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Florida and Puerto Rico Secondary Science Teachers' Knowledge and Teaching of Climate Change Science

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Abstract Misconceptions about climate change science are pervasive among the US public. This study investigated the possibility that these misconceptions may be reflective of science teachers' knowledge and teaching of climate change science. Florida and Puerto Rico secondary science teachers who claim to teach extensively about climate change were surveyed in regard to their conceptions of climate change science and the climate change-related topics they teach. Results show that many teachers hold naïve views about climate change (e.g. that ozone layer depletion is a primary cause of climate change) and climate change science (e.g. that it must be based on controlled experiments for it to be valid). In addition, teachers in both groups neglect crucial topics such as how evidence for climate change is developed and the social, political, and economic dimensions of climate change. Our results suggest the need for teachers to understand how to teach climate change and the nature of climate change science using authentic contexts that promote effective socioscientific decision-making and climate change mitigation.

Keywords Climate change education · Nature of science · Secondary school science · Science teacher education

We dedicate this article to the memory of Walter J. Rosales-Mejía whose intelligence and kindness supported us in this endeavor. Any opinions, findings, conclusions, and recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Introduction

Climate change is arguably one of the most significant environmental issues, with a global average warming of 1 °C since 1900 and an additional 1.5 to 6 °C by 2100 (U.S. Global Change Research Program, 2009). Climate scientists attribute the rising global average temperatures to higher atmospheric greenhouse gas concentrations that stem primarily from anthropogenic sources (e.g. combustion engines, power plants). Impacts from climate change include those that are ecological, human health related, cultural, and socioeconomic and range in scale from personal to global (Intergovernmental Panel on Climate Change [IPCC], 2007a, b, 2013).

In order to mitigate the effects of climate change and to decrease the production of heat-trapping gases, people need to change their beliefs and actions. One way to make this happen is through education, in particular the science education of K-12 students. However, for this to occur, there need to be science teachers whose knowledge and perceptions about climate change are in line with those of the vast majority of scientists. In addition, no matter what the state of their knowledge and perceptions, they will have little effect on their students' learning unless they actually teach climate change science, and do so in ways that lead to conceptual understanding.

The purpose of our study was to reveal the extent that Florida (FL) and Puerto Rico (PR) secondary science teachers are knowledgeable and instruct about climate change and climate change science. We chose FL and PR teachers for this study because these teachers work and reside in regions that are particularly vulnerable to the effects (e.g. sea level rise) of climate change. We purposefully selected those teachers who made claims in our survey that they taught extensively about climate change to get a sense about how their climate change science knowledge could influence their teaching of specific climate change-related topics. Importantly, students' and more broadly the general public's climate change engagement may be impacted by the robustness of science teachers' knowledge and teaching of climate change science.

Public Understanding of Climate Change Science

Various science education reform documents and standards show an increased focus on climate change and how climate change science works in an effort to improve the public's understanding of these important topics (AAAS, 2007; Next Generation Science Standards [NGSS] Lead States, 2013). For example, the NGSS direct teachers to instruct on how (1) anthropogenic activities have increased carbon dioxide concentrations and affected climate change (HS-ESS3-6, MS-ESS3.D); (2) climate change is understood by scientists through a plethora of approaches such as modeling (HS-ESS2-4, HS-ESS3-5), and (3) climate change models involve a tangible degree of complexity, uncertainty, and dependence on unknown and unforeseen factors (HS-ESS2-4, HS-LS2.C). Furthermore, climate change-focused standards urge instruction on the constraints (e.g. safety, economics) as well as the social and economic implications associated with climate change and its mitigation (HS-ESS3-1). Although these standards are primarily in the earth sciences, they can be readily addressed in other science subjects, including biology, marine science, environmental science, and general science.

The US Population's Understanding of Climate Change Science

While contemporary standards explicitly call for students to understand climate change and climate change science, recent literature points out that the majority of the general public falls well short of these important educational goals. For example, Bord, O'Connor and Fisher (1998) found that a large portion of the US population misconceived that aerosols, insecticides, and the depletion of the upper ozone layer have a significant impact on climate change. Reynolds, Bostrom, Read and Morgan (2010, p. 1520) found that the respondents in their investigation "did not appear to fully appreciate key facts such as that global warming is primarily due to increased concentrations of carbon dioxide in the atmosphere, and the single most important source of this carbon dioxide is the combustion of fossil fuels."

