The impact of experiments on students' knowledge and explanations of significant aspects of the greenhouse effect

El impacto de las experimentaciones y explicaciones en la enseñanza sobre el efecto invernadero

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Abstract

In this work, the impact of experiments in teaching on students' knowledge and explanations on significant aspects of the greenhouse effect has been investigated. In particular, the study focused on the students' knowledge and explanations on the chemistry of gases that are involved in the phenomenon and the radiation that causes the phenomenon. Two different approaches of teaching were applied in a high school in Greece: One involved a lecture, which was based on an extensive theoretical analysis of these topics (i.e. the gases and the radiation), whereas the other involved a lecture, which was accompanied by experiments related to the same topics. The main objective was to find out, which of these approaches was the most effective with respect to the students' knowledge and explanations. Results show that the experiments had a somewhat more positive impact on students' learning of the relevant topics, than the theoretical analysis by itself on these topics.

Key words: *Chemical education, greenhouse effect, experiments, gases of greenhouse, radiation*

Resumen

Este trabajo muestra el impacto de los experimentos y las explicaciones sobre los aspectos significativos del efecto invernadero en el conocimiento de los estudiantes. En particular, el estudio está enfocado en el conocimiento de los estudiantes y las explicaciones sobre la química de gases y la radiación que ocasiona este fenómeno. Dos enfoques diferentes de enseñanza se aplicaron en una escuela superior en Grecia: uno involucra una conferencia, con base en un análisis teórico extensivo de los temas de los gases y la radiación; el otro involucra una conferencia, acompañada por experimentaciones relativas a los mismos temas. El objetivo principal de esta investigación fue averiguar, cuál de estos enfoques era el más efectivo con respecto al conocimiento de los estudiantes y las explicaciones. Los resultados muestran que las experimentaciones tuvieron mayor influencia en el aprendizaje de los estudiantes sobre temas relevantes, que del análisis teórico sobre estos temas.

Palabras clave: *educación química, efecto invernadero, experimentos, gases de invernadero, radiación.*

Introduction

"Greenhouse effect" is one of the most discussed environmental issues in the present days. Over the last 15 years a number of studies have been carried out at all the levels of education about the ideas of children, students or pre-service teachers concerning this phenomenon. With respect to students attending secondary level education, researchers have recorded a number of alternative ideas, some interesting points of which are the following (BOYES and STANISSTREET, 1997; FISHER, 1998; KOULAIDIS and CHRISTIDOU, 1999; RYE and RUBBA, 1998; RYE, RUBBA and WIESENMAYER, 1997):

- Students don't consider the phenomenon as a natural phenomenon, which continuously contributes to the configuration of the climate on earth. For them, greenhouse effect is a result of the air pollution.
- Knowledge about the mechanism of the phenomenon is limited. Students ignore how the infrared radiation is produced by an absorption / re-emission mechanism taking place on the earth.
- Students cannot define the kind of the radiation that causes the phenomenon. Ultraviolet, visible and infrared (thermal) radiation are included in the explanations given by students. However there is often no such distinction and it is very common for the students to consider all these kinds as one.
- Knowledge about the characteristics of the gases of the greenhouse is very limited as well. Students know mainly carbon dioxide (and methane) as the gases that cause the phenomenon, whereas they ignore the characteristics which are important in making the contribution of a gas to the phenomenon significant.
- According to students' views, greenhouse effect and ozone layer are two phenomena directly connected with each other. The idea that the destruction of the ozone layer leads to the creation of holes, which leave radiation to pass through and cause or intensify the greenhouse effect, is very common.

Several suggestions have occasionally been made concerning the students' learning of the greenhouse effect. Some of them have focused on the content of a possible teaching approach of the phenomenon (RYE, RUBBA and WIESENMAYER, 1997; ROSENTHAL, 1990), whereas other suggestions have focused on the methodology of teaching the phenomenon (MEADOWS, 1999; RYE, RUBBA and WIESENMAYER, 1997). Also, several tools have been identified, which could be used by teachers in order to present the phenomenon in the classroom in a more comprehensive way. Especially designed experiments have been considered as such (ADELHELM and HÖHN, 1993; PAPAGEORGIOU and OUZOUNIS, 2000).

