



The Effect of Deliberative Argumentation on Knowledge, Trust, and Willingness to Mitigate Climate Change in a Group of Chilean High School Students

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Abstract

This study describes the knowledge and alternative conceptions as well as trust in science and willingness to take action on climate change in a group of 100 secondary school students aged 15–18 years from Chile before and after deliberative argumentation instruction. The study used a quantitative approach with a quasi-experimental design with three experimental and two control groups, in which a previously validated Climate Change Questionnaire was applied. In the experimental groups, the teacher implemented a unit of 6 lessons of 80 min each including six activities in which deliberative argumentation about controversial issues in CC were included. The results demonstrated that the whole group of students had a low knowledge about climate change, presenting alternative conceptions, such as confusion about greenhouse gases, solar radiation, and the false relationship between ozone layer thinning and the greenhouse effect, but after instruction, all experimental groups significantly improved their knowledge. Although students improved their knowledge of the human impact on CC, the greenhouse effect, the albedo effect, and the carbon cycle, alternative conceptions of ultraviolet rays and the hole in the ozone layer persisted in most students after instruction. After the instruction, trust in science improved in two of three classes and the willingness to take action of climate change did not change in all classes. The results are discussed in the context of the complex relationship among all variables.

Keywords Climate Change · Alternative conceptions · Trust in science · Willingness to act · Argumentation

Introduction

Climate Change (CC hereafter) include, among other changes, alterations in precipitation patterns and an increase in temperature and frequency of extreme weather events (such as droughts and floods) on a planetary scale (IPCC, 2023; Ripple et al., 2024). Therefore, it is

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necessary that people understand CC in general, and global warming in particular, so that they can be able to decide appropriately and responsibly how to act, promoting both actions that contribute to climate change mitigation and adaptation (Assaraf et al., 2024; Bhattacharya et al., 2021; Cofré et al., 2023). In this sense, the importance of CC education is crucial for the population to understand their role and degree of responsibility in this global problem (Bhattacharya et al., 2021; IPCC, 2023; UNFCCC, 2024).

Despite the fact that the occurrence of global warming resulting from human action has a broad consensus in the scientific community (Cook et al., 2016; IPCC, 2023; Ripple et al., 2024) and the increase of available information on Climate Change Education (CCE hereafter) in the last decades its teaching remains complex and challenging for teachers of science and geography (e.g., Abasto et al., 2025; Assaraf et al., 2024; Bhattacharya et al., 2021; Plutzer et al., 2016; Rousell & Cutter-Mackenzie-Knowles, 2020). Furthermore, recent reviews on the topic report a great diversity of alternative conceptions that hinder the learning process for students including, for example, thinking that global warming is caused by the ozone hole, and that pollution or acid rain are causes of climate change (e.g., Cofré et al., 2023; Monroe et al., 2017; Rousell & Cutter-Mackenzie-Knowles, 2020). These alternative conceptions are present in primary, secondary and tertiary education students (Rousell & Cutter-Mackenzie-Knowles, 2020), and pre-service and in-service teachers (e.g., Herman et al., 2017; Abasto et al., 2025). Within the alternative conceptions associated with CC there are also those that have to do with the validity and nature of climate change science (Herman et al., 2017; Wildbichler et al., 2025), even going as far as denial or disbelief of the existence of the anthropogenic effect on CC (Cofré et al., 2023; Oreskes, 2022). More specifically, scientific uncertainty surrounding CC research has been shown to be difficult to communicate to the public (Joslyn & LeClerc, 2016) and that, when scientists use concrete estimates (e.g., minimum and maximum values) to express uncertainty in climate change predictions, it increases confidence in their work and in climate science (Howe et al., 2019). This finding is consistent with recent results shown by Larrain et al., (2025) in which confidence in climate science is the variable most correlated with willingness to take CC mitigation actions by high school students.

The CCE literature agree that general climate knowledge and literacy would be fostered through educational approaches characterized by engaging in deliberative discussions addressing student' preconceptions and utilizing critical pedagogies that articulate climate, environmental and socio-historical, and political knowledge through critical analysis and evaluation of local situations (e.g., Dillon & Herman, 2023; McNeill & Vaughn, 2012; Monroe et al., 2017; Rousell & Cutter-Mackenzie-Knowles, 2020; Oberman & Sainz, 2021; Rhodes & Wang, 2021), both inside and outside the formal curriculum and classroom (Kolenaty et al., 2022). Deliberative discussion helps to emerge and challenge students' preconceptions about complex concepts of understanding such as the greenhouse effect and the role of irradiated infrared radiation (e.g., Dawson & Carson, 2020), while pedagogy focused on relevant and local issues tries to develop a critical vision of our actions as citizens, to encourage the willingness to make changes towards more sustainable behaviors (e.g., Rhodes & Wang, 2021).

The problem is that these pedagogies are not widely observed in CC instruction, and existing teaching practices are believed to be based primarily on delivering expert information (Monroe et al., 2017; Rousell & Cutter-Mackenzie-Knowles, 2020). Moreover, the studies that have evaluated the effect of argumentation as a teaching approach on students' learning

outcomes and attitudes usually do not include control group (e.g., Dawson & Carson, 2017, 2020; Jacobson et al., 2017; Mason & Santi, 1998; Klosterman & Sadler, 2010; Öhman & Öhman 2013), therefore the effect of these types of pedagogies on CC understanding and literacy should still be explored in more refined designs. In this context, the main goal of this study was to examine whether a science teacher using deliberative argumentation as an instructional strategy for climate change improved students' knowledge of climate change, trust, and their willingness to act compared to students who are taught using traditional pedagogy. Furthermore, the contribution of the paper is to consider not only knowledge and willingness to act, but also of trust in climate science by students.

