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Generational differences in University Students:
Challenges or opportunities?

ARTICLES

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What ideas about climate change do future science teachers possess and how do they integrate them when arguing about greenhouse effect? A case study

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Abstract: Climate change is one of the socio-environmental problems with the greatest complexity and media impact in the world. However, difficulties have been observed in its understanding. In this study, we worked on this social problem in the classroom through argumentation, from the evaluation of different statements made about the causes and consequences of climate change, considering the evidence provided. The study was carried out with a group of 18 future physics and chemistry teachers to encourage argumentation. They had to write an essay expressing their opinion about a statement extracted from a news item, considering whether the big corporations that manage hydrocarbon reserves are really responsible for denialism, containing arguments that supported and refuted the theory. The data collected and analysed were their essays and their answers to the question: How do you think gases can affect the increase in temperature? The analysis is framed in qualitative content

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analysis. The results show that justifications based on evidence from reliable sources were scarce, being mostly opinions. Future teachers have difficulty in both assessing the reliability of data and integrating evidence in their justifications. They positively valued the activity and expressed their intention to put it into practice in their professional future. We consider it essential that initial teacher training includes how to teach the same activities that it would be desirable for teachers to put into practice.

Keywords: climate change; greenhouse effect; argumentation; higher education; initial teacher training.

I. Introduction

Spanish law (Ministerio de Educación y Formación Profesional 2022) currently indicates that "Competence in science involves understanding and explaining the natural and social environment, using a set of knowledge and methodologies, including observation and experimentation, in order to raise questions and draw conclusions based on evidence". In other words, it advocates the development of scientific skills such as recognition of researchable problems, design of experiments, analysis and interpretation of data, or the obtention of conclusions based on evidence, all framed in real problems such as climate change, as selected in this article. Therefore, there is a shift in science education from an education that focuses on theoretical content to an education that provides students with opportunities to develop scientific skills and enables concerns and involvement in environmental problems, making them aware that their behaviour could contribute to solving them (Jaén and Barbudo 2010). This change of educational approach would make it possible to develop a better relationship among causes, consequences, and actions to be taken in order to the face the climate crisis (Bello Benavides et al. 2021).

I.1. The chosen context: climate change

Currently, climate change is a socio-environmental problem with great complexity and media impact (García-Rodeja and De Oliveira 2012; Shapiro Ledley et al. 2017), and it has a relevant role in the Spanish secondary education curriculum. However, its study is associated with a series of recurring difficulties. Prieto and España (2010) detected that students, media, and the general public use terms such as "climate change", "global warming" and "greenhouse effect" interchangeably. This leads to the error of understanding the greenhouse effect as a negative phenomenon instead of a necessary process to allow life on Earth (Prieto and España 2010). It has been also observed that

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students tend to associate climate change with other phenomena, such as the hole in the ozone layer or acid rain (Bello Benavides et al. 2021; Fernández Ferrer et al. 2011; Hoyuelos-Álvaro and Ibáñez-Quintana 2023). Regarding greenhouse gases, and in particular CO_2, some students possess preconceptions about its possible toxicity to living beings without considering its role in processes relevant as photosynthesis (Boronat-gil et al. 2018).

These difficulties in understanding climate change are due, among other factors, to the fact that most people have the media as their only or main source of information (Meira Cartea et al. 2009; Morote and Moreno 2022; Prieto and España 2010). This means that their conceptions about its causes and consequences derive from what comes through the media (Bingle and Gaskell 1994). This can lead to confusion, because the topic is often treated in a disjointed way according to the news of the moment. Besides, the reliability of some of the sources of information is questionable. As Oreskes (2004) pointed out, although there is unanimity in scientific journals on the anthropogenic nature of global warming, more than 50 per cent of press publications express doubts about the existence of climate change and its possible causes.