METHODOLOGY APPLIED IN THE INVESTIGATION

The main purpose of this study was to investigate the impact of a number of specific experiments in teaching on students' knowledge and explanations on significant aspects of the greenhouse effect, focusing in particular on the following two points:

- The gases that are involved in the phenomenon.
  What are the gases that cause the phenomenon? What are their characteristics? How do these characteristics affect the phenomenon?
- The radiation that causes the phenomenon.
  What kind of radiation causes the phenomenon? What are its characteristics? How is this radiation formed (mechanism)?

Two different approaches of teaching were applied by one of the researchers in a high school in Greece. The sample was students of high school, 13-14 years old, who had been divided in three groups. A group of students (group A) attended a lecture, which was accompanied by experiments that were carried out by the teacher (i.e. researcher), while students recorded and elaborated the data resulting from the experiments. A second group (group B) attended a lecture, where the same items were analysed and explained in detail, but without the support of any experiment. A third group (group C) was the control group, where no intervention took place. After the interventions, groups were compared with respect to their knowledge and explanations on the issues that have been taught. More details about the sample of the study and the interventions per group are presented in table 1.

Table 1
Some significant data for the sample

	Number of students	Number of boys	Number of girls	Duration of the intervention (min)	Kind of intervention
Group A	22	8	14	90	Lecture/Experim.
Group B	18	8	10	60	Lecture
Group C	25	12	13	0	None

The level of students' learning was examined two months after the intervention. Data were selected from all groups through a questionnaire, especially constructed for this study, which was the same for all groups and it had two parts. In the first part, students were asked through an open-ended question to describe the phenomenon in their own words. In the second part, there were six questions, five of which were open-ended and one was a multiple-choice question. The completion of the questionnaire lasted 50 minutes (5 minutes for the first part and 45 minutes for the second). Students were asked to complete the first and the second part separately.

In order to carry out the intervention in groups A and B, two teaching approaches were designed. The main characteristics of these approaches were generally the same. However, there were three phases of teaching for group B, whereas there was one more phase for group A. table 2 presents a general description of the phases of the two approaches. Due to the development of the experiments in group A, which could substitute corresponding parts of the theoretical development, the extent of the lecture was minimised, accordingly. However, the procedure in group A lasted 30 minutes more than in group B, due to the time that students needed for the recording and the elaboration of the data in phases 3 and 4. This elaboration involved the construction of relevant diagrams, which helped students to draw conclusions, comparing data and diagrams of exp. 1 with those of each one of the other experiments (see table 3). The four experiments reported in table 2, were especially designed for this study and were based on the construction, which has been presented by Papageorgiou and Ouzounis (2000), (see also figure 1).

Table 2
Teaching approaches for groups A and B

No of Phase	Content of the lecture	Groups/ Duration	Exp.
1	(General characteristics of the phenomenon) The kind of radiation the earth accepts. Description of the spectrum of the light. The mechanism of reflection and absorption/ re-emission of the light. As some specific gases absorb infrared radiation, temperature arises. Which these gases are. The greenhouse effect is a natural phenomenon. Human activities that have as a result a non-normal increase of the phenomenon.	A (15 min) and B (20 min)	-
2	(Working with the experiments) Description of the way of working with the experiments. Explanations about the simulation of the phenomenon. The way of working with the diagrams.	A (5 min)	-
3	(Characteristics of the radiation) More details about the radiation that causes the phenomenon. More details about the mechanism of reflection and absorption/ re-emission of the radiation. What's the reason this mechanism leads to an enrichment of the infrared radiation. The role of the intensity of the radiation.	A (40 min) and B (15 min)	1, 2, 3
4	(Characteristics of the gases) More details about the gases that cause the phenomenon. Their characteristics, their ability to cause the phenomenon, time of their residence in the troposphere and factors that affect it, percentage of their contribution etc.	A (30 min) and B (25 min)	4

Table 3.
A general description of the experiments

Exp.	Description of the process	Aim
1	An amount of CF_2Cl_2 was entered into a beaker, below a lamp 120W – visible radiation.	A general simulation of the phenomenon.
2	The same procedure as exp. 1, but below a lamp 120W – infrared radiation.	The impact of the sort (wavelength) of the radiation.
3	The same procedure as exp. 1, but the lamp was placed in a higher position.	The impact of the intensity of radiation.
4	The same procedure as exp. 1, but the gas was CO_2.	The impact of the characteristics of the gas.