Literature Review

CCE is a complex problem to address due to concepts and core ideas needs to understand climate change, global warming, and others phenomena associated come from different scientific disciplines (Eilam, 2022). Therefore, this subject concerns not only biology education, (e.g., Cofré et al., 2023) and earth science education (e.g., Orion & Libarkin, 2023), but also geography/education (e.g., Favier et al., 2021; Enke & Budke, 2023), and environmental education (e.g., Kolenatý et al., 2022; Dillon & Herman, 2023). According to this Eilam (2022) proposed the scarce epistemological conceptualization as a body of knowledge of CC generates that its presence in the curriculum concentrates on its causes and consequences, but not on the central principles for its understanding (Eilam et al., 2020). This argument is corroborated in the study by Dawson et al. (2022), who, in a comparative analysis of the national curriculum documents of six countries (England, Australia, Israel, Finland, Indonesia and Canada) conclude that CC is often presented as a context for other scientific concepts, but not as an independent topic and that it is dispersed and spread over several educational levels. Similarly, Bhattacharya et al. (2021) noted that little time is devoted to teaching climate change because it is rarely mentioned in curricula globally, and because there is a shortage of curricular resources for teachers (see also Plutzer et al., 2016).

Another major challenge for CCE is the varied and persistent alternative conceptions presented by students on different topics related to this phenomenon (Bhattacharya et al., 2021; Dawson, 2015; Monroe et al., 2017; Dillon & Herman, 2023; Wildbichler et al., 2025). Some of these preconceptions are, students perceive climate change as synonymous with global warming (e.g., Chang & Pascua, 2016; Dawson, 2015; Varela et al., 2020); understanding the greenhouse effect as a harmful phenomenon per se (e.g., Dawson, 2015; Libarkin et al., 2015); CO₂ alone causes the enhanced greenhouse effect (e.g., Dawson, 2015; Jarrett & Takacs, 2020), the greenhouse gases are destroying the ozone layer thus allowing more heat or radiation to enter the atmosphere or reach the Earth (e.g., Dawson, 2015; Frappart et al., 2018; Jarrett & Takacs, 2020; Libarkin et al., 2015; Varela et al., 2020); confusion between different types of radiation, such as solar and terrestrial, or ultraviolet and infrared, usually associating ultraviolet with global warming (Dawson, 2015; Jarrett & Takacs, 2020; Libarkin et al., 2015; Varela et al., 2020); recognizing a direct relationship between pollution or acid rain and global warming (Dawson, 2015; Frappart et al., 2018; Varela et al., 2020), climate and weather are confused (Dawson, 2015), carbon cycle is not understand (e.g., Jarrett & Takacs, 2020), and the belief that generic actions, such as recycling can have a major role in mitigating CC (Varela et al., 2020).

A complex issue is also the relationship between knowledge about climate change and the beliefs, behaviors, and attitudes of students and the general population (e.g., Hornsey et al., 2016; Kolenatý et al., 2022; Larrain et al., 2025; McNeill & Vaughn, 2012). For example, in a pre and posttest study, McNeill and Vaughn (2012) found that students had a significant increase in their understanding of climate change and were more engaged in actions to limit their personal impact on CC after the implementation of climate change curricular unit. In another study, Kolenatý et al. (2022) show how climate change knowledge fosters climate change concern, self-efficacy, and willingness to act among schoolchildren. Moreover, although knowledge seems to be crucial for climate action, the latter requires a wide range of skills and behaviors. In the same vein, the study by Ranney and Clark (2016), showed an association between knowledge and acceptance and willingness to act on CC. Notwithstanding the above, other studies have not found direct associations between knowledge or education and positive attitudes towards CC. These inconclusive results may be due to the action of indirect effects between different variables, as shown in the study by Larrain et al. (2025), which included 386 high school students in Chile. According to their results, there would be a mediating effect of confidence in science on the effect of knowledge in CC, and of interest in science, towards a greater willingness to mitigate the effects of CC.

Specifically, the effect of trust in science or understanding of the validity of CC science has already been proposed as a crucial element in the development of climate change literacy (e.g., Oreskes, 2022; Larrain et al., 2025; Herman et al., 2017; Liu & Roehrig, 2019; Wildbichler et al., 2025), especially when it comes to students understanding the uncertainties inherent to science, as well as the diversity of methods and evidence generated to validate this knowledge (e.g., Holthuis et al., 2014; Schauss & Sprenger, 2021; Tasquier et al., 2016). For example, prior research indicates that students often lack robust epistemological knowledge regarding climate change (CC) modeling and its inherent uncertainties. While Tasquier et al. (2016) found a widespread lack of vocabulary and basic conceptual understanding of models among students, Schauss and Sprenger (2021) noted that students could accurately grasp model limitations despite having an inadequate understanding of climate system processes. On the other hand, when assessing scientists' opinions about Global Warming, Holthuis et al. (2014) found that 50% of 742 upper and lower secondary students participating in their study thought that most scientists agree that Global Warming is happening. However, about 30% of the participants believed that scientists disagree whether GW is happening, with 2% believing that most scientists think GW is not happening. However, according to Wildbichler et al. (2025) only seven from 44 studies about students' ideas of climate change include descriptions of students' ideas of the nature of climate science. The main themes reviewed in these seven studies were: Models, Scientist's consensus, climate projections and interpretation and analysis of data. Therefore, it remains to be explored how this variable does or does not contribute to climate change understanding and literacy.

On the topic of climate change instruction, most studies evaluating different strategies to change understanding, attitude and behavior in relation to global warming and its consequences have been conducted in North America, Europe and Australia, with almost no studies in Africa and South America (Monroe et al., 2017; Rousell & Cutter-Mackenzie-Knowles, 2020; but see Abasto et al., 2025 for an example of study from South America). These international studies report that climate change challenges traditional science teaching, requiring both curricular and extracurricular actions. From the point of view of science and geography teachers, this is a particularly challenging topic, also because it involves a

