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Effectiveness of Interdisciplinary Instruction in Pre-service Teacher Education for Sustainability: Issues From the Big History and the Study of Climate Change

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Abstract

The paper analyzes the impact of interdisciplinary instruction on the perception, awareness, and knowledge about climate change of 102 Spanish pre-service primary teachers using a pre- and post-test design. Our findings demonstrate that pre- to post-test scores significantly increased in all the studied categorizations and that students' academic background influences score improvement. Data also reveal that there is a positive and significant correlation between teaching capability perception and knowledge, suggesting that knowledge instruction is crucial for teachers' confidence in climate change education. The study also confirms the opportunity to explore sustainable teacher education from an interdisciplinary perspective, carrying out congruent teaching from different approaches on a complex phenomenon to understand it in a holistic way.

Keywords: Climate change education, climate literacy, education for sustainable development, higher education, interdisciplinarity.

Introduction

Climate change (CC) represents one of the most pressing challenges of our time. The negative effects of the phenomenon on natural and human systems make it necessary to mobilize society in general, and each individual in particular, to create a coherent and coordinated response. There is a common consensus that education is a driving force in addressing the challenges of CC and in promoting the social change required to achieve a more sustainable world. One of the necessary prerequisites to achieve this goal is to educate and train teachers to accurately integrate climate change education (CCE) in their daily routine, in the overall context of environmental education (EE) and education for sustainable development (ESD) (Mochizuki & Bryan, 2015). Nevertheless, there is no broad agreement on what teaching approaches are the most effective in CCE. In the systematic review carried out by Monroe et al. (2017), two ideas were highlighted as strategies to increase the effectiveness of CCE programs: 1) making CC infor-

mation personally relevant and meaningful to students; and 2) using active and engaging teaching methods. Furthermore, any EE program should: 1) include hands-on and inquiry-based activities; 2) connect new contents with students' personal relevant experiences; 3) allow students to compare ideas and discuss different viewpoints; 4) make students think using models, data collection and analysis; and 5) promote lifelong learning (NAAEE, 2004; Svihla & Linn, 2012).

On the other hand, if we consider teachers' role in delivering adequate instruction in socio-scientific topics, such as CC, it is essential for them to understand the subject scientific content, as well as students' assumptions and possible reasoning patterns, and aspects related to morality and behavior (Sadler et al., 2004). Thus, teachers are expected to receive training programs that allow them to teach the contents included in curriculum frameworks, integrating a wide range of pedagogical capabilities and subject-matter knowledge (James & Pollard, 2012). This integration is what Shulman (1986) called pedagogical content knowledge and has been widely considered as the knowledge used to transform subject-matter content into forms that students may understand more easily. Teachers' pedagogical decisions – questions they ask, activities they design, simplifications they propose – are partly based on their subject-matter knowledge. Hence, meaningful and comprehensive subject-matter knowledge is essential to achieve effective education, putting into practice teaching methods that establish educational environments that allow and encourage students' participation, learning and exploration. Therefore, it is widely accepted that an important aspect in improving teaching, although not the only one, is better subject-matter preparation for teachers. Nevertheless, the role of knowledge in determining changes in environmental behavior and education for sustainable development is controversial in the literature, being questioned by some (Kollmuss & Agyeman, 2002) and defended by others (McNeal et al., 2017; Shi et al., 2016). People's perceptions and attitudes towards CC, and the will to act are influenced by what they know about the issue and its causes (Lorenzoni et al., 2007; Shi et al., 2016; Tobler et al., 2012). Thus, knowledge should be recognized as one of the many prerequisites for the development of competence leading to sustainable action and the achievement of climate literacy. Regarding teaching education programs, it is important to incorporate ESD contents in teacher training in order to improve the development of ideas about sustainable development and sustainable education (Salīte et al., 2021). In the specific case of CC, teachers do not need to have extensive knowledge of CC before teaching their students to think about the transition to a more sustainable future (Stevenson et al., 2017). Nevertheless, knowledge is essential to integrate action and content and to foster involvement in inquiry-based activities to promote critical and creative thinking, which is something expected in any CCE intervention (Stevenson et al., 2017). In this regard, many teachers are untrained, especially those in the area of science, where subject knowledge tends to be more factual (Oversby, 2015). According to Pegalajar-Palomino et al. (2021), a reorientation of teacher training curricula towards high-quality ESD skills development, relationships, guidance and support is necessary if Schools of Education would contribute to a more sustainable future.

