A review of the Greenhouse Effect and Climate Change in High School Textbooks

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Abstract. The recent reintroduction in the Italian high school curricula of civic education, especially concerning sustainable development, opened the field to the design, implementation, and evaluation of teaching-learning sequences, focusing on the greenhouse effect and climate change, in high schools. These themes have gained weight in the student curriculum and, consequently, more space is being devoted to them in high school textbooks. In this work, we report on a critical analysis we performed, concerning the actual presence of improvements in the treatments dedicated to these topics in current textbooks. Furthermore, starting from the results of previous studies, we will compare our findings with those present in the literature, highlighting any improvements found.

1. Introduction

Since several years, our research group in physics education at the university of Trento has been working on the design, implementation, evaluation, and redesign of teaching-learning sequences (TLS), about the physical basis of the greenhouse effect (GHE) and of climate change (CC) [1–4].

In the last years, the issue of CC has become more urgent and present in mass-media and in politics. In the case of Italy, this contributed to the reintroduction of civic education in high school curricula (Italian D.M. 35, 22 June 2020 [5]), with particular emphasis on sustainable development in the framework of the 2030 Agenda – Sustainable Development Goals [6]. Consequently, we decided to start testing our TLS both with high school students and with in-service and pre-service teachers.

This work, focused on the textbooks analysis, is motivated by the recognition that the students' understanding of key concepts crucially depends on the textbook authors being aware of the common misconceptions on CC [7]. Hence, in the design progression, the necessity of critically analysing the related content of current high school textbooks in physics, chemistry and Earth science arises.

2. Theoretical framework

Concerning the theoretical framework, we developed the procedure shown in Figure 1, taking inspiration from the literature and then adding the peculiar features of our research.

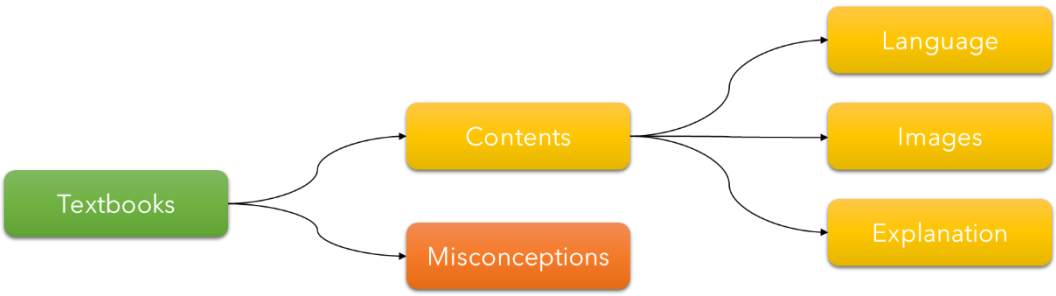

Figure 1. Textbook analysis procedure

The procedure involves two kinds of investigation of the text: the analysis of contents and the analysis of misconceptions.

Concerning the **contents**, we perform a conceptual analysis, using the control list method proposed by Ibañez and Ramos [8], with reference to the key concepts about GHE which are well known in the literature [2,9]; we consider three aspects:

- **language**, examining the definitions, and how they are introduced [10];
- **pictures**, using a semiotic-based theoretical framework [11,12];
- **explanation**, checking their logical completeness, according to the proposal of Viennot and Decamp [11].

For what concerns **misconceptions**, we took into account the methodology proposed by Choi [7,13], tracing, for every misconception we found in the literature, the corresponding scientific concept.

3. Research questions

We here seek to answer the following research questions:

- **RQ1**: How do current textbooks treat the theoretical concepts needed to understand GHE and climate change? Are they clear and comprehensive?
- **RQ2**: How much are current textbooks suitable to this new need, compared with older ones?