political field of action, to which many of them are not accustomed, as well as feeling unprepared to teach the content itself (Cofré et al., 2023; Monroe et al., 2017). In fact, according to Monroe et al.'s (2017) systematic review of CCE, four effective teaching strategies emerged: (1) engaging in deliberative discussions; (2) interacting with scientists; (3) addressing alternative conceptions; (4) implementing school or community projects. Therefore, most of reviewed successful teaching experiences include the use of active learning and highlight the use of discussion and deliberation as a learning strategy and address alternative student conceptions. For example, Jacobson et al. (2017) report research with high school students where teachers taught CC with computational models and evaluated the differential effect of group work on problem solving prior to direct instruction. Their results indicate that students who discussed problem solving in small groups not only performed better on the posttest of complex knowledge, but also on transfer tasks (near and far transfer). However, although it can be hypothesized that the learning mechanism was deliberative argumentation, the study did not directly control it. Dawson and Carson (2017) also report a study in which an argumentation-based intervention with Australian high school students attending a vulnerable school promoted CC knowledge and argumentation skills. In a subsequent study, Dawson and Carson (2020) showed an improvement in climate change understanding including students' understandings of the differences between weather and climate, types of greenhouse gases, the time scale for climate change, the role of the enhanced greenhouse effect in increasing the Earth's temperature and the role of irradiated infrared radiation. Again, both studies do not include control group. Klosterman and Sadler (2010) report similar results with North American high school students from two different schools ($n = 108$). In a study including an intervention of seven learning exercises focused in discussion of global warming as a socioscientific issue (SSI), students expressed more accurate and sophisticated understandings of scientific concepts and the controversy associated with these issues, but again in the absence of a control group. In the same vein, Mason and Santi (1998), also in a study without a control group, report conceptual gains around climate change in primary school students. Finally, Ohman and Ohman (2013) analyze deliberative discussions of high school students about climate change, and report excessive orientation among participants to consensus, which could weaken the learning effect.

On the other hand, because many studies reported that scientific knowledge does not correlate with changes in attitude or behavior towards climate change (Dijkstra & Goedhart, 2012; Rousell & Cutter-Mackenzie-Knowles, 2020) other instructional strategies have also been identified such as: interacting with scientists conducting scientific inquiry experiences and addressing alternative conceptions when implementing school or community projects (Monroe et al., 2017). In conclusion, evidence from science education calls for the development of new forms of climate change education that directly engage young people in responding to the scientific and social complexities of climate change, in which scientific argumentation has a central role as a teaching strategy and as a guide for the generation of curricular material (Dawson & Carson, 2017, 2020; Monroe et al., 2017; Wildbichler et al., 2025).

It is worth noting that scientific argumentation involves both structural and dialogical dimensions, which has been recognized as crucial scientific epistemic practices in science (Osborne, 2010), as they involve not only the reasoned establishment and evaluation of the relation between evidence and conclusions (typically called *scientific* argumentation) but also debate, deliberation, and dispute within a scientific community, which involve criti-

cal mutual persuasion (typically called *dialogical* argumentation, in the restrictive sense of dialogical). When in this paper we say that deliberative argumentation is a key pedagogical practice for CCE, we mean, inspired by Dewey (1933), that the practice of collaboratively evaluating pros and cons in order to reach the best possible answer given the available information is a potentially powerful pedagogical means that deserves to be carefully examined.

Research Questions

Considering the literature reviewed so far, the central research questions that will guide this study are:

- What are the alternative conceptions about climate change presented by a group of high school students in Chile before and after deliberative argumentation instruction?
- What is the effect of deliberative argumentation on their climate change knowledge?
- What is the effect of deliberative argumentation on their understanding of the nature of climate change?
- What is the effect of deliberative argumentation on their willingness to mitigate climate change?

Methods

Research Design and Participants

The study uses a quantitative approach, is descriptive and explanatory in nature, and has a quasi-experimental design with three experimental and two control groups. All study participants signed an informed consent in accordance with the University Bioethics commission and the guidelines of the National Agency for Research and Development (ANID). Consent letters were given to parents or guardians and assent letters to the students. Only those students who agreed to participate (they and the parents) in each class were included in the study. The participants were 100 secondary school students aged 15–18 years who took the subject of science for citizenship in grade 11 of compulsory education in a state-subsidized school in the Valparaíso region of Chile, with a high index of school vulnerability (81%, which represent the percentage of students who are in a priority socioeconomic situation) and a low socioeconomic index. The school included 1,600 male students, mostly residents in Valparaíso city. The school offers technical-professional and humanities-scientific education. The mean number of students by class was 35. One class included 16 students (Experimental class 1=EC1), another class included 22 students (EC2), and a final experimental class included 20 students (EC3). Control classes included 24 and 18 students respectively (CC1 and CC2). Since each of these courses are independent groups, created before the study and with different characteristics in terms of other variables that have not been controlled, the hypothesis tests and the analysis of results are done for each course, since they are not replications.

Intervention

In this study, argumentation is understood as an epistemic and dialogic practice through which students construct evidence-based claims, evaluate competing explanations, and generate counterarguments in collaborative settings. This conception is aligned with the NRC Framework for K-12 Science Education (NRC, 2012), specifically Practice 7 — Engaging in Argument from Evidence — which positions argumentation as a core scientific practice involving the construction, justification, and revision of explanations based on evidence and reasoning. Its Chilean curricular analogue, the Bases Curriculares de Ciencias Naturales (Mineduc, 2019), similarly includes argumentation with scientific evidence as a key inquiry skill. However, our intervention extends this framework by incorporating a deliberative dimension that varies across lessons.

In January 2022 (Summer vacation) a teacher professional development course on scientific argumentation and climate change education (CCE) was delivered in one university in central Chile in which 25 science teachers participate (more information about the course in Abasto et al., 2025). After the course, all science teachers were invited to participated in a second state of the study about CCE. One of the science teachers that was willing to participate in this second professional development experience was the biology teacher who conducts the lessons in the experimental groups of this study. Because generally the classes to which the teachers have to teach are assigned in the previous year (in this case December 2021), the participating teacher implemented the teaching of CC by deliberative argumentation in all the classes that he had already been assigned (EC), while the courses assigned to the other biology teacher of the school were recognized as a control group, since she has not experience of Professional Development on ECC or scientific argumentation. Both teachers are biology teachers and have more than 15 years of experience teaching science in the school system. The biology teacher in charge of the experimental classes was pursuing a master's degree in science education at the time of the intervention. All classes have an 80 min lesson once a week. Both treatments have to teach environment and sustainability module which includes CC content according to the curriculum of the Ministry of Education of Chile (Mineduc, 2019). In the control groups the topic of climate change was teaching using teacher-based instruction, mostly with traditional lectures.

