Biology Education Research

Contemporary topics and directions

Edited by
**Blanca Puig, Paloma Blanco Anaya,
María José Gil Quílez and Marcus Grace**

A selection of papers presented
at the XIIth conference of European Researchers
in Didactics of Biology (ERIDOB)

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CONFERENCE: PUBLISHED BOOK OF SELECTED PAPERS FROM THE CONFERENCE

2018 Zaragoza, Spain: *Biology Education Research. Contemporary topics and directions*. Edited by Blanca Puig, Paloma Blanco Anaya, María José Gil Quílez and Marcus Grace.

2016 Karlstad, Sweden: *Challenges in Biology Education Research*, 2018. Edited by Niklas Gericke and Marcus Grace.

2014 Haifa, Israel: *The Future of Biology Education Research*, 2016. Edited by Tali Tal and Anat Yarden.

2012 Berlin, Germany: *Research in Biological Education*, 2014. Edited by Dirk Krüger and Margareta Ekborg.

2010 Braga, Portugal: *Authenticity in Biology Education: Benefits and Challenges*, 2011. Edited by Anat Yarden and Graça S. Carvalho.

2008 Utrecht, The Netherlands: *The Nature of Research in Biological Education: Old and New Perspectives on Theoretical and Methodological Issues*, 2009. Edited by Marcus Hammann; Arend Jan Waarlo and Kerst Boersma.

2006 London, UK: *Biology in Context: Learning and teaching for the twenty-first century*, 2008. Edited by Marcus Hammann; Michael Reiss; Carolyn Boulter and Sue Dale Tunnicliffe.

2004 Patras, Greece: *Trends in Biology Education Research in the New Biology Era*, 2005. Edited by Marida Ergazaki; Jenny Lewis and Vassiliki Zogza.

2002 Toulouse, France: *Biology Education for the Real World: Student – Teacher – Citizen*, 2003. Edited by Jenny Lewis; Alexandra Magro and Laurence Simonneaux.

2000 Santiago de Compostela, Spain: *Proceeding of the III Conference of European Researchers in Didactic of Biology*, 2001. Edited by Isabel García-Rodeja Gayoso; Joaquín Díaz de Bustamante; Ute Harms and María Pilar Jiménez Aleixandre.

1998 Göteborg, Sweden: *Research in Didaktik of Biology*, 2000. Edited by Björn Andersson; Ute Harms; Gustav Helldén and Maj-Lis Sjöbeck.

1996 Kiel, Germany: *What? - Why? – How? Research in Didaktik of Biology*, 1998. Edited by Horst Bayrhuber and Fred Brinkman.

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FOREWORD

Biology Education Research. Contemporary topics and directions

This volume consists of 29 original papers presented at the 12th Conference of European Researchers in Didactics of Biology (ERIDOB) organized by the University of Zaragoza in collaboration with University de Santiago de Compostela, hosted in July 2018 by the Faculty of Education, University of Zaragoza, Spain.

Recognizing the importance and potential of being well-trained in biology, the bi-annual Conference of ERIDOB is now a firmly established and leading forum for European and non-European researchers to discuss and reflect on research in biology education, to find new ways of ensuring continued advances in teaching and learning this discipline.

Biology is a field of research in constant growth. Its advances have brought not only enormous benefits to humanity in fields from Human Biology to Ecology, but also great repercussions in our daily lives. This context makes it necessary for biology education to equip young people with the tools and resources needed to become scientifically literate, critical thinkers and social activists. Some of these concerns are highlighted in this book, whose 29 papers have been selected after having passed a double blind review process by at least one member of the ERIDOB Academic Committee together with an experienced reviewer of the ERIDOB academic community.

In the introduction of this volume the keynote conference, *How to gather and analyse quality evidence about successful biology classrooms,* presented by María Pilar Jiménez Aleixandre, methodological issues related to classroom studies are addressed. Special attention is on qualitative research studies and on successful biology teaching and learning with a double goal: 1) debriefing the processes leading to quality research studies; 2) providing teachers with models, rather than focusing on the problems of unsuccessful teaching.