Regarding possible solutions to reduce CO_2 emissions, most students from all countries propose a radical reduction of CO_2 emissions but without showing awareness of the possible economic consequences (Andersson and Wallin 2000). According to Andersson and Wallin (2000), this highlights the current limitation of relating social and economic aspects to scientific aspects. Therefore, working in the classroom on problems related to science in social contexts, such as climate change, allows students to be aware that to address these issues it is not enough to know science. They must consider economic, ecological, political, ethical aspects, because they also come into play in the decision-making processes (Prieto and España 2010).

I.2. Addressing climate change in the classroom

In recent years, studies have been carried out to analyse how students and their teachers perceive climate change (Boon 2010; Punter et al. 2011) and how it should be addressed in the classroom (Ariza et al. 2021). According to Allen and Crowley (2017) or Stevenson et al. (2017), the approach to climate change should have a socio-cultural and global participatory dimension. For this type of problem, Alméstar et al. (2022) proposed a multidimensional, quintuple helix approach in which different institutions work together with the objective of driving competencies and actions from the educational community to the neighbourhoods. Society should link thinking with problem-solving, and innovation skills with knowledge of scientific methods.

After conducting a literature review, Ranney and Velautham (2021) proposed a series of ten brief and compelling types of information for use in class to promote the development of students' scientific skills while achieving a successful revision of climate change beliefs. Examples are representative statistics on greenhouse gas/temperature/glacier changes or texts that enhance understanding of the physicochemical mechanism of global warming. Ranney and Velautham also integrated this information in activities that encourage reasoned discussions among students.

Working on climate change in the classroom could be done through argumentation, since evaluating the different claims about the causes and consequences of climate change in light of the evidence provided can help students to improve their understanding of the phenomenon itself (Ariza et al. 2021; Dawon and Carson 2020). To do so, the development of argumentation skills is crucial. Argumentation promotes that students can develop a greater understanding of scientific phenomena by having to evaluate the validity of the evidence that supports, or not, a given conclusion based on their conceptual knowledge or by selecting those data they consider adequate to support a conclusion (Bravo-Torija and Jiménez-Aleixandre 2018; Dogruer and Akyuz 2020). Therefore, students should evaluate the information provided, identifying the important data, interpreting them, and considering their reliability. Then they should establish a justified conclusion, evaluating the different options provided.

I.3. Training of teachers in strategies to address climate change

The introduction of argumentation into the classroom, especially to work on complex problems such as climate change, is therefore a necessity in which teachers play a relevant role. However, promoting this type of activity is not an easy task for teachers (Vílchez-González and Bravo-Torija 2015). Pérez-Mora and Gértrudix Barrio (2020) showed that early childhood and primary education teachers could have sufficient conceptual knowledge of environmental problems but they were deficient when it came to working on these issues in the classroom. These difficulties have also been reported in pre-service secondary science teachers, for whom Erduran et al. (2006) recommended formative feedback in argumentation activities. One reason for this problem could be related to their previous education. Ariza et al. (2021) found that pre-service secondary science teachers tended to replicate the educational models they experienced as students, mainly a traditional approach based on the transmission of theoretical concepts. Therefore, during teacher training, is necessary to confront them with situations far from these traditional models

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based on "what do we want to know?" with a focus on learning a closed body of knowledge (Grandy and Duschl 2007); situations should instead focus on "what do we want to know how to do and what do we need to do for that?", wherein the learners should understand how scientific knowledge is constructed and validated by the scientific community and the processes involved in it. This paradigm shift would have major repercussions, since the consideration of what science is and how it is learned and taught is a key element in how future teachers approach science education (Reiser 2013; Revel Chion et al. 2021).

In relation to climate change, a study conducted by Fernández Ferrer et al. (2011) concluded that it is necessary to train teachers in critical thinking, with better training on environmental issues, especially at a time when they receive most of their information on climate change from social networks, which constitutes a risk regarding the interpretation, search, and contrast of information (Morote and Moreno 2022). Therefore, in teacher training there is a need to carry out training activities that encourage the young teachers to contrast information derived from media and academic work.