A significant fraction of the general US public is also conflicted about the nature of climate change science. For example, interviews by Leiserowitz, Maibach, Roser-Renouf, Feinberg, Rosenthal and Marlon (2014) revealed that 33 % of the participants thought a significant amount of disagreement existed within the scientific community about whether global warming is occurring. These findings align with arguments from Rudolph (2007) and Herman (2015) that claim that much of the public does not understand that many valid scientific methodologies (e.g. observational and historical science) in which variables cannot be directly tested and controlled by the researcher account for climate change. Instead, much of the public wrongly believes that climate change science methods only produce reliable knowledge if they mirror step-by-step controlled experiments.

Science Teachers' Understanding and Instruction of Climate Change Science

The studies reviewed above suggest that in general, the US population lacks knowledge of and holds misconceptions about the causes of climate change, as well as the nature of climate change science. There is also some evidence that science teachers' knowledge about climate change and climate change science is similarly deficient, which would undoubtedly influence their teaching. Wise (2010) surveyed and reported on the climate change instructional practices of 628 Colorado secondary science teachers. Findings from this study showed that 43 % of the teachers responded that they teach climate change through formal lessons. Of those teachers, over 80 % indicated that they emphasized the nature of climate change science as their primary strategy for addressing controversies related to climate change. Focusing specifically on the surveyed earth science teachers (N=183), of which 65 % provide formal instruction about climate change science, Wise (2010) showed that approximately half of the teachers erroneously agreed or somewhat agreed that the ozone hole contributes to global warming and that substantial disagreement exists among scientists about global warming causes.

Monroe, Oxarart and Plate (2011) showed that 77 % of 675 surveyed secondary science teachers from the Southeastern USA self-reported covering climate change at varying degrees. Furthermore, approximately 70 % self-reported having at least a moderate understanding of climate change and being somewhat to very comfortable teaching this subject. However, these assertions were not confirmed by formal assessments of the teachers' climate change knowledge.

Dawson (2012) surveyed 39 Australian science teachers and found that there was wide variation in their understanding of both the greenhouse effect and climate change. Twenty percent of them believed that the greenhouse effect provided protection from

ultraviolet radiation. In addition, "One third of teachers were unable to provide a definition that related greenhouse gases and their impact on radiation from the Earth's surface to increasing temperature" (p. 12). Dawson also found that two thirds claimed teaching about the greenhouse effect and that 57 % claimed teaching about climate change. Clearly, this raises the question as to what they are teaching and if they possess sufficient knowledge to do so.

The last and most relevant investigation reported here was conducted by Sullivan, Ledley, Lynds and Gold (2014) who reported the collective responses from 877 middle and high school science teachers across four survey efforts, each with a different focus, between 2009 and 2011 about those teachers' climate change instruction preparation and practices. We focus on the responses from survey efforts 3 (N=141) and 4 (N=101) from teachers who explicitly instructed formal lessons about climate change. These teachers appeared to be more knowledgeable about climate science than the general public (Leiserowitz, Maibach, Roser-Renouf & Hmielowski, 2012). Focusing specifically on the findings from survey effort 3, Sullivan et al. (2014) report approximately 70 % of the teachers spend less than a quarter of their time on climate science, with only 20 % teaching climate science as a stand-alone topic. Furthermore, 80 % of survey effort 3 teachers considered climate change mitigation and adaptation, and up to 50 % consider an equal mix of scientific and social aspects when instructing about climate science. Survey effort 3 and 4 teachers also indicated that when teaching about climate change, controversy and misinformation were their greatest concern. The teachers' response to this concern was to promote learning about the nature of science and evidence. However, this investigation did not report the teachers' understanding and implementation of the specific nature of climate change science ideas (e.g. the role of controlled experiments and modeling). Rather, Sullivan et al. (2014, p. 555) report that survey effort 3 teachers "seek resources that exhibit credible science, real world applicability, and opportunities for students to use real data and to have hands-on engagement."