The papers presented in this book have been organized around six sections that correspond to six of the eleven strands of the ERIDOB conference, and reflect the main threads covered during the conference. All sections include papers presented in alphabetical order.

Section 1, *Research methods* includes a contribution about curricular alignment. The authors examine whether university entrance assessments in the field of biology have adequately represented the official curriculum.

Section 2, *Students' conceptions* contains five contributions that analyze students' ideas on different topics such as plants, classification and taxonomy, climate change and HIV/AIDS.

Section 3, *Students' interest and motivation* comprises four contributions dealing with collaborative care for animals, human biology through digital storytelling, approaching microorganisms through homemade culture and through an inquiry sequence.

Session 4, *Scientific thinking, nature of science and argumentation,* comprises five papers that deal with investigable questions, socio-scientific issues, promoting data and scientific models, and ecosystems.

Section 5, *Teaching strategies and teaching environments* includes fourteen papers dealing with diverse biology topics as genetics, evolution, among others.

Section 6, *Teaching and learning with educational technology* includes one contribution that deals with the identification on woody species.

Throughout the sections, new works on biology education and up-to-date research regarding biology topics are presented, with the goal of shedding light on the important role of biology education - from addressing critically socio-scientific issues to environmental problems and other emerging topics where further research is needed.

The ERIDOB conference has been collaborating with the *Journal of Biological Education*, and three of the outstanding papers selected for this book have been also been selected for publication in the journal (Heemann & Hammann; Lampert, Müllner, Pany, Scheuch & Kiehn; and Mutanen & Uitto). These papers are currently in press in the JBE and are available as abstracts in this volume to avoid double publication.

We are thankful to all the reviewers who invested significant time and effort in the review process.

We hope that this volume will be of interest both to the biology education research community and to science teachers interested in the integration of new topics and challenges that biology education face, contributing to the development of biological education in Europe and around the world according to the needs of today's society.

KEYNOTE CONFERENCE

WHAT ARE STUDENTS' MENTAL REPRESENTATIONS OF CLIMATE CHANGE AND THE GREENHOUSE EFFECT?

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Abstract

This paper investigates the students' mental representations of climate change and the greenhouse effect. Ninety-nine secondary education students (Grades 7, 9 and 11) in Spain, participated in this study. Data was obtained by means of an open-ended questionnaire which focused on the mechanisms, causes and actions that could slow down climate change. The students' conceptions and mental models were identified by means of an inductive and iterative analysis of their explanations. With regards to the participants' conceptions, the results have shown that students tend to mention generic actions to mitigate climate change, such as not polluting. With regards to the participants' mental models, the results indicate that when students have limited previous knowledge of climate change, they are able to easily reconstruct their models by assimilating new information into existing knowledge structures. However, the evolution of extremely coherent and functional models is difficult to achieve. As educational implications, we propose creating classroom situations that will allow students to make their mental representations explicit, giving them an opportunity to compare their validity through discussion.

Keywords: climate change; greenhouse effect; mental models; science education; secondary students.

1. Introduction

Within the field of science education, emphasis is placed on the mental models that are built by students to help explain specific scientific domains. A mental model refers to a mental representation which is created by a human being from their innate predispositions and their previous experiences, which enables them to generate predictions and explanations of the facts or phenomena that occur around them (Greca & Moreira, 2000). Mental models are dynamic representations that can be expanded or improved as new information is incorporated (Johnson-Laird, 1983). From the perspective of change based on mental models, Márquez, Pujol & Bonil (2005) pointed out that the science learning process can be understood as a construction process in which the students' mental models, far from the models of school science, are modified by new experiences, new information and, especially through discussion.