This background highlights two relevant facts. The first is the importance of developing scientific literacy, with a perspective of awareness in order to reach action (using what is known to make decisions and take actions), and it is essential to promote an adequate capacity for argumentation that allows us to relate what we know to making meaningful decisions. To do so, future teachers should have opportunities during their training to carry out activities that can serve as a reference framework to address these issues with their future students. In this work, we use an argumentation activity contextualized in the greenhouse effect with a double purpose: 1) to analyse the capacity of physics and chemistry teachers in training to integrate ideas of climate change with provided data in order to write an essay to answer how greenhouse gases can affect the increase in global temperature; and 2) to serve as a model for teaching science from the perspective of "what do we want to know how to do and what do we need to do for that?"

We posed the following research problems:

What ideas about climate change are teachers in training able to combine and integrate when answering the question about how greenhouse gases can affect the increase in global temperature?

What aspects do teachers in training use when evaluating the statement considering whether the big corporations that manage hydrocarbon reserves are really responsible for denialism?

How many of these aspects are scientifically substantiated?

II. Materials and methods

II.1. Methodology

The present research work is a case study in which the argumentative process on a socio-scientific topic is used as a teaching strategy for future teachers (Kim, Anthony, and Blades 2014). In this research, we conducted a qualitative study on how students apply the ideas they have about climate change, identified through content analysis (Bardin 1996), and how they justify them based on the sources of information used.

II.2. Participants

This study was carried out at the University of Murcia with a group of 18 students (11 women and 7 men) following a Master's degree in teacher training, required to become a science teacher in secondary education. These students had previously studied chemistry (6), physics (6), biochemistry (4), chemical engineering (1) and food technology (1).

II.3. Proposed activity

The proposed activity consists of providing a current news item (https://elpais.com/elpais/2019/09/18/eps/ 1568820907_023534.html) that deals with the opinions of people from different fields on climate change.

The purpose of this activity is to encourage argumentation and evaluate how students justify different positions. It is proposed that future teachers read the press article and look for complementary information to respond in an informed manner to a series of questions such as "How do you think gases can affect the increase in temperature?", the answers to which are analysed in this paper.

This will be followed by a group discussion to encourage collective debate. Finally, individually, they should write an essay (also discussed in this paper) expressing their opinion on a statement extracted from a news item considering whether the big corporations that manage hydrocarbon reserves are really responsible for denialism, containing arguments that support and refute the theory. To do this, it is necessary to start from the scientific ideas that have been discussed in the didactic unit, along with value aspects (ethical, moral, health, environmental).

II.4. Data collection and analysis

The data collected and analysed were the students' written responses to the two tasks proposed in the activity.

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Considering the research question, what ideas about climate change are future teachers able to combine and integrate when answering the question about how gases can affect the increase in the temperature of planet Earth? In order to identify which content knowledge is required by future teachers to answer the question and how they should relate to them; firstly, we selected different sources of information considering the topic and how it is addressed in secondary education. The sources were: a) secondary school textbooks, specifically those that refer to the greenhouse effect and climate change; b) scientific reports and articles that address the greenhouse effect, its increase and its consequences for the planet (Zein and Chehayeb 2015; PCC 2014); and c) studies related to the ideas that students present about what the greenhouse effect is and how its increase influences climate change. Then, to characterize the core scientific ideas in these documents, we followed the methodology of analysis based on reading (textual or visual) which is characterized by systematic, objective, replicable and valid reading aiming to discover and extract the basic contents of a given phenomenon (Noguero 2009). From crossing these sources, the ideas that it is considered that teachers in training should be able to identify and integrate to respond to the task are as follows:

A) Energy exchange (or energy transfer on Earth). The Earth receives a large amount of energy from the sun in the form of radiation that includes all electromagnetic frequencies. Some of this radiation passes through the atmosphere, is reflected and returns to space; other radiation reaches the ground and increases its temperature to the point of equilibrium and is re-emitted to space in the form of infrared (IR) radiation (700–1000 nm).