In the teacher professional development course eight curricular deliberative activities to discuss global warming and climate change issues were developed. These topics were controversial in nature in that each question had two or three options that the groups had to evaluate and choose according to the evidence and argue their decision. In the intervention groups, the teacher applied a unit of six lessons of 80 min each which included an activity (i.e., 1 per lesson). In each lesson, the teacher handed out the material, and the students read the activity individually. Then, in groups of 4 to 5, they discussed one or two questions related to some concept about CC associated with some preconception about global warming. The lessons included: (1) the albedo effect, (2) the functioning of the atmosphere, (3) the greenhouse effect, (4) the historical aspects of knowledge on global warming development, (5) discussion about students' agency and attitude of society on CC mitigations and actions, and (6) the effect of global warming on the biological interactions at the Valdivian temperate rain forest. Lessons 1–4 instantiate scientific argumentation in its epistemic sense: competing explanations reflect documented student preconceptions, and a scientifically better-supported answer can be identified through evidence and reasoning — consistent with NRC

Practice 7. In contrast, lessons 5 and 6 introduce genuine socio-scientific controversy, where legitimate disagreement may persist even after considering the scientific evidence, because normative judgments about values, social responsibility, and collective action are also at stake. This gradient from epistemic to deliberative argumentation was intentional, reflecting the nature of climate change as both a scientific and a socio-political issue.

One example of an activity is presented in Table 1. Each lesson began with small group work in which students engaged with problem situations to discuss their ideas. Finally, they concluded with plenary sessions in which students shared their outcomes in whole-class interactions guided by the teacher whose role was to orchestrate and scaffold discussions and to elicit reasons, formulate implicit controversies, and discuss them to reach a classroom agreement.

Data Collection, Variables, and Instruments

The independent variable corresponds to the type of instruction for climate change, being a binary categorical variable: normal instruction vs. teaching including deliberative argumentation. In the intervention classes, the teacher delivers lessons using curricular materials particularly consistent with the aim of fostering argumentation insofar as each one was designed to promote discussion and exploratory talk in both whole-class and small-group interactions (e.g., Larrain et al., 2018). The control teacher was asked to deliver their lessons in the usual, non-deliberative argumentation, way. The intervention teacher attended a professional development course on climate change education at the University, where he was given full information about the climate change education project and materials. The program was dedicated to introducing him to key aspects of the use of argumentation for science teaching and learning. The teacher received the curriculum materials and explored them collaboratively (more information about the course can be obtained in Abasto et al., 2025). Both teachers planned the climate change unit together and reviewed the questionnaire used to assess the students' knowledge. Six lessons were planned for each treatment, which reviewed the same content taught in two different ways.

The dependent variables correspond to 'Climate change knowledge (CCK)', 'Trust in climate science knowledge (TCCK)' and 'Willingness to act (WA)'. Climate change knowledge was operationalized through the sum of the answers to 16 questions on a scale translated and adapted from the literature (Aksit et al., 2018; Libarkin et al., 2018). The final version of the scale displays an acceptable reliability coefficient ($\text{Alpha}=0.68$) and was

Table 1 Example of the question and alternatives discussed by students in groups in Lesson 3. These questions, along with a text explaining the greenhouse effect, were included in the worksheet

How is it possible that (relatively small) variations in CO_2 and CH_4 are related to global temperature variation, if these gases make up such a small proportion of the atmosphere?

- Small variations in these gases are related to significant changes in the ozone layer hole, which regulates the Earth's temperature.
- These gases chemically react with infrared radiation emitted by various surfaces on the planet, increasing the temperature.
- Pollution in general, while producing CO_2 and CH_4 , also generates an increase in global temperature.

Now, as a group, reach a consensus on which is the option that best explains the relationship between CO_2 and CH_4 and the Earth's surface temperature.

Why does the chosen alternative better explain the issue?

Remember to provide arguments and counterarguments to critically evaluate the different options.

measured as the sum total of the correct answers. We used a scale developed by Tolppanen et al. (2021, 2022) for the variable called ‘Trust in climate science knowledge’. It comprised four Likert-scale-type items, with a scale of four levels (1=completely disagree, 4=completely agree). The scale was also translated and adapted. The final version displays a high reliability coefficient ($\text{Alpha}=0.79$). It was measured as the mean of the total answers. ‘Willingness to act’ was also assessed by a previous instrument developed by Tolppanen et al. (2021, 2022), which included 15 Likert-scale-type items. This scale was also translated and adapted. The final version displays a high reliability coefficient ($\text{Alpha}=0.90$). It was measured as the mean of the total answers. More information on the psychometric characteristics of the scales used can be found in Larrain et al. (2025). The whole instrument (including the three scales) was administered by the science teacher in charge of the classes in regular lessons at schools in one pedagogical hour (45 min).

Table 2 shows the transcript of a typical group discussion in one of the classes where the intervention was carried out. The excerpt corresponds to lesson 3. In the classes that participated as control groups, another teacher, who did not participate in the professional development program on teaching climate change, taught the classes in the same way as she did the previous year. She planned alongside the teacher who taught the experimental classes and taught six lessons covering the same content. The main materials used in these classes were the textbook, PowerPoint presentations, and related videos.

Data Analysis

Statistical analyses were performed following the suggestions of Field (2009). Initially, the distribution of each data group was analyzed through the statistical test of Shapiro–Wilk. Since three of the five data groups did not have a normal distribution, nonparametric statistical tests were used to compare the groups. After that the Wilcoxon nonparametric paired samples test was applied to determine if there are significant differences between the pre- and post-test of all variables (CCK; TCCK and WA). We also calculated the effect size of the intervention by Pearson’s correlation coefficient r . The analyses were performed in SPSS, version 22.0.

Results

The analysis of the responses to the CCK scale showed a significant improvement in CC knowledge in the three classes where it was taught through deliberative argumentation. The Wilcoxon test showed significant differences between the values of CC knowledge between pre-test and post-test (EC1: $z = -2.073, p < 0.05, r = 0.51$; EC2: $z = -3.142, p < 0.01, r = 0.67$; EC3: $z = -2.836, p < 0.01, r = 0.63$). On the other hand, the two control classes, where there was traditional lecturing teaching, showed no statistically significant improvement (CC1: $z = -1.04, p > 0.05, r = 0.2$; CC2: $z = -0.19, p > 0.05, r = 0.05$). Figure 1 shows the comparison of means values between pre and post for each class.

