grade band 6–8) (National Marine Educators Association, 2010), according to which sixth graders should accomplish to understand the role of the ocean in the carbon cycle, as well as the effects of the increased CO₂ on the pH of the seawater, and (c) educational sources concerning both the carbon cycle and the ocean acidification (e.g., Matraccia & Zillmer, 2012).

The intervention included 8 h of inquiry-based and knowledge-integration activities, particularly experiments, concept maps, virtual laboratories, and interactive online activities, concerning photosynthesis, respiration, web chain, the carbon cycle, pH and ocean acidification. In these activities, students were asked to present their knowledge concerning the carbon cycle, emphasizing the effects of CO₂ increase on ocean acidification. The intervention was implemented by the first author (for detailed information on the teaching intervention see Boubonari et al., 2023).

4.2.3 Research Tools

The tools were a structured knowledge questionnaire and a self-assessment tool, concerning the carbon cycle and ocean acidification. Both tools were administered at the beginning and immediately after the last session of the intervention.

Questionnaire: Since no published questionnaires were found, the authors developed a questionnaire consisting of 18 items to examine students' knowledge of the components and processes of the carbon cycle and ocean acidification. Field experts checked the questionnaire, while a pilot study using a sample of 10 respondents helped to time the questionnaire, identify possible problems in terms of clarity and accuracy, and improve the final version of it. Participants were to answer “agree”, “disagree” and “do not know”, with the last option given in order to exclude the choice of random response. Each correct answer was coded as “1”, and each incorrect answer, as well as the “I do not know” option, as “0”. As for the incorrect items, it was expected that a greater number of students would disagree with them at the post-test (e.g. item 12).

Self-assessment tool: At the beginning and the end of the intervention, students were given a list of 16 terms and concepts concerning the carbon cycle and ocean acidification. They were asked how well they know them, ranking their level of knowledge using a 5-point Likert scale ranging from “I have never heard of this” to “I know this so well, I could teach someone else”.

4.2.4 Data Analysis

The changes in students' content knowledge, as well as in their answers in the self-assessment tool were estimated using both descriptive and inferential statistics. Normality tests were performed prior to inferential statistics revealing normal

distributions, and therefore parametric tests were applied. Cronbach's alpha was applied to assess the internal reliability of the knowledge questionnaire and the self-assessment tool. The "I don't know" responses of the questionnaire were treated as incorrect answers when calculating the Cronbach's alpha, so as to maintain a complete data matrix while acknowledging that a lack of knowledge represented an incorrect response in our assessment framework. Data analysis was performed with SPSS v23.0.

4.3 Results

In the following sections, the main results are presented separately for the two research questions.

4.3.1 To What Extent Did the Intervention Lead to an Increase in Students' Knowledge of the Carbon Cycle Including Ocean Acidification from Pre-test to Post-test?

The value of Cronbach's alpha showed a low internal consistency of the content knowledge questionnaire before the intervention ($\alpha = 0.509$, $n = 85$) and an acceptable internal consistency after the intervention ($\alpha = 0.619$, $n = 83$). The results of the independent-samples T-test showed that the pre- and post-intervention measurement was statistically significant for the knowledge test as the mean scores increased (Fig. 4.1). During the initial administration the students revealed a low mean percentage of correct answers (38.4%), while after the intervention this value significantly increased (62.4%) (Table 4.1).

Before the intervention, items 16, 7, 3 and 2 concerning the "increased seawater pH because of the increased CO₂, carbon release during decomposition, and the role of carbon in respiration and photosynthesis", were particularly difficult for the students (6.1%, 12.3%, 15.3%, and 16.5%, respectively) (Table 4.1). In addition, the students were not aware of the "role of decomposers in the carbon cycle" (item 9: 22.0%), the "dissolution of CO₂ in seawater" (item 14: 23.5%), and the "release of carbon into the deep during decomposition of dead organisms" (item 8: 27.4%). Students' performance was also low on items 5 and 12 (32.9% for both items), which concerned the "continuous recycle of the carbon on Earth" and that "the ocean is the biggest carbon sink" (Table 4.1) Finally, in 7 out of 18 items, the relative frequencies of the "I don't know" answers were high (42.9 to 75.0%).