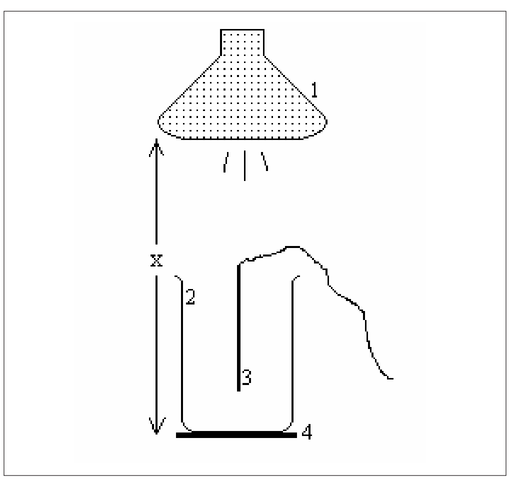

Figure 1. The equipment used in the experiments: (1) lamp, (2) beaker, (3) temperature sensor, (4) a black surface, (x) distance between the lamp and the bottom of the beaker.

RESULTS AND DISCUSSION

Part 1

In the first part of the questionnaire, students were asked to describe in their own words the main characteristics of the greenhouse effect. Table 4 shows the main categories concerning students' answers on the two points under focus (i.e. the radiation and the gases).

With respect to the characteristics concerning the radiation, the students of group A focus mainly on the two first categories of Table 4, indicating characteristics that are quite general, whereas there are two students of this group (A) that refer to the terrestrial radiation. On the contrary, students of groups B and especially C give a greater range of answers concerning radiation.

As far as the means that absorb the radiation are concerned, students of group A appear to focus on only two categories. This could mean that these students approach the phenomenon in a general way, including in their answers as more gases as possible. Also, the total number (13) of students' answers of group A, which fall into these two categories is greater compared to that (7) of group B. This probably means that, with respect to the gases of the greenhouse, more students of group A have a wider view of the phenomenon. On the contrary, students of group C tend to be more

Table 4.
Students' answers on the characteristics of the phenomenon concerning the gases and the radiation: Frequencies (N) and percentages (%) per group

Students' answers on the characteristics of the phenomenon	Group A N (%)	Group B N (%)	Group C N (%)
Characteristics concerning radiation			
Radiation (generally) causes an increase of the temperature	6 (27.3)	3 (16.7)	3 (12.0)
Solar radiation (no further specifications) causes an increase of the temperature	10 (45.4)	7 (38.9)	7 (28.0)
Thermal radiation from the sun causes an increase of the temperature	0 (0.0)	0 (0.0)	1 (4.0)
Terrestrial radiation (which is formed by reflection of the solar radiation on the earth) causes an increase of the temperature	2 (9.1)	1 (5.6)	1 (4.0)
Ultraviolet radiation from the sun causes an increase of the temperature	0 (0.0)	3 (16.7)	2 (8.0)
Characteristics concerning the mean that absorbs the radiation (mainly the gases)			
Radiation is absorbed by some gases (generally)	6 (27.3)	4 (22.2)	2 (8.0)
Radiation is absorbed by specific gases (or the gases of the greenhouse)	7 (31.8)	3 (16.7)	0 (0.0)
Radiation is absorbed by exhaust gases or smog	0 (0.0)	1 (5.6)	5 (20.0)
Radiation is absorbed by the carbon dioxide	0 (0.0)	0 (0.0)	2 (8.0)
Radiation is absorbed by the earth	0 (0.0)	3 (16.7)	0 (0.0)
Other cases			
Some gases cause an increase of the temperature	4 (18.2)	1 (5.6)	5 (20.0)
No answer concerning gases or radiation	0 (0.0)	3 (6.7)	6 (24.0)

specific and focus on carbon dioxide and exhaust gases. The latter reveals a case of misconception, where students seem to consider the phenomenon as an extension of the air pollution. They report exhaust gases as the main factor that leads to the increase of the temperature. These results are similar to those of KOULAIDIS and CHRISTIDOU (1999) who reported a model, according to which students described the phenomenon without mentioning radiation as a dimension of the atmospheric pollution. However, in our piece of research students reported that an absorption of radiation by the pollutants (exhaust gases) occurs and leads to the increase of the temperature.

In addition, there are three students of group B, who report that the increase of the temperature is due to the absorption of radiation by the earth. This misconception could be probably due to the effort of the teacher to explain the phenomenon through the absorption and re-emission of the radiation by the earth. It is possible that students paid attention only to the fact that the earth absorbs the radiation. Also, a small number of students of all groups describe the phenomenon as a case, where only the appearance of some gases in the atmosphere (no report of radiation) can cause an increase of the temperature.