While alternative conceptions are conceived as isolated ideas, mental models are constituted by a generative structure of beliefs and images that allows individuals to explain and predict natural phenomena (Chi, 2008; Schwarz et al., 2009). If the individual's mental models involve many distortions, preconceptions and alternative conceptions, these might lead to inaccurate explanations (Reinfried & Tempelmann, 2014). However, due to the dynamic nature of mental models, those that differ in content and structure from the scientific models can evolve if appropriate teaching strategies are implemented. According to Gutiérrez (2004), students will modify their mental models when the criteria of consistency, robustness and correspondence are broken. A model is consistent when it lacks internal contradictions; it is robust when it can be used in unforeseeable situations when the model was constructed; and correspondence exists when the model is able to describe with fidelity the system's real behaviour (Gutiérrez, 2004). From the perspective of mental models, Gadgil, Nokes-Malach & Chi (2012) understand conceptual change to be the transformation of prior knowledge that conflicts with the learned concepts. Gadgil et al. (2012) establish that the cognitive processes associated with this change include inference generation and knowledge revision.

This paper discusses alternative ideas and describes the levels of sophistication of the students' mental models on climate change. Several studies have revealed that students tend to link climate change with other environmental problems, such as the destruction of the ozone layer (e. g. Boyes & Stanisstreet, 1993; Dove, 1996; Pruneau et al., 2001; Punter et al., 2011; Rye et al., 1997). With regards to the causes of climate change, several studies have reported that students tend to identify carbon dioxide as a greenhouse gas, but they do not identify methane or chlorofluorocarbons as such (e. g. Fisher, 1998). With regards to the consequences of climate change, there was a common misconception among students that global warming increases the incidence of skin cancer (e. g. Boyes & Stanisstreet, 1993). In general, these studies have identified the following trends (García-Rodeja & Lima, 2012): the tendency to understand and interpret the greenhouse effect exclusively as an environmental problem; to ignore the fact that it is the result of a natural mechanism; to confuse the nature of environmental problems (climate change and ozone depletion) or attribute them a causal relationship, and to confuse the causes, effects, and possible strategies for mitigating these problems.

Schraw, Crippen & Hartley (2006) considered that students must construct appropriate mental models in order to be able to integrate the functional and causal relationships of complex systems like global climate. Other authors went further by studying the students' understanding of climate change, inferring that these mental models are the means by which the students' conceptions of climate change are structured (e. g. Andersson & Wallin, 2000; García-Rodeja & Lima, 2012; Koulaidis & Christidou, 1999; Reinfried & Tempelmann, 2014; Shepardson, Niyogi, Choi & Charusombat, 2011). What makes this particular study relevant is the fact that although the subject of climate change is one of today's most important social scientific issues, numerous studies have demonstrated that students' ideas and mental models about climate change remain inappropriate. Further research is therefore needed in order to gain a better understanding of students' ideas and mental models on climate change that will make it possible to plan the curriculum, and design teaching materials in order to enable these mental models to evolve towards those of school science (Shepardson et al., 2011).

2. Research questions

This study represents a new contribution to the area of Environmental Education given that it aims to describe the levels of sophistication of students' mental models on climate change before and after instruction. Moreover, this study compares the views of different aged students on climate change. The objectives of this study are summarised in the following research questions:

1. What is the view of different aged students on climate change?
2. How do the mental models on climate change and the greenhouse effect of seventh grade students evolve after instruction?

3. Research design and method

3.1. Sample

The participants were 99 Spanish students from middle school and high school. The distribution of students by grade was as follows: 40 students from the seventh grade (12-13 years), 40 students from the ninth grade (14-15 years), and 19 students from the eleventh grade (16-17 years). Out of all of the participants in this study, only the seventh graders received specific instruction about climate change during their Biology and Geology lessons. The teaching unit consisted of five 50-minute sessions and included the following content:

structure, composition and functions of the atmosphere; impact of human activities on the atmosphere; air pollution; the natural and the enhanced greenhouse effect. The pretest can be considered as a part of the sequence of instruction given that it allows students to activate and make explicit their previous ideas. In the second activity, participants watched a video and discussed several questions in a large group. The video dealt with the structure, composition and the major environmental problems in the atmosphere, identifying the causes, effects and possible solutions for climate change. The teacher also described the functions of the atmosphere. In addition to these explanations, she also showed students different diagrams of the mechanisms of the greenhouse effect, and addressed different actions aimed at slowing down climate change. The third activity was a negotiation table in which students prepared a series of arguments for or against the construction of a thermal power plant in their city. It is important to note that the teacher taught her class as normal, without implementing any of the patterns established in this research. The sequence of activities is included in Table 1.