The easiest items before the intervention concerned the "presence of carbon on Earth in abiotic and biotic components" (item: 82.1%), "oxygen inhalation and CO₂ exhalation of animals" (item 4: 76.5%), the "increase of CO₂ on Earth" (item

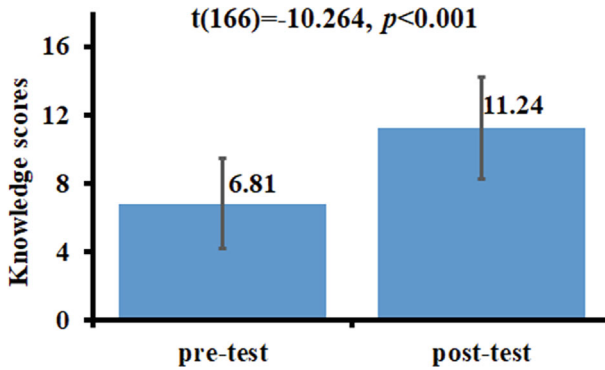


Fig. 4.1 Students' mean knowledge scores in pre- and post-questionnaire

13: 66.3%), and “carbon release by combustion of fossil fuels” (item 10: 53.7%) (Table 4.1).

After the intervention, students' performance increased in all items, exhibiting statistically significant difference in 13 out of 18 statements (Table 4.1). Moreover, the frequencies of the “I don't know” answers were very low in all items (2.4–8.9%). However, their scores presented only a slight increase on items 2, 16, and 9, which concerned the role of “CO₂ in plants' respiration, the increased seawater pH due to increased CO₂ levels and the role of decomposers in the carbon cycle” (Table 4.1).

4.3.2 To What Extent Did the Students' Self-assessments of Knowledge About the Terms and Concepts of the Carbon Cycle Change from Pre-test to Post-test?

The value of Cronbach's alpha showed a high internal consistency of the self-assessment tool before and after the intervention ($\alpha = 0.873$ and 0.903 , respectively). Independent-samples T-test showed a statistically significant difference in students' perceived knowledge between pre- and post-self-assessment tool surveys (Fig. 4.2). Before the intervention, the mean value of all items was relatively low (M 2.87; SD 0.65) the less known concepts were alkalic, decomposers, pH, acidic, and ocean acidification (ranging from 1.57 to 2.14) (Table 4.2).

After the intervention, with an evident increase in the mean value (M 3.80; SD 0.66), students reported that they knew most of the concepts quite well, while the concepts “decomposers”, “alkalic” and “fossil fuels” remained rather difficult (scores ranged between 3.04 and 3.39) (Table 4.2).

Table 4.1 Relative frequencies of correct and "I don't know" answers for the pre- and post-questionnaire. The italicized items are incorrect

Knowledge questions	Pre-test (n = 85)		Post-test (n = 83)	
	Correct answers	I don't know	Correct answers	I don't know
1. There is carbon in the atmosphere, in plants and animals, in soil, in subsoil and in the ocean	82.1	14.3	97.6	2.4
2. <i>Plants use carbon dioxide from the air for their respiration</i>	16.5	14.1	24.1	1.2
3. Phytoplankton use carbon dioxide from water in photosynthesis	15.3	76.5	60.2	28.9
4. Humans and animals breathe in oxygen and breathe out carbon dioxide	76.5	14.1	86.7	1.2
5. Carbon is continually recycled in the earth	32.9	34.1	55.4	16.9
6. Photosynthesis in land and marine plants is part of the carbon cycle	40.0	47.1	68.7	13.3
7. Carbon is released during decomposition	12.3	44.4	69.9	6.0
8. Some carbon gets into the deep ocean when living things in the ocean die	27.4	42.9	47.0	24.1
9. <i>Decomposers (such as bacteria) break down dead organisms and release oxygen</i>	22.0	58.5	36.1	24.1
10. Fossil fuels are sinks for carbon until they are burned and then they become sources	53.7	35.4	71.1	18.1
11. Ocean is the biggest carbon sink	43.2	21.0	75.9	4.8
12. <i>Land is the biggest carbon sink</i>	32.9	25.6	72.3	4.8
13. Carbon dioxide in the atmosphere has increased in the last years	66.3	25.3	78.3	14.5
14. <i>Carbon dioxide is hardly dissolved in ocean water</i>	26.2	38.1	51.8	16.9
15. <i>Increased carbon dioxide emissions have no effect on the ocean environment</i>	51.9	32.1	61.4	25.3
16. <i>Increased carbon dioxide levels increase seawater pH</i>	6.1	72.0	24.1	15.7
17. <i>Increased amounts of dissolved carbon dioxide in the ocean do not affect organisms that have shells</i>	50.0	37.8	74.7	7.2
18. Increased amounts of dissolved carbon dioxide in the ocean are harmful to the corals	36.1	55.4	68.7	20.5
Mean percentage	38.4	38.3	62.4	13.7