Part 2

The second part of the questionnaire was constituted by two groups of questions (see also table 5): One group focused on detailed characteristics concerning the gases (questions 1,2 and 3) of the greenhouse effect and the other focused on detailed characteristics concerning the radiation (questions 4,5 and 6).

Table 5
A description of the questions of the second part of the questionnaire

Quest.	Description of the question
	Detailed characteristics concerning the gases of the greenhouse effect
1st	Students faced two different situations dealing with the concentration of carbon dioxide in the air (troposphere). In the first situation, the concentration of carbon dioxide was higher than the one in the second situation. Students were asked to specify which of these two situations is related to a more intense phenomenon and explain why.
2nd	We provided students with two different situations dealing with the concentration of the gases CO_2 and freon 12 (CF_2Cl_2) in the air (troposphere). In the first situation, CO_2 was in higher concentration than freon, whereas in the other, the opposite happened. In both situations the total percentage of CO_2 and freon 12 in the atmosphere was the same. Students were asked to specify which of these two situations is related to a higher increase of the temperature and explain why.
3rd	Students were asked to describe what captures the radiation in the troposphere.
	Detailed characteristics concerning the radiation of the greenhouse effect
4th	Students faced a hypothetical situation where the intensity of the phenomenon could be measured in two different seasons (winter and summer). The question was: "What is the season you expect the greenhouse effect to be more intensive? Explain why".
5th	Students were asked to specify the kind of radiation (visible, infrared or ultraviolet) which causes the phenomenon.
6th	Students were asked to give explanations for the mechanism of the transmission of the radiation: The question was: "During the phenomenon absorption of radiation happens. Where does this radiation come from; the sun or the earth? Give an explanation for your answer".

Table 6.
Students' answers concerning the gases of the greenhouse effect: Frequencies (N) and percentages (%) per group

Students' answers N (%)	Group A N (%)	Group B N (%)	Group C
Answers concerning the concentration of CO_2 in the air (1st question)			
The phenomenon will be more intense when the concentration of CO_2 is higher, because CO_2 can absorb more radiation than the other gases	6 (27.3)	4 (22.2)	2 (8.0)
The phenomenon will be more intense when the concentration of CO_2 is higher (no further explanation)	15 (68.2)	13 (72.2)	19 (76.0)
The phenomenon will be more intense when the concentration of CO_2 is lower (no explanation)	1 (4.5)	1 (5.6)	3 (12.0)
In both situations the phenomenon will be the same (no explanation)	0 (0.0)	0 (0.0)	1 (4.0)
Answers concerning the comparison between carbon dioxide and Freon 12 (2nd question)			
Temperature will be increased when CO_2 is increased	6 (27.3)	5 (27.8)	13 (52.0)
Temperature will be increased when the freon 12 is increased	16 (72.7)	12 (66.7)	5 (20.0)
In both situations the increase will be the same	0 (0.0)	1 (5.6)	4 (16.0)
No answer	0 (0.0)	0 (0.0)	3 (12.0)
Answers on what captures the radiation in the troposphere (3rd question)			
Some gases (in general)	4 (18.2)	3 (16.7)	3 (12.0)
Some specific gases or the gases of the greenhouse	7 (31.8)	2 (11.1)	2 (8.0)
The earth	0 (0.0)	3 (16.7)	0 (0.0)
The clouds	3 (13.6)	2 (11.1)	0 (0.0)
Exhaust gases or smog	0 (0.0)	1 (5.6)	6 (24.0)
Carbon dioxide	6 (27.3)	4 (22.2)	5 (20.0)
Freon 12	6 (27.3)	6 (33.3)	2 (8.0)
No answer	1 (4.5)	3 (16.7)	9 (36.0)

Table 6 presents the students' answers to the questions concerning the gases of the greenhouse effect. As one can see, there were no dramatically differences between the three groups concerning the students' answers in the first question. Although there were small differences in the explanations given by the students, the majority of them in all groups agreed that the phenomenon will be more intense when the percentage of CO_2 is higher. This was expected to a certain degree, since carbon dioxide is the best known gas, which is connected to the greenhouse effect by those who have never been particularly occupied with this phenomenon.

However, some remarkable differences could be seen, with respect to the students' answers in the second question. Students of both groups A and B believe that freon 12 could cause a higher increase of the temperature than carbon dioxide, whereas students of group C believe the opposite. Although there are not so obvious differences between groups A and B in Table 6, there are some differences, concerning the reasons given by students for the different increase of the temperature in cases of CO_2 and freon 12, respectively. These are presented in Table 7.