Regarding the alternative conceptions found in the experimental as well as control classes before instruction, the pattern is very similar (Fig. 2). Regarding Q3 (the amount of carbon dioxide has increased since the industrial revolution), and Q4 (that global warming

Table 2 Example of transcript of a discussion of Group 8 - Session 3 for the activity guide on the Greenhouse Effect in lesson 3–2022. In this example, you can observe different preconceptions of the students, as well as episodes of justificatory questions and counterarguments that are offered to explain why an option is chosen from the guide. That is, the excerpt shows evidence of how the strategy of deliberative argumentation works to expose and challenge alternative conceptions

-
- E1- So
 E2, which one do you say it is? The C?
 E2- The C, I don't know why. It says here that in ancient times the temperature also increased, so I don't know if it would also be pollution.
 E1- I see.
 E2- Because up until year 0, it was rising. Although between the years 350 and 300, it decreased (inaudible), and there wasn't even back then.
 E1- Yeah, because there wasn't something (inaudible). So, which one do you think it should be (to E2)? A, B, or C?
 E2- Eh, B.
 E3- It could still be C, because B says "infrared radiation emitted by various surfaces of the planet," and if it were talking about the sun, maybe it would make a bit more sense.
 E1- What is pollution?
 E3- Pollution?
 E1- Yes.
 E3- I don't know.
 E1- So, which one do you think it is (to E3), B or C?
 E3- Eeh, I'm between those two, but now I think it's C.
 E1- And you, (to E4)?
 E4- I'm still thinking.
 E2- Hey, pollution is important because it's about the air and water, since we're talking about Antarctica, right?
 E1- Yes.
 E5- Yes.
 E2- That's why, air and water—pollution is greater in winter. In Antarctica, more pollution could be produced.
 E1- It's colder there.
 E3- Pollution is contamination (explains to E1).
 E1- Ahh.
 E4- Oh, so if it's natural pollution, it would be C!
 E1- Which one?
 E4- It would make sense if it were C.
 E1- So, C. What did you think (to E5)?
 E5- First, it was B, but I went with C.
 E1- And you (to E2), which one do you say it is? B, C, or A?
 E2- After seeing the pollution part, I'd probably say C, although (inaudible).
 E1- I didn't understand anything, so try to explain to me why it would be C and not A or B. I mean, why isn't it A, since no one chose A.
 E3- Eeehh...
 E1- I mean, what invalidates A for C to be chosen?
 E2- The ozone layer is never mentioned, I mean, it's not mentioned here. In those times, there was no effect on or change in the ozone layer, so there's no relation between them.
 E1- There wouldn't be a relation.
 E2- Between the times from 0 to 400.
 E1- Okay, and why did you think it was B? I mean, I understand why it's not A, but why did you think it was B and then switched to C?
 E2- "gases react chemically with the infrared radiation emitted by various surfaces of the planet, increasing the temperature" (reads the option) ... It was more about the temperature.
 E1- About the temperature, what about the temperature?
 E2- It goes up and then down, it goes up and down (shows the graph). It remains stable.
 E1- Like the three lines do the same thing. But what makes B invalid?
 E4- I mean, what E2 was saying about...
 E1- More than invalidating it, why is C more concrete?
 E4- What E2 was saying, what B says about the infrared radiation emitted increasing the temperature, let's see... I feel like the infrared radiation comes from the sun, but not from the earth.
 E3- If it talked about bouncing, maybe it would be more accurate.
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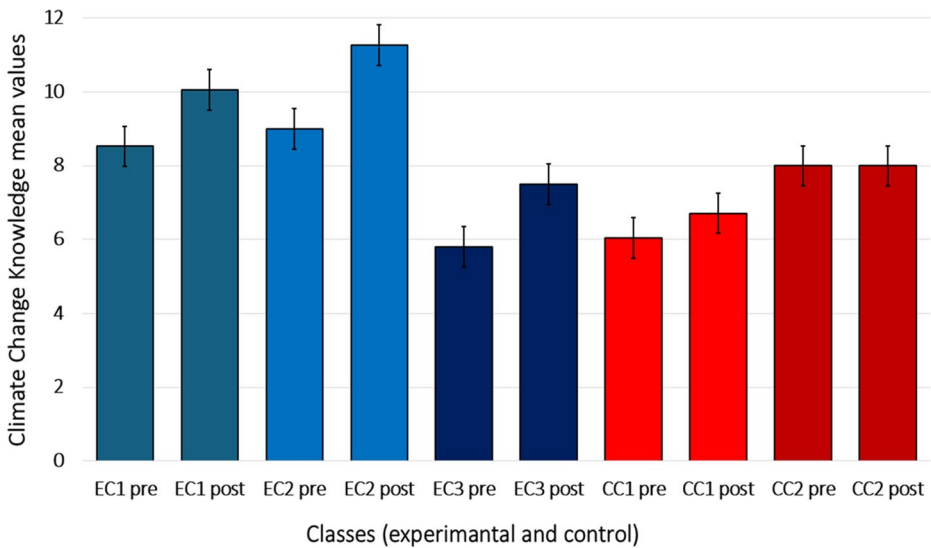


Fig. 1 Graph of averages and standard error for the CCK variable in each of the courses before and after the intervention. Blue colors represent all experimental classes, and red colors represent all control classes

over the past 50 years is mainly due to human activities), many students in all classes have an informed conception, with more students improving this view after the instruction.

In Q5, less students recognize change in air temperature over the last hundreds of thousands of years before the industrial revolution is mainly due to natural processes, and about 50% of students in all classes have knowledge of the transfer of thermal energy from one place to another on the earth (Q6). These two themes are the only ones that improve, both in experimental classes and in controls. On the other hand, concept in Q8, Q9, Q10, Q14, and Q16 improve only in all experimental classes. For example, nearly 60% of the students showed knowledge of the albedo effect as a factor that affects the variation of the planet's temperature by relating the decrease in the amount of ice floating in the ocean to the increase in global temperature (Q8). After instruction, most of the students know what a greenhouse gas is (Q10) and another significant difference is related to infrared rays as the most common form of radiation emitted by the earth's surface (Q16). Finally, students in all classes showed very little knowledge about three interrelated topics: the amount of light absorbed by greenhouse gases (Q11); the most common radiation emitted by the sun (Q12) and the perceived relationship between the hole in the ozone layer and the greenhouse effect (Q13) (Fig. 2). Students have the alternative view that greenhouse gases mainly absorb rays coming directly from the sun, and that these rays are ultraviolet and, to a lesser extent, infrared. Therefore, it is not difficult to explain why they also hold the alternative view that ultraviolet rays are what cause global warming and that greenhouse gases destroy the ozone layer (Fig. 2).