4. Methods

In this work, we have analysed ten of the best-selling textbooks in physics, chemistry and Earth science that are currently used in Italian secondary schools. In fact, although the conceptual areas involved in understanding the phenomenon mainly refer to physics and chemistry (see Table 1), the Italian educational curriculum envisions the greenhouse effect being addressed (mainly) in technology, Earth science and geography, hence our choice fell on books devoted to these subjects. Specifically, we considered: three technology and science books for the middle school; three geography books for the high school; four Earth science books for the high school. The analysis concerned both the pictures and the related explanations in the main text. Regarding the former, we used the already explained theoretical framework based on semiotic, according to which pictures are classified in terms of their representative structures, which can be narrative or conceptual [12]. As for the text, we used both the concepts involved in the understanding of CC, and the common misconceptions the students have on these concepts [7].

Performing this analysis allowed us a comparison with analogous studies carried out a decade ago, both at the Italian and international level.

4.1. The analysis protocol

The analysis protocol envisages examining each textbook, in order to verify the presence in it of the topics present in a given checklist. The list was derived from the studies reported in Ref [2], which identified the conceptual areas listed in Table 1.

Table 1. Topics to teach. For each conceptual area, the corresponding concepts to be taught (subareas) are listed [2].

Conceptual area	Sub-areas
Heat	Heat propagation Heat and energy Microscopic interpretation
Electromagnetic spectrum	Energy of the electromagnetic spectrum bands Stefan-Boltzmann Law Wien Law
Energy balance	Radiative balance Stationary states Energy forms
Greenhouse effect definition	Greenhouse gases properties Albedo effect Mean surface temperature
Radiation-matter interaction	Reflection Refraction Absorption Diffusion Selective transparency

Once the topics in the textbook have been identified, each of them has been analysed according to the framework described in the preceding Section. In Table 2 below we present an evaluation grid, including the three relevant aspects, i.e., language, pictures, and explanation.

Table 2. Evaluation grid to be used for each topic, according to the above-described framework.

Aspect	Features to be checked
Language [10]	(L-1) previous appearance of the concept (yes/no) (L-2) explanation of the concept using familiar words (much/enough/little)
Pictures [11,12]	(P-1) presence, in the same picture, of elements representing both real world and schematic or symbolic entities (yes/no) (P-2) presence of elements to be selected or conceptually highlighted in relation to textual/graphical features which make them salient or not (yes/no) (P-3) presence of elements which require appropriate interpretation of symbols (i.e., synonymy, homonymy, or polysemy) (yes/no) (P-4) presence of elements to be read as an important part of the image (yes/no) (P-5) presence of two or more conceptually related images (yes/no) (P-6) presence of compositional structures that require the interpretation of spatial distribution and different representational structures (yes/no)

Explanation [11]	(E-1) presence of all the logical connections required for a satisfactory explanation (yes/no) (E-2) completeness of the material (very complete/complete/incomplete/inaccurate/wrong/popular level explanation)

Finally, the typical misconceptions associated with the topic are looked for in the textbook. For this phase we prepared an evaluation grid which is analogous to that proposed by Choi in Ref. [7] which collects the misconceptions present in the literature. The grid has been supplemented with the following further misconceptions, which were identified in the research work by the groups of Trento and Pavia:

- **Basic notions**: confusion about the definition of heat (misconception or inaccuracy in the use of the term "heat")
- **Basic notions**: confusion between natural and anthropogenic greenhouse effect (failing to distinguish between greenhouse effect and anomalous greenhouse effect)
- **Causes**: heat flux (explanation with reference only to heat-related thermal effects; confusing explanation between radiative phenomena and heat)
- **Causes**: trapping (explanation with the trapping model)

4.2. The literature results

There are some past studies in the literature concerning textbook analysis on this topic. In the following Table 3 and Table 4 we summarize the results of an Italian study (reported in Ref [14]) and an international study (reported in Ref [7]). Comparison with these data will allow us to evaluate, at least qualitatively, our results and provide our answers to the research questions.

Table 3. The critical items considered in an Italian study [14]. The percentage shows the extent to which these items are present with respect to all the analyzed textbooks.

Item	**[%]**
Reference only to the thermal effects related to heat	7%
Reference to the radiative phenomena	50%
Confusion between radiative phenomena and heat	43%
Reference to the difference between spectrum and radiation	57%
Reference to the transparency and opacity of the atmosphere	50%
Reference to energy balance	36%
Right figure and caption	7%
Reference to the scientific debate on global warming	29%

Table 4. The critical items considered in an international study [7].