Study Purpose

This study is part of a larger externally funded project focused on the state of climate change education in FL and Caribbean coastal areas and purposefully investigates the climate change science knowledge and content coverage of FL and PR secondary science teachers that claimed to deeply teach climate change. The aforementioned literature suggests that misconceptions about climate change are pervasive among the general public and science teachers and that secondary science teachers may not facilitate students to accurately understand climate change and how climate change science works in a manner that prepares them to participate as informed citizens who can efficaciously evaluate arguments and make reasoned decisions about climate change.

If teachers are to help their students conceptualize the complex topics regarding climate change, they must have an understanding of these topics sufficient enough to be able to accurately and effectively include them in their practice (Bartholomew, Osborne & Ratcliffe, 2004). Furthermore, while it has been found that teachers' practice may at some times appear to be disjoint from their beliefs (Cohen, 1991), there is also much evidence that teachers' beliefs influence what and how they teach (e.g. Mansour, 2013). Thus, an intuitive first step toward rectifying this problem is to determine teachers'

conceptions and beliefs about fundamental climate change science ideas, and the extent they address those ideas in the classroom. Our review of the literature suggests that there have been a few studies of practicing teachers. However, scant attention has been afforded to the nuanced climate change science knowledge and content coverage of secondary science teachers who claim they provide significant attention to climate change. In addition, we have found no studies that are cross-cultural or compare teachers in different countries. While PR is a part of the USA, and Puerto Ricans are US citizens, there are differences in the educational systems, as well as major cultural differences, and of course the school instruction is in English on the mainland and in Spanish on the island. Therefore, we believe in many respects that a comparison between FL and PR teachers can be considered cross-cultural. In addition, we did not find any studies that compared teachers' conceptions of the causes of climate change with those of the general population. Therefore, we sought to answer the following research questions:

1. How do FL and PR secondary science teachers' and the general US public's conceptions about the causes of climate change compare?
2. How do FL and PR secondary science teachers' conceptions about the validity and nature of climate change science compare?
3. How does the self-reported climate change content coverage of FL and PR secondary science teachers compare?

Methods

Context

The science teachers whom we surveyed live and teach in FL and PR. In FL, 75 % of the population resides in coastal areas, with increases coming in future decades (Boesch, Field & Scavia, 2000; US Census Bureau, 2010). The PR population of 3.7 million people, 56 % of whom live in coastal municipalities, is geographically restricted to the 9104-km^2 island of PR (Puerto Rico Climate Change Council [PRCCC], 2013). These coastal communities are highly susceptible to climate change impacts including sea level rise, increased sea surface temperatures, salt water intrusion and diminished freshwater resources, ocean acidification, coral reef bleaching, extreme weather events, and increased human casualties (Boesch et al., 2000; IPCC, 2007a, b, c, 2013). Economically, it is projected that FL stands to lose over 300 billion dollars by 2100, and losses in PR may reach 2.5 billion dollars annually by 2050 when accounting for climate change impacts (Borisova, Breuer & Carriker, 2008; Bueno, Herzfeld, Stanton, & Ackerman 2008).

Instrumentation

We ascertained FL and PR secondary science teachers' climate change conceptions and content coverage by using a survey that included qualitative and Likert prompts. This survey contained six sections asking the participants to report their (1) definition of climate change; (2) perceptions of the causes of climate change (nine Likert items, each

with three categories—not a cause, minor or secondary cause, and major or primary cause); (3) perceptions about the validity and nature of climate change science (11 Likert items, each with five categories—strongly disagree (SD), disagree (D), undecided (U), agree (A), and strongly agree (SA)); (4) general climate change teaching practices (one Likert item with four categories—avoidance, mentioned briefly, taught deeply as distinct unit/lessons, and unifying theme of the course); (5) teaching of specific climate change-related topics (13 Likert topics, four categories—none, little/implied, some, and extensive/explicit); and (6) subjects taught. We drew the items in section 2 from Bord et al. (1998) who used those items to gauge the US public's perceptions about the causes of climate change. All other items were researcher generated or based on items drawn from prior survey efforts that determined the perceptions about climate change among various groups (e.g. Herman, 2015; Bord et al., 1998; Leiserowitz et al., 2014). FL teachers completed surveys written in English, and PR teachers completed surveys written in Spanish. This was done to reduce the impact that language barriers would have on survey readability. The English version of the survey used for this study appears in Appendix A (see on-line supplementary materials), and the Spanish version is available from the authors. We received IRB approval for this study.