The results obtained from the analysis of the responses to the TCCK scale show a tendency to increase but the improvement in trust in climate science knowledge varied in the three classes where it was taught through deliberative argumentation (Fig. 3). The Wilcoxon test showed significant differences between pre-test and post-test for EC1 ($z = -2.05$, $p < 0.05$, $r = 0.53$); a marginal significant difference for EC3 ($z = -1.93$; $p = 0.055$, $r = 0.45$);

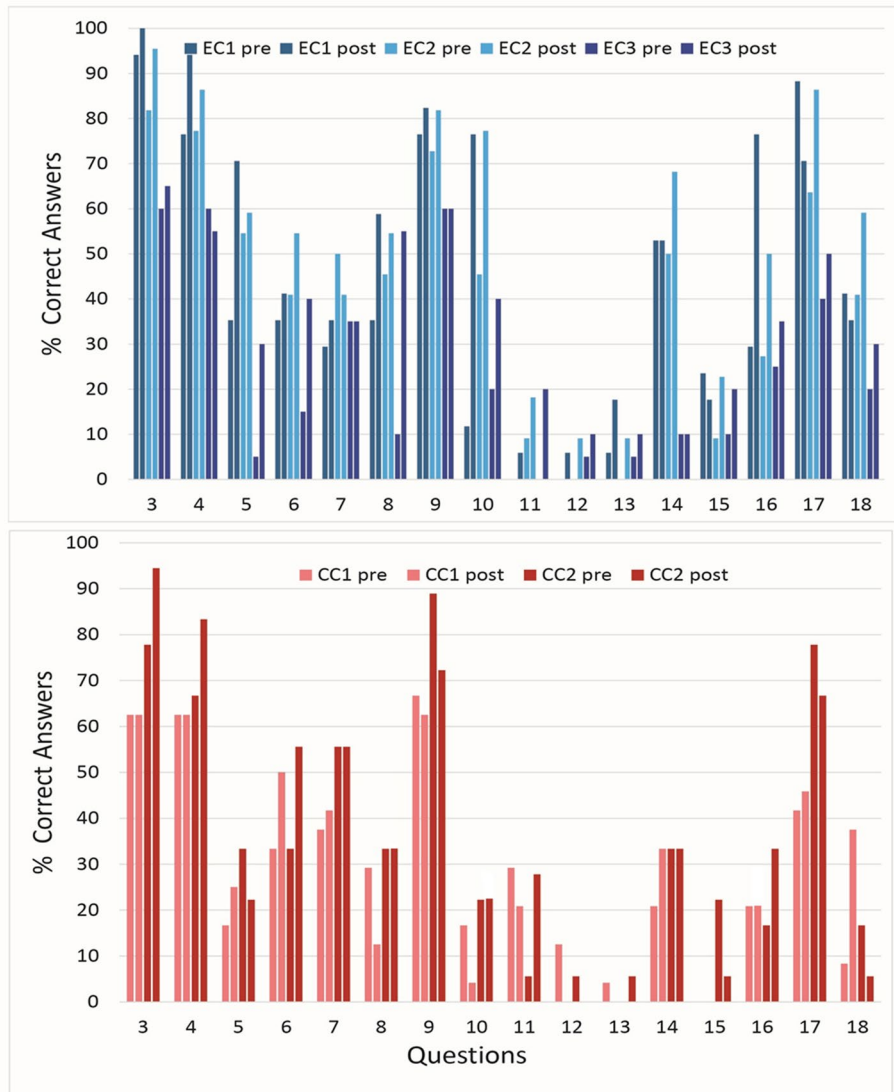


Fig. 2 The graphs show percentage of correct answers for all questions in experimental classes (top) and control classes (bottom)

and no significant difference for EC2 ($z = -1.09$, $p = 0.28$, $r = 0.27$). On the other hand, the two control classes, where there was teacher centered instruction, there was no statistically significant improvement (CC1: $z = -1.05$, $p = 0.29$; CC2: $z = -0.94$, $p = 0.35$).

The results obtained from the analysis of the responses to the WA scale show no improvement in willingness to act in the three classes where it was taught through deliberative argumentation (Fig. 4). The Wilcoxon test showed no differences between pre-test and post-test (EC1: $z = -0.13$, $p = 0.89$; EC2: $z = -0.06$, $p = 0.96$; EC3: $z = -1.0$, $p = 0.32$). On the other

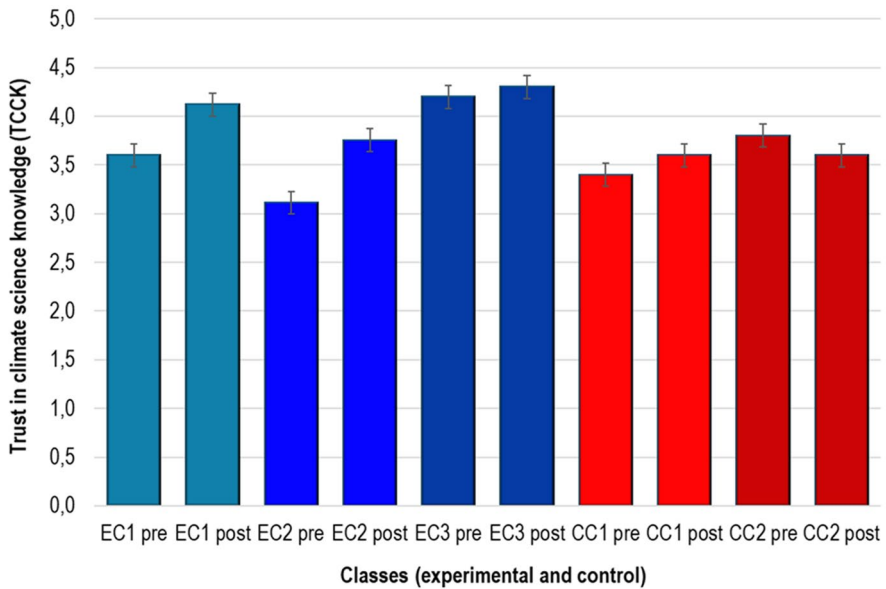


Fig. 3 Graph of averages and standard error for the TCCK variable in each of the courses before and after the intervention. Blue colors represent all experimental classes, and red colors represent all control classes