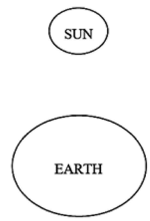
TABLE 1
DESCRIPTION OF THE SEQUENCE OF ACTIVITIES

No. of activity	*Activity*	*Educational purpose*	*Content*
1	Pre-test (1st session)	Give students the opportunity to express their initial ideas.	—
2	The atmosphere and climate change. (2nd and 3rd sessions)	Learn about the major environmental problems in the atmosphere and their causes.	Students watched a video about the structure, composition and the environmental problems in the atmosphere. It included several diagrams about the mechanism of the greenhouse effect in which a distinction was made between infrared radiation, ultraviolet radiation and visible light.
3	Negotiation table (4th and 5th sessions)	Relate human activities to their impact on the atmosphere. Propose agreed solutions.	Students had to propose arguments for or against the construction of a thermal power plant in their city.

3.2. Data collection and analysis

Data collection included the students' responses to an open-ended questionnaire (Figure 1). The questionnaire focused on the mechanism, causes and actions that could slow down climate change. The first question, which was taken from the Dawson's questionnaire (2015), aimed to make explicit the students' ideas regarding what climate change is. The second and fourth questions, which were adapted from García-Rodeja & Lima's questionnaire (2012), aimed to indicate the causes of climate change and identify the actions that can be taken to slow down climate change. The purpose of the third question, which was taken from the Dove's questionnaire (1996), was for students to represent their ideas about the greenhouse effect. The seventh graders responded to the same questionnaire on an individual basis both before and after instruction. The ninth and eleventh grade students only completed the questionnaire once because these two groups were not given specific teaching on climate change and the greenhouse effect.

1 What is climate change?
2 What are the causes of climate change?
3 Try to illustrate the greenhouse effect using this diagram.



4 What actions do you suggest to slow down climate change?

Figure 1 Questionnaire items

The students' answers were analysed twice. The first analysis aimed to identify the conceptions held by students from all three grades. The second analysis aimed to identify the mental models of seventh grade students before and after instruction. During the first analysis, categories were generated in order to describe the elements of explanation, which students referred to in their answers (Fisher, 1998). In the second analysis, each questionnaire which had been completed by the seventh grade students was analysed carefully by reading the answers to each of the questions, and incorporating each student's conceptions into broader constructs, referred to as the students' mental models (García-Rodeja & Lima, 2012; Shepardson et al., 2011). The pre-test was used to infer an initial model and the post-test was used to infer a final model. Additionally, since mental models are idiosyncratic in nature, different levels of sophistication were established making it possible to group together the mental models that share certain characteristics for each level.

4. Results and discussion

We will firstly describe the categorisation of each of the questions for all three grades. Each category is accompanied by a number that represents the frequency with which each of the explanatory elements appear in the participants' answers. Secondly, the levels established for the seventh grade students' mental models on the greenhouse effect are described, and the evolution of each participant after instruction is evaluated. For ethical reasons, each participant was identified by a code.

4.1. Alternative conceptions

Question 1. What is climate change?

When analysing the students' answers to this question, six main categories were identified (Table 2). This categorisation was inspired by previous studies (Dawson, 2015). From the group of seventh grade students, most of the answers, both before (40%) and after (43%) instruction, corresponded to the category that only mentions increases in temperature. One of the commonest explanations amongst the ninth and eleventh grade students was that climate change is the change in the Earth's average temperature. The fact that 30% of the ninth graders gave wrong answers and repeatedly associated climate change with the destruction of the ozone layer (20%) was also significant. This idea has already been described at length by other authors (Andersson & Wallin, 2000). For example, a ninth-grade student wrote: "It is the melting of the icecaps which is caused by the ozone layer breaking down" (Student 81, ninth grade).