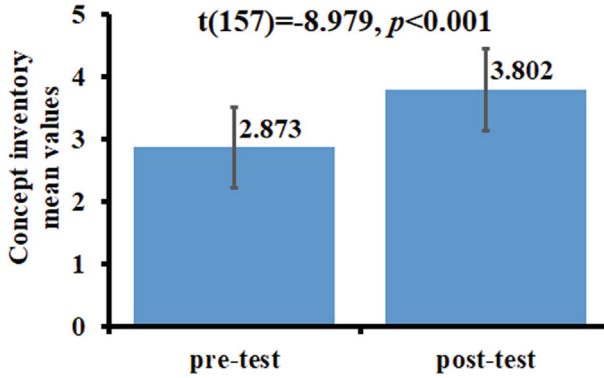


Fig. 4.2 Students' mean scores in pre- and post- self-assessment tool

Table 4.2 Mean values of the pre- and post-intervention self-assessment tool

Terms and concepts	Pre-test (n = 78)		Post-test (n = 81)	
	M	SD	M	SD
Photosynthesis	3.08	1.125	4.00	0.880
Carbon	3.44	0.975	4.23	0.795
Oxygen	4.40	0.631	4.44	0.707
Respiration	4.44	0.713	4.49	0.656
Carbon cycle	2.44	1.241	4.00	0.894
Food chain	3.63	1.353	4.19	0.956
pH	1.96	1.057	3.53	1.073
Acidic	2.00	1.294	3.44	1.123
Alkalic	1.57	0.895	3.14	1.159
Marine organisms having a shell	3.07	1.436	3.95	1.117
Phytoplankton	2.62	1.328	3.86	0.978
Fossil fuels	2.66	1.304	3.39	1.108
Ocean acidification	2.14	1.085	3.46	1.102
Decomposers	1.67	0.892	3.04	1.214
Producers	3.32	1.400	3.72	1.143
Consumers	3.36	1.309	3.86	1.118
Mean value	2.86	0.886	3.80	0.435

4.4 Discussion

The statistically significant increase in the mean correct answers, the dramatically decreased mean score in the “I don't know” responses and the statistically significant improvements in 13 out of 18 items in the post-questionnaire demonstrated students' overall knowledge improvement. Additionally, the analysis in the self-assessment tool revealed a statistically significant difference in their perceived knowledge.

Specifically, the results of the post- questionnaire serve as evidence that the intervention had a positive effect on students' understanding of the subject matter and that their answers weren't based on conjecture, thus, the instructional methods used were successful. Additionally, the noteworthy reduction in the “I don't know” responses after the intervention suggests that students became more confident in their knowledge following the instructional changes, indicating increased engagement with the material. However, it must also be said that the close-ended questions of the questionnaire in combination with the treatment helped them give the correct answers, which concerned factual knowledge and not differentiated understanding. Thus, to have more explicit results, we also used qualitative tools (Boubonari et al., 2023).

Some of the most challenging concepts which significantly improved after the intervention were the release of carbon during decomposition, the understanding of carbon's role in respiration and photosynthesis, the continuous recycling of carbon on Earth and the grasp of the ocean as a carbon sink. Students' knowledge gaps about photosynthesis and respiration have also been identified in previous studies (e.g., Dimec & Strgar, 2017; Lin & Hu, 2003; Marmaroti & Galanopoulou, 2006), and have been attributed to pupils' poor understanding of the cycling of matter and the flow of energy (e.g., Lin & Hu, 2003). Additionally, the fact that there was a low score in the item concerning photosynthesis by phytoplankton probably could be ascribed to the fact that in Greek primary textbooks the process of photosynthesis is mainly discussed for terrestrial plants, and explicit references or connections to the oceans are rare in any thematic sections of the Greek science education curricula (Mogias et al., 2021). The experiments, concept maps, virtual laboratories, and interactive online activities, concerning photosynthesis, respiration, food chain and decomposition, using paradigms from land, as well as ocean life during the intervention helped students improve their factual knowledge about these concepts. Students' knowledge improvement in these concepts is important because it underlines the feasibility of teaching such complex subject matter at the primary school level.

The best-understood concepts concerned carbon's presence in biotic and abiotic components, animal respiration (oxygen intake/CO₂ output), increasing CO₂ levels on Earth and carbon release from fossil fuel combustion, indicating that students had grasped more visible or commonly discussed aspects of carbon, thus leaving little room for improvement after the intervention.