To achieve meaningful and effective CCE, since CC science draws from many disciplines, it is necessary to work in an interdisciplinary way. Educational initiatives can become powerful drivers for the deep change that is required, provided they break free from narrow disciplinary approaches and cultivate knowledge interconnectedness (Fioramonti et al., 2021). However, the rigid structure of the highly compartmentalized national

systems represents an important barrier to such approaches in CCE (Dimenäs & Alexandersson, 2012; Schreiner et al., 2005). In this regard, academic fragmentation at universities constitutes a barrier to interdisciplinary education for sustainability. Certain studies have suggested that one of the major problems in training future teachers in CC is the lack of connection between the different subjects involved in this matter (Oversby, 2015).

The present research focuses on the specific case of education of primary school teachers. In Spain, primary education pre-service teachers (PSTs) receive training in CC in the context of some science and social science education subjects, with no connection or complementarity between disciplines, which causes compartmentalization of an already very complex phenomenon. Hence, these training programs do not help to promote an interdisciplinary approach to work on CCE in primary education classrooms. For this reason, we maintain that there is a need for PSTs to be trained in how to introduce interdisciplinary learning processes that may enable them to consolidate the abilities and knowledge that they have acquired during their studies (Santaolalla et al., 2020). As these authors suggest, it would be interesting to provide PSTs with training in teaching methodologies that they can later implement in their lessons. Thus, it can be concluded that the current challenge is to offer future teachers the opportunity to receive appropriate interdisciplinary training, both in scientific and pedagogical content knowledge.

The Goal and Research Questions

The main goal of this study is to examine the impact of educational interdisciplinary instruction in CCE and ESD in the early stages of primary education teacher training. Specifically, this study was guided by the following research questions:

1. How did PSTs' perception, awareness, teaching perception and knowledge about CC change after completing an interdisciplinary instruction program?
2. How does academic background influence this knowledge, and, more specifically, the type of pre-university major they studied?

Material and Methods

Participants

A convenience sample of 129 PSTs was recruited from a medium-sized public university in northwestern Spain during the academic courses 2018/2019 and 2019/2020. One hundred and two students (79 %) completed all the instruction activities and both the pre-test and post-test surveys. The rest of the students were discarded for analysis. Sixty-nine (68 %) were female and 33 male (32 %), with an average age of 20.0 years. PSTs had not yet received any specific training in CCE during their previous university teacher training. Before participation, PSTs were informed about the research goals, duration and procedure. Participation was voluntary and written informed consent was obtained. Data were collected and analyzed anonymously.

Data Sources

The research is based on a quantitative approach and uses a pre- and post-test design to evaluate the effects of an interdisciplinary instruction in climate change in a teacher training course. Before and after engaging in the instruction, PSTs completed two closed-

ended questionnaires: a perception and attitude questionnaire (PCCQ) and a knowledge-content questionnaire (KCCQ) (Table 1, and Appendices I and II).

The PCCQ consists of 17 items aimed at exploring the participants' overall perception of CC and their attitude towards it, and self-efficacy for CCE (Table 1). Items are scored using a Likert scale ranging from 1 (strong disagreement or not at all) to 5 (strong agreement or very much). It was adopted from the studies performed by Akerlof et al. (2010) and Effeny and Davis (2013). Cronbach's alpha for internal consistency reliability was 0.864.

The KCCQ contains 36 statements about current CC and past climate changes and was adopted from previous studies (Meira-Cartea et al., 2018; Tobler et al., 2012). Cronbach's alpha for internal consistency reliability was 0.829. The KCCQ covers a broad range of climate-related knowledge based on reports issued by the Intergovernmental Panel on Climate Change (IPCC), including climate system and climate science (12 items), physical knowledge about CO_2 and the greenhouse effect (11 items) and causes and consequences of climate change (13 items). All the items consisted of 16 correct and 20 wrong statements. We were careful that the positive or negative wording gave no indication of the correctness of the statements. Correct and wrong statements were arranged in a random order. Items included different difficulty levels, ranging from a basic understanding of climate change to expert knowledge. For each statement, respondents were to indicate whether they believed it was true, false, or whether they did not know. As indicated by Tobler et al. (2012), the latter response option was included to prevent participants from guessing.