B) Identification of greenhouse gases and their characteristics. There are many gases in the atmosphere, but only some of them can absorb IR energy. The ability of a gas to absorb IR energy depends on its structure and the types of bond that form it. Specifically, the major gases N_2 and O_2 cannot absorb this range of wavelengths, while carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O) and ozone (O_3) can, since they have vibrational modes that allow them to absorb IR photons. For this reason, they are known as greenhouse gases.

C) Use of the kinetic model. The energy absorbed by the greenhouse molecules provides motion and therefore kinetic energy to them. Since the temperature of a gas is a measure of the velocity of its component molecules, the absorption of IR photons increases the velocity of its molecules, which increases the temperature of greenhouse gases.

D) Role of the greenhouse effect on Earth and the consequences of its increase for the planet's temperature. Without this natural greenhouse effect, the Earth's equilibrium temperature would be about -18°C; however, the average temperature of the Earth's surface is roughly 14°C, a difference of around 33°C, which gives us an idea of the magnitude of the effect. This natural effect is therefore beneficial. However, in recent years, excessive greenhouse gas emissions (mainly from the burning of fossil fuels) have begun to modify the Earth's climate at a problematic rate. In the last 50 years alone, we have doubled greenhouse gas emissions.

Table 1

Definition and examples of the categories of analysis constructed for this study

Category	Future teachers are able to	Example
C1	Relate the absorption of IR from the Earth to the molecular structure of greenhouse gases and their effect on temperature, with the consequences of the increase of the greenhouse effect on the planet.	No examples.
C2	Relate the absorption of IR from the Earth to greenhouse gases and the increase in the Earth's temperature, without considering the consequences for the planet.	A5: The greenhouse gases mentioned above (CO_2, N_2O and CH_4) absorb the Earth's infrared radiation, causing the Earth's surface temperature to rise.
C3	Relate the excess amount of greenhouse gases to the absorption of radiation and the increase in the Earth's temperature. Negative conception of the greenhouse effect.	A18: The increase in greenhouse gases means that the generation of long-wave radiation by the Earth does not go out. Therefore, there is an increase in temperature.
C4	Relate the absorption of solar radiation by gases to the increase in the Earth's temperature.	A14: Some particles absorb solar IR radiation, which has a warming effect.
C5	Use non-task related answers.	A12: Increase of holes in the ozone layer. More ultraviolet enters. Increase in greenhouse gases.

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Taking into account the ideas described, five categories were established (Table 1). These categories were arranged in a continuum from those that combine and integrate the two criteria mentioned above (C1) to those that provide other ideas not directly related to the task (C5). The answers can range from those that refer to the relationship between the absorption of IR from the Earth with the molecular structure of greenhouse gases and their effect on temperature, with the consequences of the increase of the greenhouse effect on the planet, to those not directly related to the task, such as the supposed role of the ozone layer in the increase of greenhouse gases.

Once the core ideas and categories were established, the researchers analyzed how students used these ideas to answer the question by fragmenting students' responses into different units of analysis. Based on Henri (1992), units of analysis in written responses are defined as concrete fragments in which students refer to specific scientific ideas. In this study, the unit of analysis is any specific segment in which students reference ideas related to the increase of the greenhouse effect on the planet, including its causes and consequences.

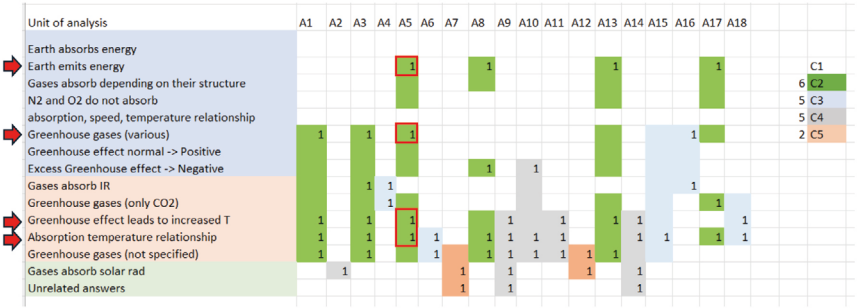

Fig. 1

Emptying of student responses based on their units of analysis. The red boxes indicate those units of analysis included in the answer of student A5 (example)