Instrument Reliability

The survey items in section 2 exhibited acceptable reliability with alpha coefficients ranging from 0.64 (non-causes of climate change, four items) to 0.74 (actual causes of climate change, five items), as reported by Bord et al. (1998). We did not calculate internal consistency and reliability coefficients for the items in section 2 because we used them as separate indicators regarding the teachers' perceptions of the causes of climate change. Similarly, reliability coefficients were not calculated for items in section 5 because they were used as indicators of the teachers' coverage of specific climate change-related topics. Reliability coefficients were calculated on the 11 items in section 3 of the instrument used here because they collectively served as an indicator of the teachers' perceptions about the validity and nature of climate change science. Cronbach's alphas and mean inter-item correlations for these 11 items were 0.72 and 0.18 respectively, thus demonstrating acceptable reliability and internal consistency (DeVellis, 2003).

Sample Population

We distributed surveys to FL (N=102) and PR (N=118) secondary science teachers as part of a convenience sample at the Florida Association of Science Teachers Conference and at schools in FL and PR. Again, this study focused only on secondary science teachers who claimed to deeply teach climate change. Therefore, we retained only those surveys if the participating teachers indicated teaching about climate change as distinct lessons, a unit, or a unifying theme of a course (see section 4 as described above and in Appendix A of the electronic supplementary materials). We then individually reviewed and removed surveys if they were clearly satisficed (e.g. incomplete or exhibited "straight-lined" Likert responses) (Krosnick, 1991). Thus, of the original 220 teachers surveyed, 56 FL and 60 PR teachers' surveys were retained for analysis.

Table 1 shows the courses taught by the teachers. At least five of the listed courses include content that can include climate change science: biology, earth science, marine science, environmental science, and general science. Forty-eight of the FL teachers and 50 of the PR teachers included in our analysis indicated that they teach at least one section of one of these courses.

Data Analyses

We used the following as our definition of climate change, which we paraphrased from the IPCC Synthesis report (2007a, b): climate change is defined as *the changes in the average weather or the variability of its properties that persist for an extended period of time (e.g. decades or longer), or both.* Based on this definition, the teachers' qualitative definitions of climate change provided in section 1 of the survey were categorized as "tautological," "incorrect," "partially correct," and "correct" based on the content of what was written. The authors independently rated the qualitative responses that achieved an 85 % level of inter-rater agreement. The remaining responses with discrepant ratings were discussed until an agreed-upon rating was determined and justified.

We used non-parametric statistical analyses to explore the respondents' climate change views and content coverage. It was justified to use non-parametric statistics for this study because Likert survey items can be conservatively considered ordinal with a demonstrable order among values (e.g. from "SD" to "SA"). However, it cannot be presumed an equal interval exists between those values (see Conover, 1999; Cohen, Manion & Morrison, 2011; and Jamieson, 2004 for relevant literature). Fisher's exact tests were used to compare the response frequency for each of the items in section 2 of the survey regarding the specific causes of climate change (e.g. people driving cars and nuclear power) provided by PR and FL secondary science teachers, and the frequencies of the general US public's responses to the same items as reported in Bord et al. (1998).

We rated and scored each teacher's response to individual section 3 Likert items as one of three categories based on the extent that the response accurately reflected the validity and nature of climate change science. These categories and scores were "incorrect, 0 points" (responding SD/D to an accurate Likert item or A/SA to an

Table 1 Secondary science subjects taught by the Florida (FL) and Puerto Rico (PR) teachers and the percentage of teachers who instruct these subjects

Subjects	FL	PR
Agriculture science	0	2
Biology	55	46
Chemistry	20	15
Earth science	13	2
Marine science	18	0
Physics	9	10
Environmental science	21	5
General science	14	36
Not reported	4	3

Percentages exceed 100 % because a teacher may instruct multiple subjects

inaccurate Likert item), "ambiguous, 1 point" (responding U to a Likert item), and "correct, 2 points" (responding SD/D to an inaccurate Likert item or A/SA to an accurate Likert item). We then summed each teacher's scored responses with a maximum score of 22 indicating the most accurate views about the validity and nature of climate change science. A Mann-Whitney *U* test was then used to detect any difference between FL and PR secondary science teachers' summed scores. Frequency distributions were also calculated that show the percentage of FL and PR teachers' "incorrect," "ambiguous," and "correct" responses to individual Likert items in section 3. Fisher's exact tests and frequencies were also calculated to compare the extent that the FL and PR teachers addressed each of the climate change topics (e.g. the carbon cycle, sea level changes) in section 5 of the survey.