Table 1

Questionnaires Used in the Study

Contents	Item examples
Perception and attitude questionnaire (PCCQ)	
Perception and awareness (14 items)	1. Climate change is really happening.
Teaching capability perception (3 items)	15. I am confident and able to include CC in my teaching and to prepare accurate teaching materials about it.
Knowledge-content questionnaire (KCCQ)	
Climate and CC science	12. Human civilization has experienced many other climate changes in the past.
Greenhouse gasses and greenhouse effect	21. Without humans, there would be no greenhouse effect.*
Causes and consequences of CC	32. In a nuclear power plant, a lot of CO_2 is emitted during the production of electrical energy.*

Note: * incorrect statements.

Data Analysis

In all knowledge items that consisted of incorrect statements (e.g., Items 21 and 32 in Table 1), responses were reversed so that the results indicated whether the answer was correct, wrong, or whether the respondent did not know the answer. As performed

by Tobler et al. (2012), the students' answers were also recoded as dichotomous variables (1 = "correct", 0 = "wrong" and "don't know"), so that students who knew the correct answer could be differentiated from those who did not.

Statistical analyses were performed using SPSS version 26. The results of the Kolmogorov-Smirnov and Shapiro-Walk tests yielded p-values (Sig.) below .05, which indicates that the pre- and post-test data in both questionnaires were not normally distributed. Non-parametric Wilcoxon signed-rank tests were run to assess possible statistical significance of pre- to post-instruction changes with the p-value threshold set at <.05. The Kruskal–Wallis test was run in the perception and awareness and knowledge questionnaires to compare pre- to post-instruction ($p < .05$), taking into account students' academic background, that is, the type of pre-university major they had previously studied. Pearson's correlation analysis was applied to assess the possible relationships between the analyzed categorizations.

Study Context: Design and Implementation of an Educational Instruction Using the Big History Approach

The present study analyzes the impact of an interdisciplinary instruction ("The Little Big History of Climate Changes") designed within the Big History approach. Big History is a unitary and holistic view of history from the Big Bang up to the present day (Christian, 2018). It can be approached through specific issues ("Little Big Histories"), taking a specific topic as a reference and putting it in context on different spatial and temporal scales, thus integrating different perspectives. This approach is especially promising when dealing with environmental problems that require a holistic understanding of the situations (Crosby, 2013).

The didactic sequence looks at the past from the earliest climate changes that occurred, through Precambrian and Phanerozoic times, to the current CC in the Anthropocene. This approach allows us to look for common and different patterns that help students to better understand the factors controlling the variability of climate changes, the importance of such changes in the rise and fall of civilizations and the development of societies, and the impact of human activities that have increased the temperature of Earth through greenhouse gas emissions since 1850.

The instruction included seven two-hour classroom work sessions that alternated between two subjects related to Natural Science Education and Social Science Education in the second year of the Primary Education Teacher Degree. In addition, an eighth session was devoted to a one-day field trip to study a glacial lake that was formed during the Last Glacial Age. Indoor and outdoor activities were conducted by the first two authors of the paper. Another teacher, who is a specialist in Modern History Education, also participated specifically in one session. In order to improve the pedagogical content knowledge of PSTs, all the sessions were designed following the structure proposed by Blankman et al. (2016) and were structured around the seven key points that should guide good geoscience teaching practices. The teaching method includes interdisciplinary and inquiry-based activities, following the so-called "congruent teaching" principle, which is the congruent way of teaching that university teachers with specific pedagogical approaches should practice (Swennen et al., 2008). We tried to promote comprehensive training of students, emphasizing access to and management of information, oral and written communication, cooperative work, decision-making and reflective problem-

solving. We also incorporated content related to CCE and EE, focusing on how to address the global problem from a local perspective. Student satisfaction with this interdisciplinary program was very high (Gómez-Gonçalves et al., 2020).