Item	**[%]**
Distinction between pollution and greenhouse effects or climate change	0%

Distinction between the ozone layer and greenhouse gases in terms of the interaction with radiation	43%
Climate change is already under way	29%
Distribution of greenhouse gases in the atmosphere	14%
Solar irradiation change and its possible impact on current climate change	14%
Projections of future climate changes according to emission scenarios	14%
The dependency of human society on fossil fuel and barriers to reducing emission of greenhouse gases	29%
Selective absorption of radiation by the atmospheric gases	43%

5. Results

As an example, let us consider Figure 2, which is taken from a high school science textbook.

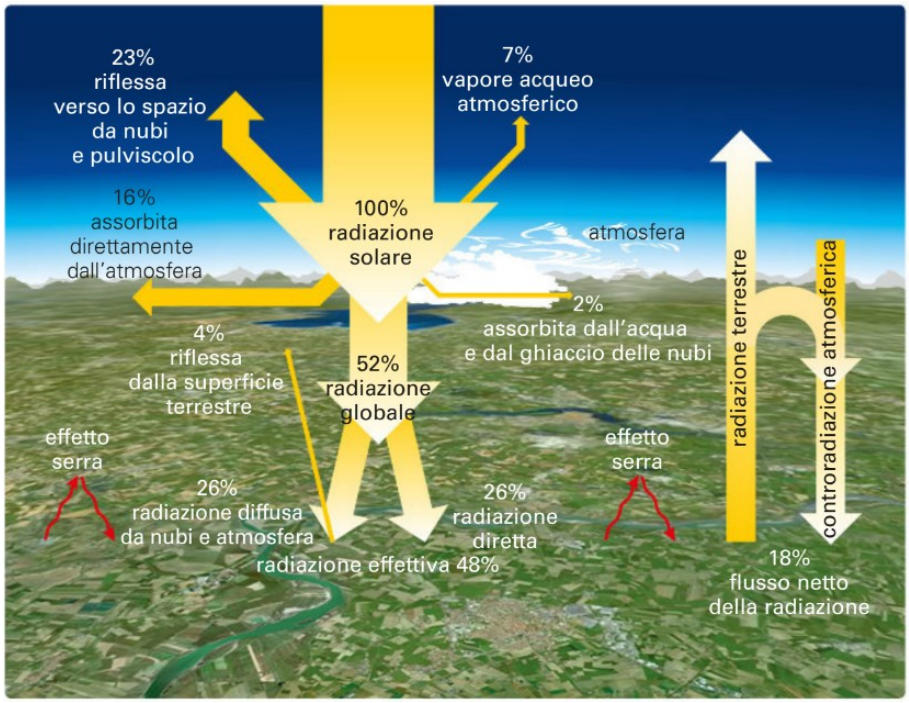

Figure 2. Thermal balance of the Earth-atmosphere system (reproduced with permission from Ref. [15], 2016 Mondadori Editore).

In it, the thermal balance of the Earth-atmosphere system is depicted. As shown in the previous section, for each textbook we identified which of the topics listed in Table 1 are present (either in the images or in the text) and we compiled the evaluation grid shown in Table 2 for each of them. In Table 5 below we show how this analysis was applied to the topic of “radiative balance”, which is part of the conceptual area "energy balance", for the case of Figure 2.

Table 5. Evaluation grid of Table 2 applied to the analysis of Figure 2.

Aspect	**Features to be checked**	**Value**
Language [10]	(L-1)	yes
	(L-2)	enough
Pictures [11,12]	(P-1)	yes
	(P-2)	no
	(P-3)	yes: polysemy
	(P-4)	yes
	(P-5)	yes
	(P-6)	no
Explanation [11]	(E-1)	yes
	(E-2)	complete
Typical misconceptions		trapping and multiple reflection; misunderstandings about radiative balance

From this analysis, we can draw some interesting considerations:

- the picture includes both real world elements and schematic and symbolic entities;
- some elements present polysemy of the symbols: yellow arrows represent incoming, outgoing, absorbed, and reflected radiation; nevertheless, arrows of different dimensions represent different entities;
- some elements (the red arrows under the caption “effetto serra”, which means “GHE”) reinforce the misconceptions of trapping and of multiple reflection [9];
- some elements (the arrows on the right of the picture, which have the same size) reinforce misconceptions about radiative balance in the Earth-atmosphere-Sun system.