Limitations of the Study

The teachers investigated here were a small sample of convenience and may not be representative of all secondary science teachers in FL and PR. Given the importance placed on climate change education among the science education community, the teachers may have embellished their self-reported climate change content coverage. Furthermore, teachers who teach climate change but were uncomfortable with their climate change science knowledge may have opted out from completing the voluntary survey used here. Therefore, estimates of the teachers' climate change science knowledge reported here may be higher than that of the FL or PR population of secondary science teachers who teach climate change. Lastly, the full extent of teachers' climate change knowledge and content coverage cannot be assessed utilizing Likert response items. Therefore, the results reported below should provide a basis for more sophisticated inquiries (e.g. qualitative and mixed-methods approaches) that more holistically describe secondary science teachers' climate change science understanding and teaching practices.

Results

Teachers' Perceptions of Climate Change

The FL and PR secondary science teachers' definitions of climate change demonstrated various levels of accuracy (Fig. 1). We rated only 14 % of FL and 4 % of PR secondary science teachers' definitions of climate change as "correct." Characteristic of these responses was an emphasis of a long-term change in the variability of average weather conditions. For instance, one FL teacher responded:

> Climate change can be thought of as the natural process in which average temperature and precipitation change over time. However, due to an influx of anthropogenic greenhouse gases from burning fossil fuels we have increased the rate of global warming. As we have increased this rate, large areas of once permanently frozen tundra have started to thaw thus adding methane, another greenhouse gas, to the atmosphere at an alarming rate.

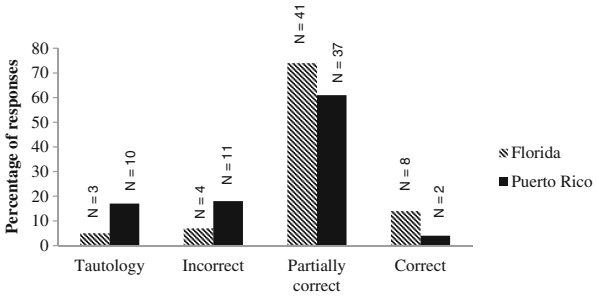

Fig. 1 Distribution of the accuracy of Florida (FL) and Puerto Rico (PR) secondary science teachers' climate change definitions

The majority of the FL (74 %) and PR (61 %) secondary science teachers provided partially correct definitions of climate change. Partially correct responses were those that indicated some (e.g. describing temperature or time), but not all, of the defining aspects of climate change, as was the case with one PR teacher's response:

> A change in the global temperatures due to an increase in greenhouse gases in the atmosphere.

Similarly, the following response provided by a FL secondary science teacher is an example of how many teachers neglected to include the many average weather factors or the length of time, or both, that should be included in an accurate depiction of climate change.

> Global variations in temperature and precipitation due to natural fluctuations in the earth's rotation combined with human activity.

The remaining FL and PR science teachers' climate change definitions were tautological (5 and 17 %, respectively) or incorrect (7 and 18 %, respectively) including one FL science teacher's response indicating anthropogenic climate change is a farce. Examples of tautological and incorrect responses include

> Climate change is a change in the average climate of a given area.

> Positive and negative effects that alter what we call nature.

Teachers' Views of the Causes of Climate Change

FL and PR secondary science teachers that claim to deeply teach climate change topics hold many of the same naïve views about the causes of climate change that are pervasive among the US public (Bord et al., 1998). Table 2 shows how FL and PR secondary science teachers' and the US public's perceptions compare regarding their responses to each of the nine possible causes of climate change. General trends portrayed in Table 2 include

Table 2 Comparison of Florida (FL) and Puerto Rico (PR) secondary science teachers' and the US public's (Bord et al., 1998) perceptions of the causes of climate change. Frequencies from 1998 do not add to 100 % as they exclude non-responses