TABLE 2

FREQUENCY OF REFERENCES TO THE DIFFERENT ELEMENTS OF EXPLANATION IN THE ANSWERS TO THE QUESTION: WHAT IS CLIMATE CHANGE?

Categories		*Seventh grade (12-13 years) Pre-test N=40*	*Seventh grade (12-13 years) Post-test N=40*	*Ninth grade (14-15 years) N=40*	*Eleventh grade (16-17 years) N=19*
Climate change is associated with a change in climate and/or an increase in temperature as a result of the greenhouse effect or the accumulation of greenhouse gases (right answer).		3 (8%)	9 (23%)	1 (3%)	3 (16%)
Links climate change to an increase in temperature with the associated consequences (partially right answer).		3 (8%)	0 (0%)	2 (5%)	2 (11%)
Links climate change to an increase in temperature (partially right answer).		16 (40%)	17 (43%)	11 (28%)	8 (42%)
Links climate change to a change in climate.		13 (33%)	10 (25%)	14 (35%)	3 (16%)
Incorrect answer.	Links climate change to the ozone layer.	0 (0%)	0 (0%)	8 (20%)	0 (0%)
	Others	4 (10%)	1 (3%)	4 (10%)	3 (16%)
No answer.		1 (3%)	3 (8%)	0 (0%)	0 (0%)

Question 2. What are the causes of climate change?

The categorisation of the answers to this question can be seen in Table 3. In the pre-test, most of the seventh grade students claimed that pollution (50%) and carbon dioxide (18%) were the causes of climate change. After the intervention, the number of seventh grade students who referred to the increase in the greenhouse effect as a cause of climate change increased by 30%.

TABLE 3

FREQUENCY OF REFERENCES TO DIFFERENT ELEMENTS OF EXPLANATION IN THE ANSWERS TO THE QUESTION: WHAT ARE THE CAUSES OF CLIMATE CHANGE?

Categories		*Seventh grade (12-13 years) Pre-test N=40*	*Seventh grade (12-13 years) Post-test N=40*	*Ninth grade (14-15 years) N=40*	*Eleventh grade (16-17 years) N=19*
Increase in the greenhouse effect.		0 (0%)	12 (30%)	1 (3%)	6 (32%)
Greenhouse effect.		2 (5%)	3 (10%)	3 (10 %)	2 (11%)
GHG emissions.		3 (8%)	8 (20%)	1 (3%)	0 (0%)
CO2 emissions.		7 (18%)	1 (3%)	4 (10%)	1 (5%)
CFC emissions.		0 (0%)	1 (3%)	1 (3%)	0 (0%)
Aerosols.		0 (0%)	1 (3%)	1 (3%)	0 (0%)
Pollution or pollutant gases.		20 (50%)	12 (30%)	24 (60%)	8 (42%)
Human activities.		5 (13%)	8 (20%)	3 (8%)	3 (16%)
Natural causes.		0 (0%)	2 (5%)	1 (3%)	0 (0%)
Deforestation.		1 (3%)	0 (0%)	2 (5%)	0 (0%)
Overexploitation of natural resources.		2 (5%)	0 (0%)	0 (0%)	0 (0%)
Effects	Melting icecaps.	3 (8%)	0 (0%)	2 (5%)	2 (11%)
	Rise in temperature	3 (8%)	2 (5%)	2 (5%)	1 (5%)
Other problems.	Acid rain.	0 (0%)	3 (8%)	0 (0%)	0 (0%)
	Destruction of the ozone layer.	1 (3%)	7 (18%)	5 (13%)	1 (5%)
Don't know/no answer.		2 (5%)	2 (5%)	0 (0%)	2 (11%)

When comparing the results of all participants, we are able to observe that the most commonly cited cause in all grades was pollution. This was interpreted as a generic answer because, although there are multiple pollutants, not all of them contribute to climate change. This finding is in line with results from previous studies (Pruneau et al., 2001).