Finally, each student response was classified into a specific category based on the units of analysis used and how these units were combined. For example, consider the response of student A5: "The CO_2, NO_2, and CH_4 gases emitted absorb the Earth's infrared radiation, causing the Earth's surface temperature to rise." This response (Fig. 1) demonstrates a partial understanding of the greenhouse effect. It incorporates two key ideas

typically found in complete conceptions: the emission of energy by the Earth and the variety of gases involved in the greenhouse effect, extending beyond just CO_2. However, the response does not fully encompass all the elements characteristic of a complete understanding. For instance, while the student connects the greenhouse effect to a rise in temperature, they fail to specify that this temperature increase is beneficial under normal circumstances, with only excessive increases being harmful.

Regarding the second and third research questions, addressing the aspects on which the future teachers base their evaluation of the statement considering whether the large corporations that manage hydrocarbon reserves are truly responsible for denialism and how many of these aspects are scientifically substantiated, the answers were analysed based on two criteria: 1) the aspects on which they focused their response (health, economic, ethical and environmental), proposed by Ruiz Gonzalez et al. (2021), adding two new categories—political and educational aspects—after considering the answers given by the future teachers; and 2) whether their answers were supported by reliable sources (Christenson and Chang Rundgren 2015; Ruiz Gonzalez et al. 2021) or only by a learned pattern or an opinion (Rodríguez et al. 2021).

Finally, an anonymous, voluntary questionnaire on students' opinion of the activity was conducted online using the wooclap platform. The questionnaire consisted of 3 sections: First, on a Likert scale of 5 (1 not agreeing at all and 5 strongly agreeing) they had to express their degree of agreement or disagreement with two statements: 1) The activity is well designed and 2) I believe that this type of argumentation activities is necessary in secondary education. Secondly, they had to indicate from 1 to 5 (1 being nothing and 5 could explain it to a friend), the knowledge they thought they had about argumentation activities before and after doing the activity. They were also given the option to include any free comments (suggestions for improvement, elements to highlight, etc.) about the activity.

III. Results and discussion

III.1. Ideas on climate change from future teachers of physics and chemistry

As can be seen in Table 2, none of the students provided an answer that could be included in category C1. This fact is remarkable, since given their previous training (most of them graduated in chemistry or biochemistry) it was expected that they would be able to establish a relationship between the

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molecular structure of gases, specifically those that are part of the greenhouse effect, and their ability to absorb infrared radiation. They should also be able to connect these ideas with kinetic theory, recognizing that an increase in the vibration of the molecules due to the absorption of radiation would imply an increase in the temperature of these gases. Besides, an increase in the amount of these gases in the atmosphere has consequences for the temperature of the planet.

Table 2

Results of the first research objective

Category	No. of students
C2	6
C3	5
C4	5
C5	2

Six answers were classified as C2 because they do identify the absorption of infrared radiation from the Earth with the greenhouse gases that cause the increase in temperature, although they do not refer to the structure—for example, A17: "Increasing the concentration of CO_2 increases the energy remaining in the Earth from the sun, in the form of heat, since CO_2 allows solar radiation to pass through, but retains IR radiation". However, these answers do not refer to whether the greenhouse effect is positive or not, but simply describe the increase in temperature produced by these gases or establish a direct relationship between the increase in gases and the increase in temperature. The lack of connection between the causes and consequences of this increase in the greenhouse effect has been previously described (Bingle and Gaskell 1994; Jeffries, Stanisstreet, and Boyes 2001; Liu 2021).