Item	US public			FL			PR			Significance of differences (Fisher's exact tests)
	Not a cause	Minor/ secondary cause	Major/ primary cause	Not a cause	Minor/ secondary cause	Major/ primary cause	Not a cause	Minor/ secondary cause	Major/ primary cause	
Emissions from business/ industry	4	25	69	2	24	74	0	15	85	US=FL (p=0.81) *US≠PR (p= 0.04)* FL=PR (p=0.30)
Destruction of tropical forests	9	25	64	6	23	71	0	19	81	US=FL (p=0.62) *US≠PR (p= 0.002)* FL=PR (p<0. 09)
People driving their cars	7	41	49	2	31	67	0	36	64	*US≠FL (p= 0.03)* *US≠PR (p< 0.02)* FL=PR (p=0.62)
Use of coal and oil by utilities	10	42	44	4	9	87	2	21	77	*US≠FL (p< 0.001)* *US≠PR (p< 0.001)* FL=PR (p=0.17)
People heating and cooling their homes	31	54	13	7	57	36	12	65	23	*US≠FL (p< 0.001)* *US≠PR (p< 0.001)* FL=PR (p=0.30)
Depletion of ozone—upper atmosphere	10	25	63	23	32	45	3	24	73	*US≠FL (p= 0.003)* US=PR (p=0.19) *FL≠PR (p< 0.001)*
Use of chemicals for insect pests	20	50	27	29	54	17	3	45	52	US=FL (p=0.22,) *US≠PR (p< 0.001)* *PR≠FL (p< 0.001)*
Use of aerosol spray cans	14	58	25	27	55	18	4	50	46	US=FL (p<0.10) *US≠PR (p< 0.001)*

Table 2 (continued)

Item	US public			FL			PR			Significance of differences (Fisher's exact tests)
	Not a cause	Minor/ secondary cause	Major/ primary cause	Not a cause	Minor/ secondary cause	Major/ primary cause	Not a cause	Minor/ secondary cause	Major/ primary cause	
										PR≠FL ($p < 0.001$)
Nuclear power generation	36	40	21	59	29	12	12	44	44	*US≠FL ($p = 0.007$)* *US≠PR ($p < 0.001$)* *PR≠FL ($p < 0.001$)*

1. Thirteen to ninety-seven percent of the secondary science teachers' responses regarding the causes of climate change were largely inaccurate. The proportion of inaccurate responses provided by the US public (Bord et al., 1998) fell within this range.
2. The majority of FL teachers and the US public responded similarly regarding the extent business/industry emissions, tropical forest destruction, and insecticides and aerosols caused climate change. Similar to the US public, a large proportion of FL and PR teachers inaccurately identified ozone layer depletion as a primary climate change cause.
3. The majority of FL and PR teachers accurately and similarly identified business/industry emissions, tropical forest destruction, driving cars, and use of coal and oil by utilities were primary causes of climate change. However, the majority of all teachers inaccurately thought the heating and cooling of homes was not a primary cause of climate change.
4. In comparison to the US public and FL teachers, PR teachers provided the highest proportion of inaccurate responses claiming that ozone depletion, insecticides, aerosols, and nuclear power generation were notable climate change causes, yet the highest proportion of accurate responses stating business emissions and tropical forest destruction were primary drivers for climate change.

In this section, we present detailed results that compare how FL and PR secondary science teachers and the US public view each of the nine causes of climate change. The first five items in Table 2 are primary causes of climate change; however, between 13 and 77 % of the responses from FL and PR secondary science teachers wrongly claimed these were not causes or were minor/secondary causes of climate change. Fisher exact tests revealed the responses between the two groups were statistically similar distributions. Only 36 % of FL teachers and 23 % of PR teachers accurately selected heating and cooling homes as a major contributor to climate change. In comparison to the general US public, a significantly greater proportion of the PR and FL teachers accurately identified that people driving cars, heating and cooling residences, and use of coal and oil by utilities were primary causes of climate change. However, only the PR teachers provided significantly more accurate responses than the general US public when 81 and 85 % of the PR teachers, respectively, indicated that the destruction of tropical forests and emissions from business and industry were primary climate change causes.