Question 3. Diagram of the greenhouse effect

Table 4 includes the elements of explanation used by students in their diagrams of the greenhouse effect. In the pre-test, 88% of seventh grade students included solar radiation in their drawings, 40% represented a layer of gases, 38% included retained heat and 38% represented the radiation being emitted back towards the Earth. The idea of a layer of gases that traps solar radiation also appears in other papers (Anderson & Wallin, 2000). In the post-test, 88% of seventh grade students represented radiation being emitted back into space and 40% included infrared radiation. This great improvement after the intervention may be due to the video that the class watched in which a distinction was made between infrared radiation, ultraviolet radiation and visible light.

By comparing the results of the seventh grade students with those of the other two grades, we are able to observe that the ninth and eleventh grade students' drawings of the greenhouse effect included solar radiation and the radiation emitted back towards the planet; however, unlike some seventh grade students in the post-test, they did not include infrared radiation or greenhouse gases. In addition, 33% of ninth grade students drew the ozone layer, while 37% of eleventh grade students drew a layer without specifying further.

TABLE 4

FREQUENCY OF REFERENCES TO DIFFERENT ELEMENTS OF EXPLANATION IN THE ANSWERS TO THE QUESTION: TRY TO ILLUSTRATE THE GREENHOUSE EFFECT USING THIS DIAGRAM

Categories	*Seventh grade (12-13 years) Pre-test N=40*	*Seventh grade (12-13 years) Post-test N=40*	*Ninth grade (14-15 years) N=40*	*Eleventh grade (16-17 years) N=19*
No answer.	2 (5%)	0 (3%)	5 (13%)	3 (16%)
Sun rays.	35 (88%)	39 (98%)	33 (83%)	16 (84%)
Infrared radiation.	0 (0%)	16 (40%)	0 (0%)	0 (0%)
Ultraviolet radiation.	3 (8%)	2 (5%)	2 (5%)	2 (11%)
Radiation emitted back into space.	9 (23%)	35 (88%)	14 (35%)	1 (5%)
Radiation emitted back towards the planet.	15 (38%)	33 (83%)	16 (40%)	6 (32%)
Retained heat.	15 (38%)	11 (13%)	5 (13%)	3 (16%)
Ozone layer	4 (10%)	4 (10%)	13 (33%)	1 (5%)
Layer of gases.	16 (40%)	6 (15%)	3 (8%)	5 (26%)
Layer.	10 (25%)	17 (43%)	11 (13%)	7 (37%)
Pollution.	0 (0%)	0 (0%)	3 (8%)	1 (5%)
Greenhouse gases (GHG).	0 (0%)	7 (18%)	0 (0%)	1 (5%)
CO2	2 (5%)	2 (5%)	2 (5%)	1 (5%)
Water vapour.	0 (0%)	2 (5%)	0 (0%)	0 (0%)

Question 4. What actions do you suggest to slow down climate change?

The categorisation of the answers to this question can be seen in Table 5. Consistent with the literature (Bodzin et al., 2014), almost half of the seventh grade students mentioned the idea of reducing the use of vehicles and increasing the use of public transport and cycling or walking short distances. After the intervention, we observed a significant increase in the number of references to energy-saving measures in the home and responsible energy consumption.

TABLE 5

FREQUENCY OF REFERENCES TO DIFFERENT ELEMENTS OF EXPLANATION IN THE ANSWERS TO THE QUESTION: WHAT ACTIONS DO YOU SUGGEST TO SLOW DOWN CLIMATE CHANGE?