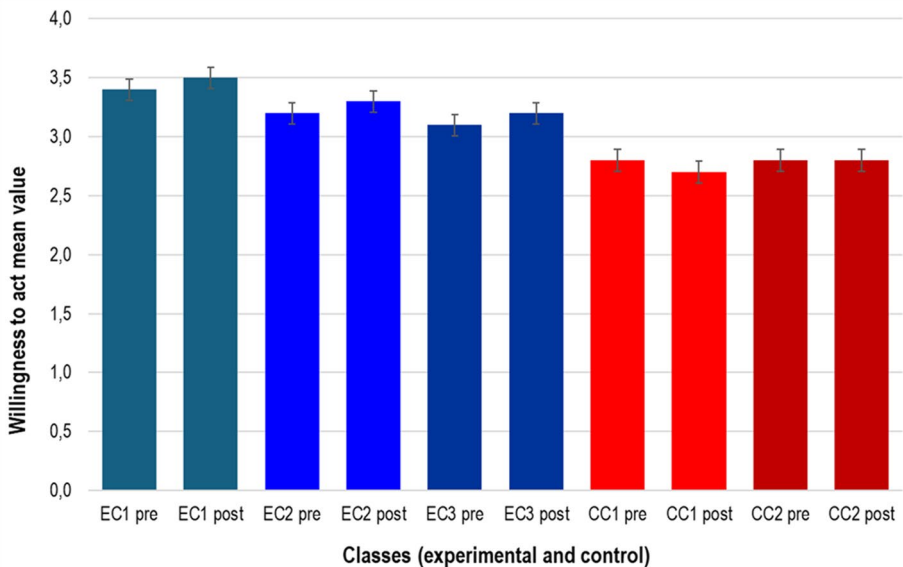


Fig. 4 Graph of averages and standard error for the WA variable in each of the courses before and after the intervention. Blue colors represent all experimental classes, and red colors represent all control classes

hand, the two control classes, where there was teacher centered instruction, there was no statistically significant improvement (CC1: $z = -1.33, p = 0.18$; CC2: $z = -0.09, p = 0.93$).

Discussion

According to the literature review of Monroe et al.'s (2017), four effective teaching strategies emerged: (1) engaging in deliberative discussions; (2) interacting with scientists; (3) addressing alternative conceptions; (4) implementing school or community projects. In this context, the intervention carried out in this study explicitly included two of these recommendations: encouraging students to discuss different topics related to global warming and climate change, and supporting this strategy with curriculum material designed to address some of the most described preconceptions in the literature. The results demonstrated that at the beginning, the whole group of students had a low knowledge about climate change, presenting several preconceptions (Dillon & Herman, 2023; Rousell & Cutter-Mackenzie-Knowles, 2020; Wildbichler et al., 2025), but after instruction all experimental groups improve their knowledge in a statistically significant way. Furthermore, this study showed that a science teacher with experience in a professional development program focused on teaching climate change by deliberative argumentation was able to use this instructional strategy to teach climate change through dialogic and deliberative argumentation, both involving small group and whole class discussions. This is to say, that when students, with limited previous knowledge engage in discussions with classmates and teachers in which they had to interactively formulate and evaluate arguments and counter-arguments to reach a consensus regarding the best possible answer or solution to a given climate change problem, they gain in their scientific understanding. This is not to say that they completely overcome every alternative conception they held. Our results show that some alternative conceptions, mostly related to ultraviolet rays and the hole in the ozone layer persisted in most students after instruction (Dillon & Herman, 2023; Rousell & Cutter-Mackenzie-Knowles, 2020; Wildbichler et al., 2025).

It is interesting to note that a learning path based on deliberative argumentation does not rely only in the construction on scientific argument, but on the critical examination of both scientific and pseudoscientific arguments. As Johnatan Osborne say (2019): in order to learn science crazy ideas, need to be posed and examined because knowing why we are wrong is equally important than being right.

Alternative Conceptions About Climate Change and Global Warming

In accordance with the recent systematic review by Wildbichler et al. (2025), most students in the current study (both before and after the intervention), recognize that the concentration of CO₂ in the atmosphere has been increasing since the Industrial Revolution and, therefore, global warming has a mainly anthropogenic explanation. Therefore, few students hold the alternative conception that the responsibility for global warming is due equally to both natural and anthropogenic factors. Other alternative conceptions that do not arise very frequently were some related to the carbon cycle (Bhattacharya et al., 2021; Jarrett & Takacs, 2020; Wildbichler et al., 2025). For example, in this study, nearly 70% of students in experimental groups thought that plants get carbon from air, contrasting results obtained by Jar-

rett and Takacs (2020), who found that only 39% of 229 students (aged between 13 and 16 years) thought plants get carbon from air (see also Bhattacharya et al., 2021). In our study, more than 70% of students understand that an important part of the CO₂ cycle is the process of absorption in the ocean, therefore it is likely that few students maintain the preconception that carbon is found almost exclusively in the atmosphere (Jarrett & Takacs, 2020). Finally, one aspect that seems to have improved after the intervention was understanding the characteristics of greenhouse gases, for example recognizing the role of methane and CO₂ and understanding that the greenhouse effect is not caused by radiation from the sun. Therefore, alternative conceptions such as CO₂ alone caused the enhanced greenhouse effect (e.g., Dawson, 2015; Jarrett & Takacs, 2020), probably do not represent a problem.