As one can see (table 7), students give three groups of reasons, which are: a) the ability of the gas to cause the phenomenon, b) its residence near the surface of the earth and c) its percentage in the troposphere. We could say that, the percentage of the gas in the troposphere is the most common reason for the increase of the temperature, in all groups (A, B and C). However, students of group C seem to pay attention only to this factor (mainly to the percentage of the carbon dioxide in the troposphere). The factor "ability" does not appear at all in the students' reasons of group C, whereas a small number of students of groups A and B pay attention to this factor. As for the third factor "residence of the gas near the earth", it is reported by both groups A and B, but mainly by group A. It should be noted that, during the lectures in groups A and B, weight of the gases was mentioned as one of the factors that affects the residence of the gases near the earth. In addition, this factor was supported by one of the experiments. Students of group A had the opportunity to see through the diagrams that freon 12 could remain longer inside the beaker than CO_2 and keep the temperature high for longer. However, due to this experience, students of group A evaluated this factor as one of the main reason for the increase of the temperature overshadowing partially the other factors.

As for the categories of the third question (table 6) and the corresponding students' answers distribution, they are similar to those presented in

Table 7.
Students' reasons concerning the comparison between carbon dioxide and Freon 12 (2nd question): Frequencies (N) and percentages (%) per group

Students' reasons* for the increase of the temperature N (%)	Group A N (%)	Group B N (%)	Group C
(CO_2): Because its percentage in the air is higher	5 (22.7)	4 (22.2)	11 (44.0)
(CO_2): No reason	1 (4.5)	1 (5.6)	2 (8.0)
(Freon 12): Because its ability to cause the phenomenon is higher	3 (13.6)	2 (11.1)	0 (0.0)
(Freon 12): Because its molecular weight is higher and it would stay near the earth for longer	7 (31.8)	2 (11.1)	1 (4.0)
(Freon 12): Because its percentage in the air is higher	6 (27.3)	6 (33.3)	3 (12.0)
(Freon 12): No reason	0 (0.0)	2 (22.2)	1 (4.0)

* None of the student gave more than one reason.

Table 8
Students' answers concerning the radiation of the greenhouse effect: Frequencies (N) and percentages (%) per group

Students' answers	Group A N (%)	Group B N (%)	Group C N (%)
Answers concerning the season during which the greenhouse effect is expected to be more intensive (4th question)			
The summer, because the solar radiation is more intense than in winter	12 (54.5)	8 (44.4)	8 (32.0)
The summer because the solar rays drop vertically to the earth (so, the radiation is more intense)	0 (0.0)	2 (11.1)	0 (0.0)
The summer because the distance between the sun and the earth is less than in winter (so, the radiation is more intense)	6 (27.3)	1 (5.6)	0 (0.0)
The summer because the weather is hot	3 (13.6)	4 (22.2)	11 (44.0)
The summer (no further explanation)	0 (0.0)	1 (5.6)	4 (16.0)
The winter (no explanation)	1 (4.5)	1 (5.6)	1 (4.0)
It is the same in both seasons	0 (0.0)	1 (5.6)	0 (0.0)
No answer	0 (0.0)	0 (0.0)	1 (4.0)
Answers concerning the kinds of radiation (visible, infrared or ultraviolet) (5th question)			
Visible radiation	0 (0.0)	1 (5.6)	4 (16.0)
Infrared radiation	10 (45.4)	4 (22.2)	0 (0.0)
Ultraviolet radiation	12 (54.5)	12 (66.7)	19 (76.0)
All kinds of radiation contributes the same	0 (0.0)	1 (5.6)	3 (12.0)
Answers concerning the mechanism of the transmission of the radiation (6th question)			
Radiation directly from the sun is absorbed (by some gases or by the earth)	9 (40.9)	9 (50.0)	18 (72.0)
Radiation from the sun is absorbed by the earth and is re-emitted in order to be absorbed (by some gases)	2 (9.1)	2 (11.1)	0 (0.0)
Radiation from the sun is reflected on the earth and then is absorbed (by some gases)	7 (31.8)	4 (22.2)	3 (12.0)
No answer	4 (18.2)	3 (16.7)	4 (16.0)

the corresponding part of table 4, (1st part of the questionnaire). Interestingly, the total number of students' answers in each group that fall into the categories "some specific gases or the gases of the greenhouse", "the clouds", "the carbon dioxide" and "the freon 12" decreases from group A to group C. This supports the view that more students of group A, compared to group B and especially to group C, can better describe the phenomenon, with respect to the gases of the greenhouse.