The last four items in Table 2 portray phenomena or actions that are intangibly linked to climate change (Bord et al., 1998). A significantly greater proportion of PR science teachers (between 44 and 52 %) wrongly indicated that insecticides, aerosols, and nuclear power generation were primary causes of climate change than FL science teachers (between 12 and 18 %) and the general US public (between 21 and 27 %). Notably, the distribution of FL science teachers' responses regarding the extent insecticides and aerosols contributed to climate change was not significantly different than that provided by the US public. However, only 14 to 29 % of the respondents from both groups correctly indicated that insecticides and aerosols are not considered climate change causes, and approximately half wrongly thought these were minor or secondary climate change causes. PR teachers responded similarly to the US public regarding the

extent that climate change is caused by ozone layer depletion, with 73 % of these teachers indicating this was a primary cause. Comparatively, FL science teachers provided a significantly greater proportion of correct responses regarding the extent ozone layer depletion causes climate change. However, almost half of the FL teachers erroneously believed ozone depletion is a major contributor to climate change.

Teachers' Perceptions of the Nature and Validity of Climate Change Science

A Mann-Whitney *U* test showed significant differences exist between FL and PR teachers' summative scores measuring their perceptions about the nature and validity of climate change science and its methodologies ($Z=-2.51$, $p=.01$). Effect size calculations show a moderate difference between these two groups, with FL teachers achieving slightly higher scores ($r=0.23$, PR median score=18, FL median score=20). Table 3 shows 13 to 77 % of all the teachers' responses to all items regarding the validity of climate change science were either ambiguous or inaccurate, with approximately half of the FL and 69 % of the PR science teachers wrongly agreeing that climate change science needs to be based on controlled experiments to achieve validity. Twenty-one percent of the FL science teachers and 46 % of the PR science teachers were unsure if or wrongly agreed that climate change is not a valid science idea because most of the knowledge is based on modeling. Furthermore, approximately one seventh

Table 3 Percentages of Florida (FL) and Puerto Rico (PR) secondary science teachers' perceptions of climate change science

	Incorrect		Ambiguous		Correct	
	FL	PR	FL	PR	FL	PR
Climate change is incapable of being scientifically tested and validated. (D/SD)	4	12	9	3	87	85
The data for climate change are ambiguous as to whether it actually occurs. (D/SD)	16	17	4	10	80	73
Most scientists accept that climate change is occurring. (A/SA)	5	14	13	2	82	84
Scientists' understanding of climate change is based on speculation and not valid scientific accounts. (D/SD)	5	7	11	7	84	86
A significant body of data supports climate change. (A/SA)	14	12	9	2	77	86
Climate change science methods are too unsure to be trusted. (D/SD)	7	11	11	10	82	79
Climate change is not a scientifically valid idea. (D/SD)	2	9	11	5	87	86
Current knowledge about climate change is the result of sound scientific research and methodology. (A/SA)	9	18	14	0	77	82
Climate change science generates testable predictions with respect to the characteristics of the earth's climate. (A/SA)	4	11	18	2	78	87
In order to be valid, climate change science needs to be based on controlled experiments. (D/SD)	50	69	18	9	32	22
Because most of the knowledge of climate change is based on modeling, it is not a valid science idea. (D/SD)	9	30	12	16	79	54

Correct selection appears in parentheses after each statement (A/SA=agree/strongly agree; D/SD=disagree/strongly disagree)

to one fourth of all the surveyed teachers were unsure if or wrongly agreed that the data for climate change's occurrence are ambiguous, scientists' understanding of climate change is speculative and not based on valid scientific accounts, and climate change science methods are too unsure to be trusted. A similar proportion were unsure if or wrongly disagreed that most scientists accept climate change's occurrence, significant data supports climate change, sound scientific research has produced current climate change knowledge, and climate change science generates testable predictions about the earth's climate.

Teachers' Climate Change Content Coverage

FL and PR secondary science teachers provide similarly sporadic coverage of climate change-related topics (Fig. 2). Fisher's exact tests of the responses provided for the 11 topics showed a significant difference exists only between FL and PR science teachers' claimed content coverage about the disruption of the carbon cycle (p=.002). Only 48 % of the FL teachers and 19 % of PR teachers indicated they extensively teach about carbon cycle disruption. Furthermore, 44 % of the PR teachers and 19 % of the FL teachers responded they provide little to no instruction about this important climate change topic. There were no significant differences between FL and PR science teachers' coverage of the remaining climate change topics presented in Fig. 2 (p>.05).