Results and Discussion

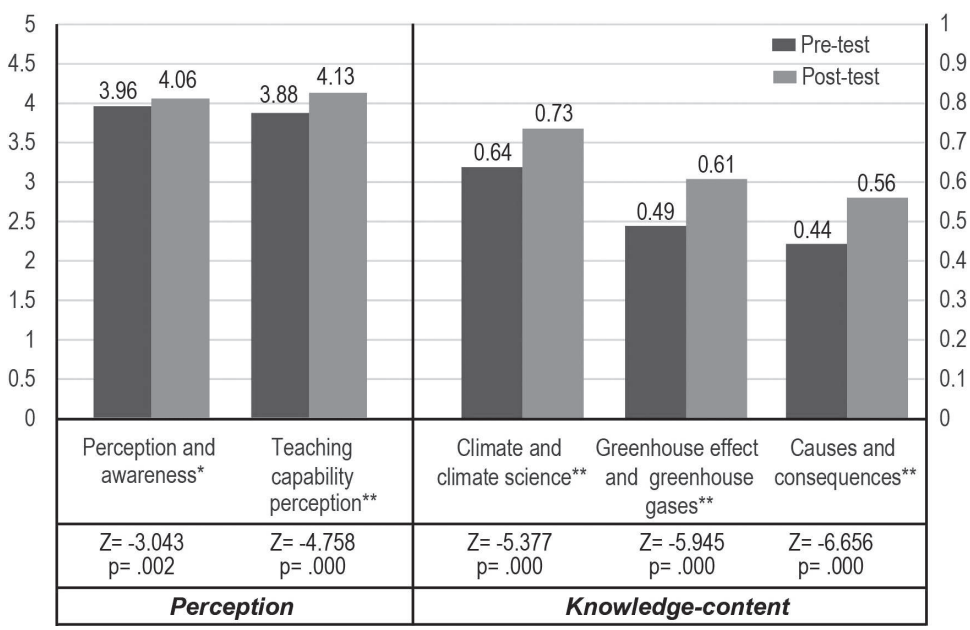
The goal of the study was to assess the impact of an educational interdisciplinary instruction in CCE and ESD in initial primary teacher education, analyzing future teachers' perception, awareness and knowledge of CC. Figure 1 displays the pre-test and post-test scores corresponding to all the categories considered in the study. Results of non-parametric statistical calculations with Wilcoxon tests evidenced that the total scores from pre- to post-test significantly increased in all the dimensions and categories considered in the study (Appendix I).

Perception and Awareness of Climate Change and Teaching Capability Perception

The analysis of the participants' answers to the pre-instruction questionnaire about perception and awareness (Fig. 1, Appendix I) revealed that most of them agreed that CC was really happening (M = 4.61 points, SD = 0.53, 5-point scale) and thought that it was a consequence of human activity (M = 4.36, SD = 0.61). Moreover, respondents agreed that they were concerned about CC (M = 4.07, SD = 0.77) and recognized that right now it was affecting many people around the globe and would continue to do so in the future. Most respondents agreed that CC was also affecting many ecosystems (M = 4.84, SD = 0.46).

Figure 1

Participants' Pre- and Post-instruction Questionnaire Scores



Regarding participants' teaching capability perception, most of them agreed that as future teachers they would be able to contribute to reducing and mitigating the effects of CC (M = 4.59, SD = 0.59) and that the origin, effects and consequences of CC should be taught at schools on a mandatory basis (M = 4.40, SD = 0.69). An interesting finding was the lack of confidence in teaching about CC (M = 2.65, SD = 0.65).

After completing interdisciplinary instruction, students substantially improved in most items (Appendix I). Specifically, there was a significant increase in the score in the following perception items: "CC is really happening" (Z = -2.746, p = .006), "I trust what the scientific community says about CC" (Z = -3.116, p = .002), "I am concerned about the problem" (Z = -3.149, p = .002) and "CC will affect future generations" (Z = -23.480, p = .013). Regarding teaching capability perception, the item referring to the ability to teach about CC also increased significantly after taking part in the interdisciplinary instruction (Z = -6,128, p = .000).

If the mean values of both categorizations are considered, the Wilcoxon signed-rank tests also revealed significant differences (Fig. 1). Pre- to post-test results of perception and awareness increased by 0.10 on a 5-point scale (Fig. 1). The difference between the two groups of scores is statistically significant at the 0.05 level (Z = -3.271, p = .001). Considering the perception of teaching capability in terms of pre- to post-test results, they increased by 0.25 on the scale. The difference between the two groups of scores is statistically significant at the .001 level (Z = -4.718; p = .000).

Knowledge About Climate Change

The analysis of the participants' pre-instruction questionnaire responses on knowledge of CC (climate system and climate science, CO_2 and the greenhouse effect and causes and consequences of CC) indicates that the respondents seemed to be well informed about the differences between climate and weather (item 1 in Appendix II, M = 0.91 (SD = 0.29), 0–1 point scale) and of the fact that climate on the Earth had changed many times since the planet was formed (items 3, 6 and 9). There is also evidence that the vast majority of students also knew that current CC was not caused by natural variations (item 7, M = 0.75, 0.43). An interesting finding is that students were less confident in the items concerning knowledge of the relationship between climate and the development of human civilizations and societies (items 4, 5 and 12).