However, other preconceptions prevail, such as climate and weather are confused (Dawson, 2015), and some students see a direct relationship between pollution and global warming (Bhattacharya et al., 2021; Dawson, 2015; Frappart et al., 2018; Varela et al., 2020; Wildbichler et al., 2025). Those that proved particularly persistent were: the depletion of the ozone layer is a causal factor of global warming through increased solar radiation (e.g., Chang & Pascua, 2016; Dawson, 2015; Frappart et al., 2018; Jarrett & Takacs, 2020; Libarkin et al., 2015; Varela et al., 2020; Wildbichler et al., 2025); and confusion between different types of radiation, such as solar and terrestrial, or ultraviolet and infrared, usually associating ultraviolet with global warming (Bhattacharya et al., 2021; Chang & Pascua, 2016; Dawson, 2015; Jarrett & Takacs, 2020; Libarkin et al., 2015; Varela et al., 2020; Wildbichler et al., 2025). According to the students' answers, the "ozone layer" alternative conception can be described as follows: "the greenhouse effect increases as a result of the thinning of the ozone layer, since this allows more heat from the sun to enter". This mental model has been previously described through multiple sources of data such as questionnaires (Dawson, 2015; Frappart et al., 2018; Jarrett & Takacs, 2020; Varela et al., 2020), interviews (Chang & Pascua, 2016; Dawson, 2015; Jarrett & Takacs, 2020), and drawings (Libarkin et al., 2015; Varela et al., 2020) or through combinations of sources. Previous studies have made it clear that this explanation given by students is very persistent and difficult to change, even after teaching (Bhattacharya et al., 2021; Varela et al., 2020; Wildbichler et al., 2025). On the other hand, the "confusion between different types of radiation" preconception can be described as: "The sun mainly emits ultraviolet radiation, which heats the atmosphere when it is absorbed by greenhouse gases". Previous studies have also described a complex mental model of the radiation involved in global warming (Bhattacharya et al., 2021; Dawson, 2015; Frappart et al., 2018; Jarrett & Takacs, 2020; Varela et al., 2020; Wildbichler et al., 2025). Although mental models seem to vary depending on the type of method used to record them (closed questions, open questions, drawings, or interviews), some common ideas seem to be: (a) it is thought that it is the sun and not the earth that emits the most important radiation, (b) ultraviolet light is more important than infrared rays.

The Effect of Deliberative Argumentation on Dispositions Variables About CC

As we described in the theoretical framework, the relationship between students' knowledge and attitudes is complex and difficult to fully understand (Hornsey et al., 2016; Kolenatý et al., 2022; Larrain et al., 2025), and our results align with this perspective. While the teaching intervention through deliberative argumentation was successful in improving students' knowledge, in accordance with results from similar interventions (e.g., Dawson & Carson,

2020; McNeill & Vaughn, 2012; Varela et al., 2020). In fact, our work presents results that closely align with those of Varela et al. (2020), who report an improvement in seventh-grade students' mental models of the greenhouse effect after five 50-minutes lessons, they also found that even after instruction, some students continued to include the role of the ozone layer and ultraviolet rays in their explanations. However, the effectiveness of the intervention implemented in our study was lower when assessing its impact on trust in climate science, and in fact, it had no effect when evaluating its impact on willingness to engage in climate change mitigation. These results appear to be consistent with those presented by Kolenatý et al. (2022), who, on a more global scale (evaluating schools participating in an out-of-classroom experience focused on improving similar variables), found significant improvements in the participating schools. However, the significance and effect size reported were smaller for variables related to willingness to act, and greater for those related to knowledge. In the specific area of willingness to take climate action, our intervention appears to be less effective than others reported in the literature (e.g., Sinatra et al., 2012; McNeill, & Vaughn, 2012). Nevertheless, the study by Sinatra et al. (2012) involved university students who were assessed immediately after an intervention that included reading a persuasive text providing scientific information about climate change. On the other hand, there are also recent studies in which an intervention aimed at improving knowledge and attitudes about climate change had no effect on students (Waltzer et al., 2026). These authors showed that, following an intervention involving 146 students aged 10 to 13, there was no significant improvement in knowledge, attitudes, or actions related to climate change compared to pre-intervention levels. Finally, although we did not find studies that have implemented a climate change teaching intervention specifically aimed at improving students' confidence in the scientific knowledge behind climate change, it has been described that this variable can be very important for enhancing both attitudes and willingness to take action in favor of climate change mitigation (e.g., Larrain et al., 2025). Therefore, these initial partially positive results may serve to improve climate change education approaches moving forward.

Limitations

There are some limitations in the study design that should be considered to better understand and weigh our findings. First, it is likely that an intervention consisting of only six lessons, in which different components of climate change literacy (knowledge, attitudes, and willingness) were addressed, was insufficient. However, within the Chilean curricular framework (Mineduc, 2019), teachers have only this limited time slot to cover topics related to climate change. Furthermore, the lesson sequence design could be improved by dedicating more time and depth to topics more directly associated with influencing willingness to act, compared to those centered on knowledge. There is an inherent limitation in using a quasi-experimental design with pre-existing classes, where random variation in student characteristics is assumed. Nevertheless, some bias related to the evaluated variables may still exist. However, this potential bias was addressed by including multiple classes for both the control and experimental groups. Finally, it is possible that the change along could create more engaged and interested students (control classes conducted lessons as usual and the experimental ones were doing something different), and also the teachers were different, one being part of a study and the other one was not. This might cause the teacher to be more

engaged and enthusiastic but not necessarily, implementing argumentation in a significant way.

Conclusions and Implications

In conclusion, we can say that the intervention was successful in its ability to improve students' knowledge and, in part, to increase their confidence in climate science, but it was clearly insufficient to produce changes in students' willingness to take action on climate change. This has direct implications for ways to address climate change in schools and the real opportunities that exist to achieve critical science literacy on the subject of climate change. It is likely that to achieve this it will be necessary to work more interdisciplinary where teachers of various subjects work together or in which the school as a community is fully committed to carrying out actions for climate change. At least in Chile and many other countries, where science teachers have high demands for work, it is likely that it will not be possible to influence the dispositions to take action on climate change unless there is a broader change in terms of curricula and educational policies on climate change awareness.

Author Contribution P.E., C.V., and H.C. played a central role in shaping the research objectives and the research design. H.C. mainly contributed to the literature review. P.E. was responsible for data collection, led the manuscript writing, and conducted the statistical analyses with C.V. H.C. created the figures. A.L. and J.D. were involved in critically reviewing and providing feedback on the final manuscript. All authors read and approved the final version of the manuscript.

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Data Availability Available from the corresponding author on reasonable request.

Declarations

Ethics and Consent to Participate This study followed educational legislation, ethical guidelines, and research participant protection protocols. Using a unique identifier enabled the anonymous pooling of materials, and no compensation or incentives were offered to the subjects. All study participants signed an informed consent in accordance with the University Bioethics commission and the guidelines of the National Agency for Research and Development (ANID).

Conflicts of interest The authors declare no conflicts of interest.

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