Although there were overall gains, it's important to note that certain items related to more complex concepts, i.e. CO₂'s role in plant respiration and the role of decomposers in the carbon cycle, showed only slight improvements. These processes are not evident to the unassisted eye, and children's knowledge seems firmly anchored in

things they can directly see (Ero-Tolliver et al., 2013). Furthermore, previous studies also highlighted students' difficulty with decomposition and concluded that children have little to no understanding of what happens during this process (e.g., Leach et al., 1996). They believe either that matter from dead animals and plants simply disappears (Hellden, 1992; Sequeira & Freitas, 1986), or decay is a state that happens to materials, and no explanation is needed (Smith & Anderson, 1986), or they think about decomposers as "sweepers of nature" (Özkan et al., 2004). Students' gaps in plant respiration and decomposition underline the need for educators to focus on these processes. Respiration could be approached in a carbon cycle context, focusing on the sub-system photosynthesis-respiration, instead of teaching them in different grade levels or lessons, so as students can interrelate the two topics. In addition, the process of decomposition requires specialized teaching techniques, such as videos and animation, to help children understand this process.

It was expected that students wouldn't know about ocean acidification before the intervention, since they had never been taught about it. Their post-questionnaire answers indicate that they achieved to understand that the increased carbon dioxide in the atmosphere is transferred to the sea and brings the carbon system out of balance, affecting the marine organisms, thus realizing the human's impact on ocean acidification and its effects on the marine organisms. However, although they understood that the seawater becomes more acidic, they interpreted acidification as an increase in pH values and not a decrease; this misunderstanding implies that more activities concerning the pH scale should be added, so as to help students realize that more acidity means lower pH values.

Overall, while our current intervention may have effectively covered numerous aspects of factual knowledge concerning the carbon cycle and ocean acidification, it may not provide sufficient time for students to internalize and reconstruct their understanding of these complex concepts. This reflects a need for a shift in instructional priorities for better educational outcomes. Future evaluations should prioritize depth of teaching over breadth. This means narrowing the focus on fewer concepts but exploring them thoroughly to ensure that students not only know the facts but can apply their understanding critically. A curriculum design that incorporates lessons dedicated to deeper explorations of the most difficult concepts of the carbon cycle might lead to better long-term retention and understanding.

The relatively low Cronbach's alpha values observed in the questionnaire warrant careful consideration when interpreting our findings (Taber, 2018). Several factors may have contributed to these reliability coefficients. Firstly, treating "I don't know" responses as incorrect answers, while methodologically necessary for maintaining a complete data matrix, could have introduced measurement noise (Denman et al., 2018). Alternative approaches to handling "I don't know" responses, such as incorporating them as a separate response category or using item response theory models that can accommodate missing data, might provide more nuanced insights into student knowledge development. Moreover, the questionnaire itself contains items that measure different facets of knowledge about the carbon cycle, resulting in lower internal consistency (Taber, 2018). This heterogeneity could indicate that our assessment captured a broader construct than initially anticipated, suggesting that future

research might benefit from developing more homogeneous subscales. Additionally, the sample size for the reliability analysis may have affected the stability of the Cronbach's alpha estimates. Typically, larger sample sizes provide more precise reliability coefficients. Despite these limitations, the pre-post improvements observed in our study remain meaningful, though the magnitude of these effects should be interpreted with appropriate caution given the reliability considerations discussed above.

Furthermore, the statistically significant difference in perceived knowledge in the self-assessment tool indicates that the intervention had a meaningful impact and students felt more confident about their understanding of the concepts after it, which is important when dealing with environmental problems, since previous studies have demonstrated a relationship between self-assessment of knowledge and motivation (e.g. Sitzmann et al., 2010). However, although there was an overall improvement, certain concepts like "decomposers," "alkalic," and "fossil fuels" still posed challenges, indicating that while students improved, there are specific areas that require additional focus in future teaching efforts. Students' replies to the pre- and post-questionnaire and self-assessment tool typically matched, indicating that they probably had a fairly accurate understanding of their performance and learning requirements, providing guidance for future learning (Baas et al., 2015). On the other hand, studies have shown that summative self-assessment tends to be inconsistent with external judgements the younger the learners are (Andrade, 2019), and, thus, students of the present study might have slightly overestimated their knowledge.

Overall, students' significant progress which was measured both with qualitative (Boubonari et al., 2023) and quantitative tools supports the suggestion of Scope and Sequence for Ocean Literacy (NMEA, 2010) that the carbon cycle and ocean acidification can be taught in primary education. Moreover, our findings provide insight into developing primary students' understanding of ocean acidification and the carbon cycle, which is a crucial first step towards taking responsibility to make informed lifestyle choices to minimize this impact. However, the small, localized sample limits the applicability of the findings to broader contexts and, thus, more studies are needed to support our conclusions.

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