Many students knew that CO_2 is a greenhouse gas (item 15) that is not harmful to plants (item 16). A vast majority also knew that the increase in greenhouse gasses was mostly caused by human activities (item 18) and some students recognized that petroleum combustion, among other things, produced CO_2 (item 23). Only a minority showed knowledge of other greenhouse gasses, such as water vapor (item 19) or methane (item 20). The misconception that the ozone hole is the main cause of the greenhouse effect was also detected among the participants (item 22). Finally, only a minority of students showed knowledge about the greenhouse effect (items 17 and 21).

If we analyze knowledge about the causes and consequences of CC, pre-test results indicate that knowledge is relatively low in most of the items analyzed. Only a minority of students showed knowledge of health effects associated with CC (items 26 and 30) and the source of direct emissions of CO_2 and their influence on the greenhouse effect (items 31, 32 and 34). On the other hand, many students knew that a warmer climate

would increase the melting of the polar ice caps, thereby raising sea levels (item 29), and that using water efficiently would contribute to slowing CC down (item 33).

Many of the alternative conceptions previously recorded in the literature based on other contexts and on the general population were also quite common among the PSTs surveyed. For example, the belief that the reason for CC is the ozone hole is shared by high school students (Garcia-Rodeja & Lima de Oliveira, 2012), university students from different branches of knowledge (Meira-Cartea et al., 2018) and PSTs from other areas (Papadimitriou, 2004). Our results confirmed the misconception that increased UV radiation and the risk of suffering from skin cancer are a consequence of CC, which is probably influenced by confusion about ozone layer destruction. Specifically, in this study most PSTs consider skin cancer to be one of the diseases that will increase with the effects of CC. Although in a smaller proportion, this idea is also reported in other studies, such as the one conducted using the Spanish general population as a sample (Heras et al., 2017) or the studies conducted in Canada and Malta (Akerlof et al., 2010) or Switzerland (Tobler et al., 2012).

After completing the interdisciplinary instruction, students improved their scores on most items (Appendix II) and just the score of two items did not increase and remained the same (items 7 and 22). Item 22 refers to the misconception that the destruction of the ozone layer influences CC, which persisted after the instruction, once again demonstrating how deeply rooted these ideas are among students. Item 7 refers to the natural origin of current CC and the result is somewhat contradictory as compared to the results obtained in the PCCQ, where students unquestionably achieved progress in the perception of the anthropogenic origin of CC.

The Wilcoxon signed-rank tests revealed significant increases in many items ($p < .05$; Appendix II). In the category of climate system and CC science, there is a noticeable increase in item 8, referring to the Little Ice Age in Spain, from a mean score of 0.02 to 0.28 ($Z = -5.014$, $p = .000$). In the category of greenhouse gasses and the greenhouse effect there were significant increases in items 15 and 19, referring to the recognition of carbon dioxide and water vapor as greenhouse gasses, which increased from 0.76 to 0.98 and from 0.15 to 0.43, respectively ($Z = - 4.491$, $p = .000$; $Z = -4.529$, $p = .000$), and in item 23, referring to the emission of CO_2 from the burning of oil and petroleum products, with an increase from 0.68 to 0.87 ($Z = -4.082$, $p = .000$). Regarding the causes and consequences of CC, there is a noticeable improvement in item 26 (recognition that CC will affect health in many latitudes in the northern hemisphere), which increased from 0.28 to 0.48 ($Z = -3.651$, $p = .000$), in item 31 (recognition that most CO_2 emissions come from the energy sector, agriculture and livestock farming), which increased from 0.27 to 0.58 ($Z = -4.621$, $p = .000$), and in item 31 (unsustainable water management has a negative impact on CC), which went from 0.27 to 0.58 (item 33, $Z = -4.200$, $p = .000$).

If we consider the mean pre-test and post-test scores in the knowledge categorizations (climate system and climate science, CO_2 and the greenhouse effect and causes and consequences of CC), differences significantly increased at the .001 level after participating in the instruction (Fig. 1). This suggests that the interdisciplinary approach favored the learning process in all the dimensions of knowledge addressed.