An interesting aspect that emerged from this analysis, which had already been observed in this context, is that even advanced students (high school and undergraduate) keep the imprinting of possible misconceptions which they took from elementary or middle school textbooks.

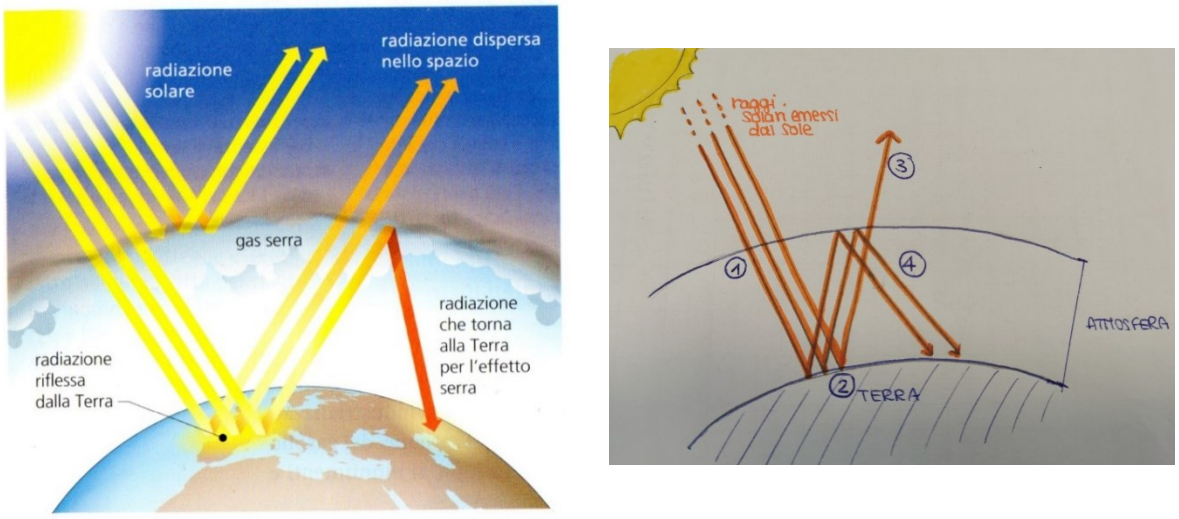

Figure 3. Misconception of the greenhouse gas layer: **(Left)** in a technology textbook for the middle school (reproduced with permission from Ref. [16] 2014 Zanichelli Editore S.p.A.) and **(Right)** in a drawing produced by a university student in the TLS pre-test.

Indeed, in our analysis we noticed clear analogies between the drawings produced by the students attending the university course where the TLS was proposed and the pictures we found in the analysed textbooks. For example, Figure 3 supports the misconception that greenhouse gases (GHG) form a well-defined and limited layer in the atmosphere.

Another frequent misconception is that reported in Figure 4, and it concerns the multiple reflection of "rays coming from the sun" and the lack of distinction between the wavelengths of the incoming and of the outgoing radiation.