Categories		*Seventh grade (12-13 years) Pre-test N=40*	*Seventh grade (12-13 years) Post-test N=40*	*Ninth grade (14-15 years) N=40*	*Eleventh grade (16-17 years) N=19*
No answer:		2 (5%)	3 (8%)	1 (3%)	2 (11%)
Gases:	Reduce CO2 emissions.	3 (8%)	3 (8%)	2 (5%)	2 (11%)
	Reduce GHG emissions.	0 (0%)	1 (3%)	1 (3%)	2 (11%)
	Reduce gas emissions.	5 (13%)	2 (5%)	3 (8%)	4 (21%)
	Reduce CFC emissions and aerosols.	1 (3%)	8 (20%)	3 (8%)	0 (0%)
	Reduce consumption of fossil fuels.	4 (10%)	0 (0%)	1 (3%)	0 (0%)
Energy:	Increase consumption of renewable energy.	3 (8%)	3 (8%)	1 (3%)	3 (16%)
	Reduce the use of cars (using public transport, bicycles, electric cars, walking).	18 (45%)	25 (63%)	14 (35%)	7 (37%)
	Save energy, responsible and efficient consumption.	2 (5%)	20 (50%)	1 (3%)	1 (5%)
Others:	Generic actions, such as not polluting the environment or being more careful with the environment.	12 (30%)	4 (10%)	16 (40%)	4 (21%)
	Not cutting down trees. Planting trees.	4 (10%)	6 (15%)	3 (8%)	2 (11%)
	Not throwing rubbish into rivers and seas.	2 (5%)	1 (3%)	2 (5%)	0 (0%)
	Recycling.	5 (13%)	5 (13%)	9 (23%)	5 (26%)
	Reducing the use of, or not using products that damage the ozone layer.	1 (3%)	0 (0%)	3 (8%)	0 (0%)
	Reducing production in factories.	3 (8%)	3 (8%)	4 (10%)	3 (16%)
	Awareness campaign and legislation.	0 (0%)	0 (0%)	3 (8%)	1 (5%)

When comparing the results of the three grades, we observed that the ninth grade students most frequently referred to strategies, such as reducing the use of products which are harmful to the ozone layer. The suggestion of this action is consistent with the results obtained from the other questions in the questionnaire, in which the ninth grade students often referred to the links between climate change and the destruction of the ozone layer. Likewise, it has been observed that ninth and eleventh grade students tended to suggest more generic actions, such as recycling and reusing materials. Furthermore, some of the older students mentioned actions aimed at increasing the surveillance and control of activities that produce pollution as well as the adoption of more restrictive laws and international treaties.

4.2. Mental models

We found that the seventh grade students' mental models regarding climate change and the greenhouse effect correspond to four levels of sophistication (Figure 2). These levels have been listed from 1 to 4 in increasing order of sophistication, attempting to show the progression in the students' learning about the greenhouse effect. The level 1 mental models are descriptive and similar to what Reinfried & Tempelmann (2014) called "isolated pieces of knowledge". The level 2 mental models incorporated the idea that the destruction of the ozone layer allows more radiation to reach the Earth, or that the thickening of the ozone layer prevents solar radiation from being emitted back into space. This level is comparable to the mental model 2 identified by Shepardson et al. (2011). The level 3 mental model embraces the idea that there are greenhouse gases in the atmosphere that trap the sun's rays. This mental model also includes the idea of a layer of gases that surrounds the Earth. The level 4 mental models are the closest to the model taught in school science.

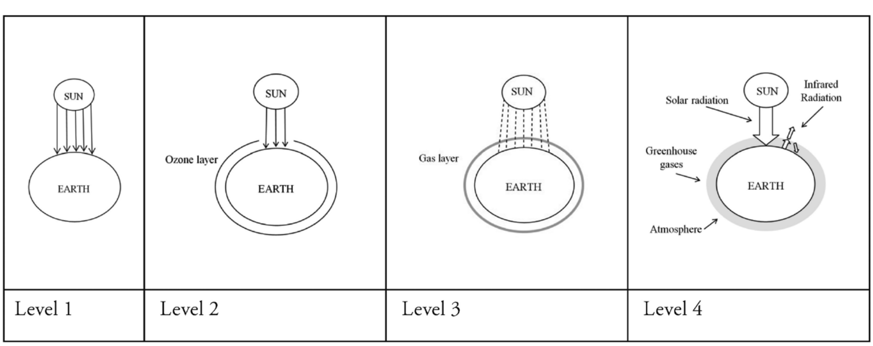


Figure 2 Diagrams of the levels in the seventh grade students' mental models on the greenhouse effect

Table 6 shows the frequencies of each level of sophistication in the students' mental models in the pre-test and post-test. It also includes the level of the mental model demonstrated by each student, identified by a code in order to monitor the evolution of each participant. We observe that before instruction, the most frequent level was level 1 (48%); whereas, after instruction, the most representative level was level 3 (38%).