Learning Outcomes and Academic Background

The analysis of results according to the pre-university major program that the students had chosen revealed that there were certain differences in the PCCQ and KCCQ values (Appendix III). However, the Kruskal-Wallis test demonstrated that all these differences among the groups of students with different academic backgrounds were not significant. Nevertheless, in the PCCQ, the Wilcoxon test revealed significant differences between pre- and post-test scores between those who had taken the Natural Science ($Z = -2.90$, $p = .022$) and those who had taken the Social Science ($Z = -3.025$, $p = .002$) majors. In the KCCQ, significant differences were found between pre- and post-test scores in the Natural Science ($Z = -4.472$, $p < .000$), Social Science ($Z = -5.478$, $p < .000$) and Arts ($Z = -2.201$, $p = .028$) majors. Thus, it can be concluded that students' academic background does not significantly influence the score in the different categories analyzed, but it does influence score improvement in pre- and post-test analysis.

Correlation Between Perception, Awareness and Knowledge

Pearson correlation between categorizations was calculated after the interdisciplinary instruction (Appendix IV). The analysis demonstrated that perception and awareness, and teaching capability categorizations positively and significantly correlated to each other. Moreover, knowledge categorizations also correlated positively and significantly with each other, which would confirm the relationship between the different knowledge topics which the PSTs were asked about. Interestingly, there is a positive and significant correlation between teaching capability perception and the three knowledge categories, suggesting that knowledge instruction is crucial for teachers' confidence in education for sustainable development in general, and in CC in particular. There is, however, no significant correlation between the perception and awareness and the knowledge categorizations, which can indicate that these variables are not linearly dependent, i.e., those students who scored high in awareness or perception items did not score high in knowledge items, and vice versa.

Conclusions and Limitations

Education systems should play a key role in teaching how to mitigate and adapt to CC and, thus, universities should address the question of how to professionally train future teachers in this field. Nevertheless, disciplinary fragmentation at universities hinders collaborative teaching practices aimed at effectively achieving this goal. The study analyzed and confirmed the perspective and opportunity to explore teacher training in the aspect of sustainability and CCE from an interdisciplinary and broader approach, carrying out congruent teaching of a complex phenomenon from different viewpoints to understand it holistically. PSTs are a relevant group, as they will become the educators of future generations, and our observations could be used to design new training strategies to improve their education in the areas of ESD and CCE.

The first main finding of the study is that after completing interdisciplinary instruction, PSTs scored substantially higher in most of the analyzed items related to perception and awareness, teaching capabilities and knowledge. There are also cases where many students maintain their misconceptions after instruction, which should encourage those

responsible for teacher training to reflect on placing more emphasis on improving this aspect. In this regard, most of the misconceptions reported herein were documented in previous studies in different contexts. This is especially worrisome because lack of knowledge could contribute to feelings of uncertainty in the area of CC, which could ultimately lead to skepticism about the reality of CC, human influence, and the need for action (Hepper, 2021; Lorenzoni et al., 2007). Second, in agreement with previous studies (McNeal et al., 2017), our research clearly shows that knowledge-based content is a key aspect to promote teachers' confidence in CCE. Furthermore, our findings point out that PSTs' academic background does not significantly influence the score between the different categories analyzed, but it influences the score improvement of pre- and post-test analysis, and hence the effectiveness of instruction, which should be taken into account in any EE and ESD training implemented in teacher education programs.

To conclude, it should be noted that there are certain limitations to this investigation. The study reports the beliefs and ideas of second-year students from a medium-sized public university in northwestern Spain and, therefore, care must be taken regarding the interpretation of the results in broader contexts. It would be interesting to carry out further research using other training programs as a basis to compare the results obtained. Nonetheless, despite its limitations, the study contributes to the understanding of how effective interdisciplinary instruction is in CCE and ESD in teacher education studies.