Thirdly, five future teachers provided a response that falls into category C3, since they recognize the existence of the greenhouse effect but attribute exclusively negative connotations to it. They consider that it is the increase in greenhouse gases, and not their presence in natural concentrations, which causes the absorption of IR radiation and, therefore, the increase in the Earth's temperature. This can be seen in in the response of A15: "The increase of gases in the atmosphere absorbs the Earth's infrared radiation, producing an increase in the temperature of the Earth's surface". As Prieto and España (2010) pointed out, this confusion, which is quite common, may

be linked to the fact that terms such as "climate change", "global warming" and "greenhouse effect" are often used interchangeably, generating the false belief that the greenhouse effect is negative per se. These results demonstrate the need to work on this content in the classroom in a deeper way to avoid confusion between relevant concepts in today's society.

Five answers were classified within category C4. This category includes those that reflect an erroneous understanding of the greenhouse effect, in which the radiation absorbed by greenhouse gases is that emitted by the sun and not that radiated by the Earth because of its warming. For instance, the answer of student 9 claims that "Greenhouse gas particles absorb solar and infrared radiation in the atmosphere and therefore have a warming effect". This alternative idea is also frequently found among secondary school students (Andersson and Wallin 2000).

Finally, we found that only two of the answers provided, A12 and A7, did not address the question posed (C5). In the case of A7, the response is as follows: "Suspended particles, depending on its composition, can have a warming effect on the climate, for example, carbon black, resulting from incomplete combustion of fuels, absorbs solar and IR radiation in the atmosphere. Atmospheric changes in ozone concentration, as UV radiation generates O-radicals, which cause a temperature increase". A12 is presented as an example in Table 1. In these answers, we find the use of ideas that are not directly related to the question posed, since although it is true that the emission of certain greenhouse gases such as chlorofluorocarbons (CFCs) destroys the ozone layer, its consequence is not an increase in the Earth's temperature, but a greater penetration of ultraviolet rays that cause damage to the skin's DNA. This idea on the part of both high school students and future primary school teachers has been previously described by other authors such as Bello Benavides et al. (2021) and Fernández Ferrer et al. (2011). However, it is noteworthy that it is also present among graduates in scientific careers in which this phenomenon is treated in greater depth. It would be expected that with the knowledge acquired during their scientific training they would be able to distinguish between what global warming is and what it produces and what the depletion of the ozone layer is and its consequences. However, we see that, although in low proportion, we continue to find these ideas among future teachers. We also highlight a difficulty in associating the term 'particle', instead of 'molecule', to gases, which, although not directly related to the question, was observed in several answers (A7, A9 and A14). This term is imprecise, as a particle, defined by Oxford Advanced Learner's Dictionary as "a very small piece of something", is usually used for smaller elements such as electrons, protons, or quarks.

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III.2. Aspects on which future teachers base their arguments and reliability of the sources consulted

Table 3 analyses the aspects (economic, ethical, social, political, etc.) that students refer to when evaluating the statement considering that the large corporations that manage hydrocarbon reserves are truly responsible for denialism. It includes three sections: the number of students selecting each aspect, the number of answers that are justified by evidence, and the number of answers that are mere opinions. The aspect that appears most frequently in the responses of the future teachers is economic (17). Most of them refer to the economic advantages enjoyed by large corporations thanks to the sale of hydrocarbons—for example, A11: "Certain organizations may promote these arguments out of economic and oil power interests." Of all these answers, only twice is the information provided substantiated, as in A7: "It may be that the denialists are responsible for the large companies that speculate on the price-oil ratio and do not care about the human cost, as reported by the CREAF blog [Centre for Ecological Research and Forestry Applications]".

All other justifications (15) are considered naïve by not including the source on which they rely, as in A2: "I think … that the origin of denialism is in large oil corporations seeking economic benefit."

Table 3. Aspects referred to by students to justify their answers (including the number of students selecting each aspect and differentiating between those that are arguments justified on evidence and mere opinions).