The students' answers, which concern the radiation of the greenhouse effect, are presented in table 8. In the 4th question, the majority of students of all groups agree that the phenomenon would be more intense during the summer. However, a significant percentage of students of group A, explaining the reasons of the possible high intensity of the phenomenon during the summer, reported that the higher intensity is due to the reduced distance between the sun and the earth during this period. Especially for the north hemisphere, where Greece is located, this answer is totally incorrect. A possible explanation for this wrong reasoning could be that: On the one hand, students' answers were may be influenced by the experiment 3, where the distance x between the lamp and the beaker (see figure 1) was varied in order to vary the intensity of the radiation, although the role of the angle (between rays and surface of the earth) was also analyzed during the lectures. On the other hand, students may believe that the distance between the sun and the earth is shorter during the summer, a fact which reveals a misunderstanding in the area of Cosmology. Only two students of group B used in their reasoning the information provided during the lectures about the angle between rays and surface of the earth. As for the category "the summer, because the solar radiation is more intense than in winter", this could be considered as a satisfying answer, although students' explanations were rather poor. The percentage of students of group A who gave this answer is higher than that of the other two groups, whereas the percentage of students of group C is the lowest. The opposite holds true for the category "the summer because the weather is hot", where students' answers are based on the results rather than the origin of the phenomenon.

With respect to the 5th question (a multiple-choice question) and independently of group, the majority of students believe that the kind of radiation that causes the phenomenon is the ultraviolet radiation. Although the percentage of students of group A who answered correctly (45.4%) is high (twice as many students as in group B), the percentage of them who mention the ultraviolet radiation is also high (54.5%). It is reminded that the students of this group had seen the red light during the experiment 2. However, as other studies report (Koulaidis and Christidou, 1999; Rye and Rubba, 1998), ultraviolet radiation is very often strongly connected to the greenhouse effect in students' minds.

According to the data concerning the sixth question, the mechanism of the transmission of the radiation appears to be very difficult. As Table 8 shows, only two students of each group A and B gave the correct answer "radiation from the sun is absorbed by the earth and is re-emitted in order to be absorbed (by some gases)". The majority of students of group C (72.0%) and a significant percentage of students of groups A(40.9%) and B (50.0%) believe that radiation, which comes directly from the sun, causes the phenomenon. It is worth reporting that the percentage of students of group A in the category "radiation from the sun is reflected on the earth and then is absorbed (by some gases)" is higher than in the other two groups. This latter category could be considered as being close to the correct answer.

CONCLUSIONS

With respect to the two points this study has focused on, namely the gases and the radiation of the greenhouse effect, results show that after the interventions there is an improvement in students' knowledge and explanations, which is more obvious in the case of the gases rather than in the case of the radiation. The kind of radiation and especially the mechanism of its transmission appear to be concepts, which are difficult enough for the age group of 13-14 years old. Only a few students, mostly of group A, tend to explain this mechanism as a way of reflection, whereas only two students from each group A and B give the correct answer. On the other hand, students of group A and B gave a better profile, compared to group C, as far as the gases involved in the phenomenon are concerned.

Comparing groups A and B, results show that more students of group A seem to have somewhat achieved a better level of knowledge and have given satisfying explanations on the relevant topics (i.e. the gases and the radiation of the greenhouse effect), although differences between the two groups were not as extensive as it was expected. More remarkable differences are presented in cases where, the gases of the phenomenon and its characteristics, as well as the kind of radiation and (to a certain degree) the mechanism of its transmission is the question. Focusing on a more practical level of these results, we could suggest that, in these particular cases, the use of the experiments, as they are described in the present work, could help better in the exploration of the greenhouse effect. On the other hand, in cases where the role of the season in the development of the phenomenon or the mechanism of the transmission of the radiation is the point, the experiments should be supported by a more extensive theoretical analysis. In addition, in some cases, where an experiment could have such an impact on students, that they could be led to an overvaluation of a factor, underestimating the effect of another more important one, a more careful handling of the relevant experiment is needed, as experiments appear to be very sensitive teaching tools. Despite the fact that some points of the suggested experiments may be revised under the light of the new evidence, results are promising as far as the teaching of the above topics is concerned with the use of experiments.

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