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Appendix I

Results of the Perception and Awareness Questionnaire (PCCQ)

Item	Pre-test M (SD)	Post-test M (SD)
Perception and awareness		
1. Climate change is really happening.*	4.61 (0.53)	4.75 (0.44)
2. Climate change is a consequence of human activities.	4.36 (0.61)	4.35 (0.61)
3. Climate change is occurring due to natural causes.	2.47 (0.92)	2.57 (0.90)
4. I trust what the scientific community says about climate change.*	3.94 (0.74)	4.14 (0.77)
5. I am concerned about the problem.*	4.07 (0.77)	4.29 (0.64)
6. With my daily actions I can help curb the effects of climate change.	3.82 (0.98)	3.98 (0.90)
7. I am willing to modify my standard of living and quality of life to mitigate the effects of climate change.	3.88 (0.62)	3.98 (0.70)
8. Society is ready to adopt climate change adaptation and mitigation measures.	2.90 (0.96)	2.98 (0.88)
9. Climate change is affecting me.	4.06 (0.79)	4.10 (0.79)
10. Climate change is affecting my family.	3.96 (0.82)	3.89 (0.88)
11. Climate change will affect future generations.*	4.61 (0.75)	4.76 (0.51)
12. Climate change is affecting other people in industrialized countries.	4.02 (0.95)	4.18 (0.86)
13. Climate change is affecting other people in developing countries.	3.88 (0.95)	3.87 (1.11)
14. Climate change is affecting ecosystems (plants and animals).	4.84 (0.46)	4.75 (0.74)
Teaching capability perception		
15. I am confident and able to include climate change in my teaching and to prepare accurate teaching materials about it.**	2.65 (0.65)	3.32 (0.79)
16. The origin, effects and consequences of climate change should be taught in schools on a mandatory basis.	4.59 (0.59)	4.64 (0.54)
17. As a future teacher, I will be able to contribute, through teaching, to reducing and mitigating the effects of climate change.	4.40 (0.69)	4.44 (0.64)

Note: Mean 0–5. * Significant at $p < .05$. ** Significant at $p < .001$.

Appendix II

Results of the Knowledge-content Questionnaire (KCCQ)

Item	Pre-test M (SD)	Post-test M (SD)
Climate and climate change science		
1. *Climate and weather are the same.**	0.91 (0.29)	0.98 (0.14)
2. The climate system consists of five major components: atmosphere, hydrosphere, lithosphere, cryosphere and biosphere. They act in a connected manner establishing a flow of matter and energy.	0.63 (0.49)	0.73 (0.45)
3. *Since records have been kept, climate in Spain has always been the same.**	0.84 (0.37)	0.94 (0.24)
4. Climate changes have contributed to the expansion and collapse of great civilizations.	0.59 (0.49)	0.62 (0.49)
5. *Climate cannot be altered by historical factors.**	0.48 (0.50)	0.65 (0.48)
6. *In the last centuries, even in the last thousands of years, the area covered by ice in the northern hemisphere remained unchanged.**	0.91 (0.29)	0.99 (0.10)
7. *Current climate change is mostly caused by natural variations, such as changes in solar radiation or volcanic eruptions.*	0.75 (0.43)	0.75 (0.43)
8. The last major climate change in Spain occurred in the 17th century.**	0.02 (0.14)	0.28 (0.25)
9. *Since the formation of our planet, climate remained practically unchanged until the last 10.000 years.**	0.70 (0.46)	0.83 (0.37)
10. *Climate change can only be known through statistical and scientific sources.*	0.71 (0.46)	0.77 (0.42)
11. *The past climate can be only known on a general scale, because there are no local records.*	0.51 (0.50)	0.55 (0.50)
12. Human civilization has experienced many other climatic changes in the past.	0.61 (0.49)	0.72 (0.45)
Greenhouse gases and greenhouse effect		
13. CO_2 concentration in the atmosphere increased significantly over the last 200 years.	0.81 (0.39)	0.90 (0.30)
14. *The current concentration of carbon dioxide (CO_2) in the atmosphere is very similar to that of 650.000 years ago.*	0.26 (0.44)	0.32 (0.47)
15. Carbon dioxide (CO_2) is a greenhouse gas.**	0.76 (0.43)	0.98 (0.14)
16. *Carbon dioxide (CO_2) is a gas that is harmful to plants.*	0.74 (0.44)	0.75 (0.44)
17. Greenhouse gases partially retain the infrared radiation emitted by the Earth.*	0.41 (0.49)	0.55 (0.50)
18. The increase in greenhouse gases is mostly caused by human activities.	0.87 (0.34)	0.94 (0.24)
19. Water vapor is a greenhouse gas.***	0.15 (0.36)	0.43 (0.50)
20. *Carbon dioxide (CO_2) contributes as much to global warming as methane (CH_4).**	0.23 (0.42)	0.36 (0.48)
21. *Without humans, there would be no greenhouse effect.*	0.45 (0.50)	0.56 (0.50)
22. *The destruction of the ozone layer (O_3) influences global warming and climate change.*	0.02 (0.14)	0.02 (0.14)
23. Petroleum combustion, among other things, produces CO_2.***	0.68 (0.47)	0.87 (0.34)