Table 3

Aspects referred to by students to justify their answers (including the number of students selecting each aspect and differentiating between those that are arguments justified on evidence and mere opinions)

Aspects	Nº students who include evidence	Substantiated evidence	Opinions
Economic	17	2	15
Environmental	11	0	11
Social	11	0	11
Ethical	6	1	5
Health	3	0	3
Political	1	1	0
Educational	1	0	1

Secondly, among the most frequent aspects, we find environmental and social aspects referred to by 11 of the 18 future teachers. When referring to environmental aspects, they cite the consequences of the increase in greenhouse gases, as in A7: "But I would point out the atmospheric deterioration due to polluting gases. It is a resource that is not always going to be present." Those of a social type are mostly related to the lack of scientific education of citizens, as in A15: "The lack of adequate information can also be responsible for denialism."

None of the responses included in these categories were classified as well founded. Most of the responses do not refer to any type of data on which to base them, and others that, a priori, seemed to be based on historical data, do not indicate their origin or location, as in the case of A6: "They claim that this increase is natural because it has been happening all our lives. And it is true that climate change (temperature increase in particular) has always been there. But using (historical) temperature data one can check the change in the trend of this increase with the beginning of industrial activity."

On the other hand, six future teachers included ethical motives in their arguments, suggesting that the owners of large corporations, despite knowing the harmful effects of hydrocarbon consumption, prioritize their economic wellbeing over social welfare. One of the answers included in this section (already reproduced in the economic motives as A7) is well-founded given that it refers to the CREAF blog as a source of information consulted. Another example is found in A14: "With these data, the only reasonable option is for capital to take precedence over morality and for large corporations to promote ignorance and anti-intellectualism for economic purposes." The difference between this statement and the one used by A7 is that in this case it is not substantiated.

Finally, and to a lesser extent, there are health, political and educational aspects. The only political answer is well founded and is previously cited in the sections on economics and ethics. The answers classified under health and educational aspects are not well founded, such as A7: "There are also a large number of diseases associated with CO_2 emissions"; or A14: "The solution lies in providing citizens with scientific tools and knowledge."

III.3. Student's opinion about the activity

12 of the 18 students in the course responded to the anonymous, voluntary question-naire. As can be seen in Fig. 2, in which they scored 4.3 out of 5, the students considered that the proposed activity was well designed. Their

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opinion on the appropriateness of incorporating this type of argumentation activities in secondary education was even higher, 4.6.

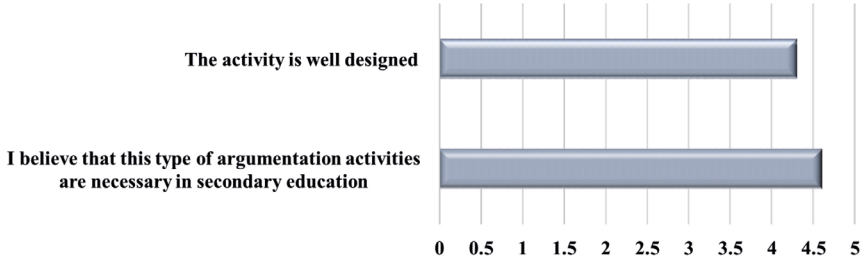

Fig. 2

Degree of agreement or disagreement of the students with respect to the activity carried out (1 not agreeing at all and 5 strongly agreeing)

Furthermore, although they considered their initial knowledge of argumentation to be adequate (3.4), there seems to be a consensus that the development of the activity was useful for them to improve considerably (4.4) in argumentation and how to take it to the classroom (Fig. 3).

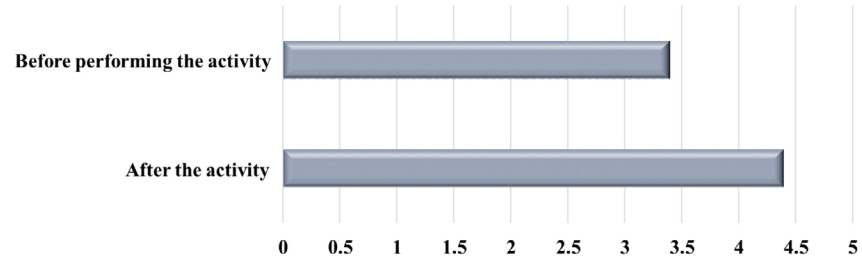

Fig. 3

Students' perception of their knowledge in argumentation activities. Before and after performing the proposed activity (1 being nothing and 5 could explain it to a friend)