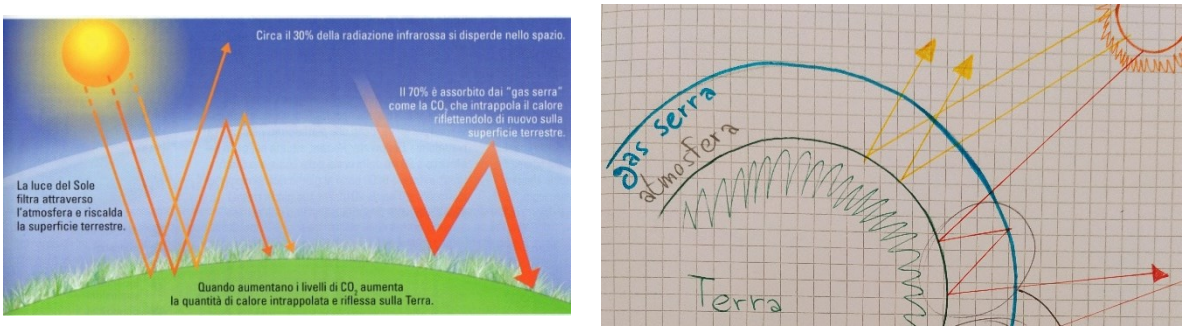

Figure 4. Misconception of the multiple reflections: **(Left)** in a technology textbook for the middle school (reproduced with permission from Ref. [17] 2014, Mondadori Education S.p.A.) and **(Right)** in the answer by a university student to the TLS pre-test.

Finally, in Figure 5, we report an example of the misconception of using an actual green house as picturing the natural GHE.

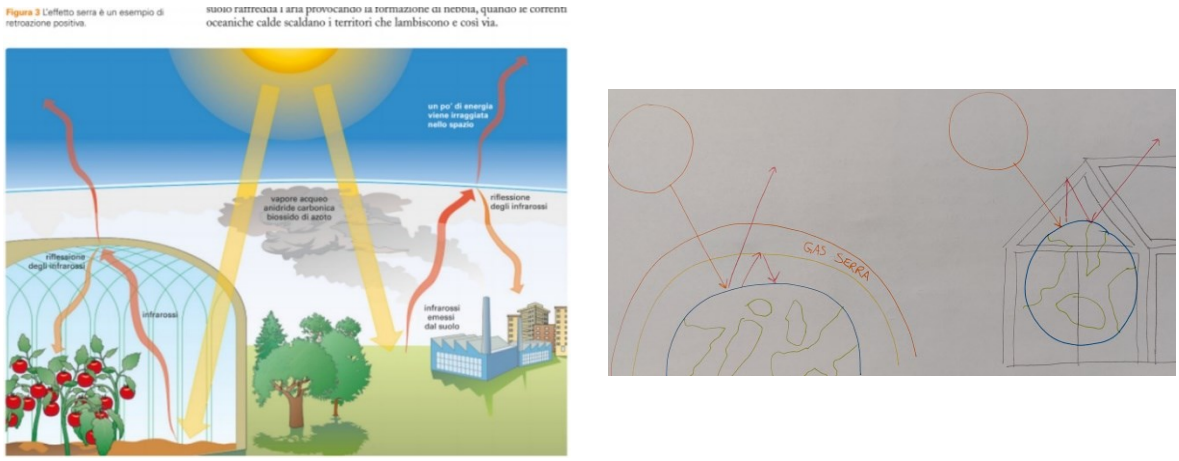

Figure 5. Misconception of the comparison with an actual greenhouse **(Left)** in a technology textbook for the middle school (reproduced with permission from Ref. [18] 2014, Mondadori Education S.p.A.) and **(Right)** in the answer by a university student to the TLS pre-test.

6. Conclusions

These analyses allow us to compare our results with those obtained from past research (which we have summarized in Table 3 and Table 4, and were derived from Ref [7,14], respectively). With reference to the topics to be taught (shown in Table 1) that were analysed, we can draw the following results:

- in 5 books (out of 10) reference is made to radiative phenomena;
- in 5 books reference is made to the selective behaviour of the atmosphere;
- in 4 books reference is made to the energy balance;
- no books explicitly involve the ozone layer in explaining this phenomenon;
- only 2 books still propose the similarity with the agricultural greenhouse.

Thus, we can observe that the percentages are in line with what we had found in the literature, except for some more recent texts that address the topic in more detail and with more attention to the students' misconceptions.

Accordingly, concerning the RQ1, we can conclude that that many of the analysed textbooks present several problems. Several theoretical concepts which are fundamental in order to understand the phenomenon are not addressed at all, or only in a superficial way.

However, regarding the RQ2, we have also been able to observe that some recent textbooks in fact do present the phenomenon in a more coherent and correct way with respect to older ones (consider e.g. Figure 2, where the portions of incident radiation that are reflected, absorbed, transmitted, etc. are clearly and correctly specified according to Earth energy budgets [19]), thus representing an actual improvement over the past.

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