See next page for continuation of appendix

Continuation of Appendix II

Causes and consequences of climate change		
Throughout the 21st century, scientists expect...		
24. ... an increase in the number and intensity of extreme meteorological events.*	0.69 (0.47)	0.79 (0.41)
25. ... *the climate to cool.**	0.60 (0.49)	0.72 (0.45)
26. ... that health effects associated with climate change (e.g., increased cases of malaria or yellow fever) will affect more northerly latitudes.**	0.28 (0.45)	0.48 (0.50)
27. ... *an increase in precipitation across the globe.*	0.34 (0.48)	0.41 (0.49)
28. ... *a warmer climate that will increase evaporation in the oceans, leading to a generalized lowering of sea levels.**	0.49 (0.50)	0.66 (0.48)
29. ... a warmer climate that will increase the melting of the polar ice caps, thereby raising sea levels.*	0.79 (0.41)	0.89 (0.31)
30. ... *an increase in CO_2 concentration that will cause greater absorption of ultraviolet rays, which will, in turn, involve a higher risk of skin cancer.*	0.10 (0.30)	0.10 (0.30)
31. Most of the Spanish CO_2 emissions come from the energy sector (energy production) and agriculture and livestock farming.**	0.27 (0.45)	0.58 (0.50)
32. *In a nuclear power plant, a lot of CO_2 is emitted during the production of electrical energy.*	0.11 (0.31)	0.13 (0.34)
33. Saving drinking water (e.g., taking a shower instead of a bath) contributes to slowing down climate change.**	0.75 (0.43)	0.95 (0.22)
34. *Cell phone and WIFI networks contribute to the greenhouse effect and therefore to climate change.*	0.22 (0.41)	0.26 (0.44)
35. Massive deforestation favors climate change.*	0.62 (0.43)	0.75 (0.50)
36. *Climate change is affecting food production globally, but only in remote regions with extreme climates.*	0.51 (0.49)	0.56 (0.50)

Note: Italics indicate incorrect statements. Mean 0–1. * Significant at $p < .05$. ** Significant at $p < .001$.

Appendix III

Results According to Students' Academic Background

	Pre-university major									
	Natural Science		Arts		Social Science		Professional training		Other	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Perception and awareness	3.99 (0.42)	4.03 (0.38)	4.00 (0.27)	4.33 (0.20)	3.93 (0.36)	4.03 (0.40)	3.75 (0.15)	4.10 (0.45)	4.03 (0.05)	4.14 (0.20)
Teaching capability perception	3.84 (0.51)	4.14 (0.39)	3.94 (0.49)	4.16 (0.27)	3.90 (0.40)	4.13 (0.44)	3.50 (0.23)	4.16 (0.23)	3.83 (0.23)	3.83 (1.17)
Climate and climate science	0.63 (0.17)	0.75 (0.15)	0.61 (0.13)	0.63 (0.24)	0.65 (0.17)	0.73 (0.14)	0.67 (0.00)	0.92 (0.00)	0.63 (0.06)	0.71 (0.06)
Greenhouse effect and greenhouse gases	0.53 (0.13)	0.65 (0.11)	0.36 (0.15)	0.56 (0.13)	0.47 (0.18)	0.59 (0.14)	0.59 (0.6)	0.50 (0.19)	0.50 (0.06)	0.59 (0.06)
Causes and consequences of CC	0.49 (0.19)	0.60 (0.17)	0.40 (0.30)	0.56 (0.24)	0.41 (0.18)	0.54 (0.18)	0.62 (0.11)	0.65 (0.27)	0.42 (0.15)	0.46 (0.11)

* Note: mean values (standard deviation)

Appendix IV

Results of the Pearson Correlation Analysis

	Perception and awareness	Teaching capability perception	Climate and CC science	GH gasses and GH effect	Causes and consequences of CC
Perception and awareness	1	.545**	.013	.121	.176
Teaching capability perception		1	.204*	.172	.346**
Climate and CC science			1	.294**	.335**
Greenhouse gases and greenhouse effect				1	.445**
Causes and consequences of CC					1

Note: * Significant at $p < .05$. ** Significant at $p < .001$.