In the last section, in which they could include any comments, the 12 students empha-sized the importance of this type of activities and how useful are for the training of future citizens. As an example, the following are some of the students' comments: ¨The activity was quite attractive and serves both to learn and to put knowledge into practice¨, ¨I think it is very important to

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deal with the issue of climate change in a scientific way and to inte-grate it into the daily knowledge of students¨ and ¨The approach and execution is very simple, which gives great value to the practice¨.

IV. Conclusions and educational implications

The results of this study reveal that the knowledge about climate change shown by future physics and chemistry teachers is incomplete or partially erroneous. This is evidenced by the fact that when asked about climate change, none of the future teachers gave a complete answer in terms of the relationship between the molecular structure of greenhouse gases and their absorption of IR from the Earth, and their effect on temperature, with the consequences of the increased greenhouse effect on the planet. The union of these concepts is essential to acquire a complete understanding of the phenomenon of climate change and thus be able to address it later in an appropriate way with their students.

Regarding their ability to select evidence to support their claims, the results show that of the 50 justifications provided by the 18 future teachers, only three were based on evidence from reliable sources. This shows the difficulty that future teachers have in assessing the reliability of the data provided, choosing the most appropriate, and integrating the data into their justifications. These argumentative skills have also been pointed out by Gotwals et al. (2012) and Sandoval and Millwood (2005) as the most complex to acquire. This demonstrates the importance of working on this type of activity in teacher training to make trainee teachers aware of the difficulties when addressing these skills in their future classrooms.

On the other hand, the number of secondary school classrooms in our country in which students learn science thanks to the incorporation of this type of activity is currently anecdotal. This is due, among other factors, to the lack of teacher training. We agree with Ariza et al. (2021) that the teaching-learning models we experience as students strongly influence the teaching model we implement during our professional stage. This fact is related to our second objective, that future teachers are aware of the importance of developing argumentation in students. What is more, even those who have sufficient knowledge about climate change lack the necessary resources to address learning it in the classroom (Pérez-Mora and Gértrudix Barrio 2020).

In this work, the participants gave a positive evaluation of the activity and expressed their intention to put it into practice in their professional future. Based on this result, we consider it essential that initial teacher

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training includes the same activities that it would be desirable for teachers to put into practice with their students.

The results of this study have several practical applications for science teachers, particularly in how they design and implement classroom strategies to teach the greenhouse effect, their causes and consequences. For instance, based on the results teachers should prioritize addressing common misconceptions, such as the idea that the greenhouse effect is inherently negative or that it involves solar radiation absorption instead of Earth-emitted radiation. Moreover, especially in the last years of secondary school, teachers should place a stronger emphasis on the molecular basis of greenhouse gases and their interaction with infrared radiation. This includes explaining the structure of these gases and their role in absorbing and re-emitting infrared radiation, which contributes to global warming. To address these conceptions, the use of models, simulations, or experiments that demonstrate these molecular interactions should be integrated in the classroom.

Regarding the ability to construct well-founded arguments and critically evaluate information sources, teachers should emphasize the importance of basing claims on reliable evidence and citing credible sources, which can be integrated into lessons by teaching students how to assess the validity of information and identify authoritative references. To do so, lessons should explicitly address the role of misinformation and denialism, equipping students with the skills to critically engage with such challenges in the broader context of climate change and environmental science. For example, educators can use real-world scenarios, such as the economic and environmental implications of hydrocarbon usage, to encourage students to research, analyze, and justify their positions with evidence rather than opinion.

Finally, educators should work on developing students' understanding of the interdisciplinary nature of these topics by addressing ethical, social, and political dimensions alongside scientific concepts, promoting a holistic approach of the problem.

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