TABLE 6
RATIO OF SEVENTH GRADE STUDENTS ASSOCIATED WITH EACH LEVEL IN THE MENTAL MODELS AND FREQUENCY OF EACH LEVEL (N=40)

Level	*Pre-test student code*	*Post-test student code*	*Number of students (pre-test)*	*Number of students (post-test)*
1	2, 3, 4, 7, 8, 11, 14, 16, 18, 19, 20, 23, 24, 25, 29, 30, 38, 39, 40.	1, 2, 3, 11, 20, 24, 30, 39, 40.	19 (48%)	9 (23%)
2	1, 5, 13, 17, 21, 36, 37.	5, 13, 16, 17, 23, 36.	7 (18%)	6 (15%)
3	6, 10, 12, 15, 26, 28, 32, 34, 35.	4, 6, 7, 8, 9, 10, 12, 14, 21, 25, 26, 29, 32, 35, 38.	9 (23%)	15 (38%)
4	9, 22, 27, 31, 33.	15, 18, 19, 22, 27, 28, 31, 33, 34, 37.	5 (13%)	10 (25%)

Moreover, by comparing the students' codes in both columns of Table 6 we can see that 22 participants stayed on the same level before and after instruction. We attribute this finding to the fact that during instruction, insufficient emphasis was placed on the students becoming aware of their initial mental models and there were few opportunities to compare their mental models with the models taught in the school science curriculum. Seven students (codes 4, 7, 8, 14, 25, 29, 38) changed their mental models from level 1 to level 3. Four students with level 1 models (codes 5, 13, 17, 36) did not change their models after instruction despite the fact that they were taught about alternative conceptions.

5. Conclusions

With regards to the conceptions of the seventh grade students, their responses to the questionnaire showed that some of them wrongly associated climate change with the reduction of the ozone layer, an idea already discussed in previous studies (Andersson & Wallin, 2000; Boyes & Stanisstreet, 1993). They generally provided generic answers with regards to the causes of this environmental problem, and they tended to use pollution as an element of explanation.

Furthermore, when comparing the results obtained from the students of all three grades, we observed no significant differences in relation to what they understand by climate change because, regardless of their age, most of them related this environmental problem to an increase in the average temperature of the planet and they failed to mention the increase in the greenhouse effect. The reason why the results obtained from the seventh grade students were similar to those obtained from students from higher grades, even before instruction, may be due to the fact that nowadays, attempts at raising awareness about climate change begin at an earlier age and this topic is considered to be more appropriate. This is important progress because it shows that existing training plans are beginning to yield positive results.

With regards to the seventh grade students' mental models of the greenhouse effect, we observed a general evolution in this group of students' mental models, moving towards more sophisticated mental models following instruction. The results reveal that descriptive models such as those included in level 1 can be easily modified and evolved towards models which are close to the model offered in the school science classroom. Students with level 1 mental models have limited prior knowledge of the greenhouse effect. As a consequence, they are able to easily reconstruct their mental models by assimilating new information into existing knowledge structures. On the contrary, the evolution of models in level 2 is difficult to achieve due to the fact that it implies the modification of a highly coherent and functional initial model. The differences between their previous ideas and the new information are so profound that students have to build a new mental model in order to be able to explain the mechanisms of the greenhouse effect (Reinfried & Tempelmann, 2014).

As educational implications, we propose creating classroom situations that will allow students to make their mental representations explicit, giving them an opportunity to compare their validity through discussion. It must be made clear that this study does not seek to generalise results to other cases. However, it does allow for comparisons to be made with other studies of a similar nature, contributing to the knowledge of students' conceptions and mental models on climate change.

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