FL and PR secondary science teachers' climate change content coverage focused primarily on climate change impacts on ocean and sea levels, water resources, local weather patterns, species' adaptations, and biodiversity. Thirty-four to 58 % of the teachers extensively instructed and 6 to 24 % provided little to no instruction about these topics. Approximately one fourth to one third of the teachers claimed to explicitly

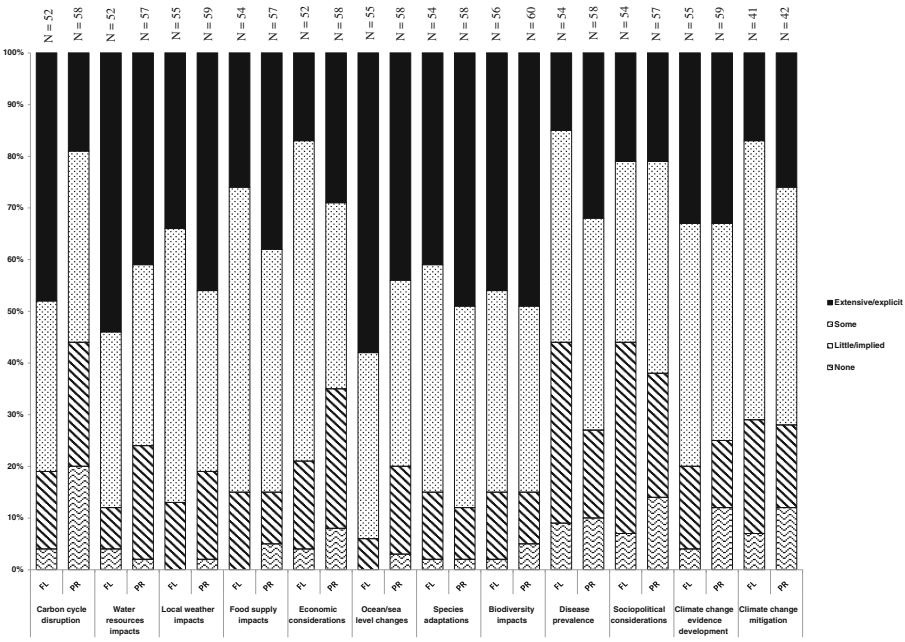

Fig. 2 Percentage of Florida (*FL*) and Puerto Rico (*PR*) science teachers who teach specific climate change topics

and extensively address the impacts of climate change on food supplies and how climate change evidence is developed.

Less than one fourth of the teachers in one or both groups reported extensively teaching about climate change mitigation and related social, political, and economic considerations. The remaining teachers in both groups responded they provide some (35 to 62 %) or little to no (21 to 44 %) instruction about these topics. It is important to note that these results are from the teachers who reported that they teach climate change science either as distinct lessons, a curriculum unit, or as a course theme.

Discussion

The undeniable realities of climate change persist as human activity continues to release heat-trapping greenhouse gases. If the rate of change of the climate is to be reduced, people need to change their actions. However, studies of the general public and teachers suggest that erroneous conceptions persist among these groups about climate change causes and climate change science methodologies. Clearly, this suggests that much still needs to be done to better educate the public. One way to do this is through formal K-12 education. There has been little published about the details of inservice science teachers' knowledge and teaching of climate change science. In addition, we found no international comparisons of science teachers in this area. Therefore, we sought to determine and compare FL and PR secondary science teachers' conceptions about climate change science and to compare their conceptions with those of the general US public. We also sought to determine and compare FL and PR secondary science teachers' climate change content coverage. We discuss each of these below and address how teachers' conceptions of climate change science may impact their teaching of this topic.

Defining Climate Change

If K-12 education is to have a positive effect on the public's understanding of climate change science and the actions that they are willing to take to help mitigate its causes, then teachers need to have the requisite climate change science knowledge and effectively transfer it through their lessons. We found only small percentages of the teachers that we surveyed, those who indicated that they deliberately teach about climate change either as individual lessons, curriculum units, or a theme for their courses and gave correct definitions of climate change—changes in the average weather and over an extended time period. A much larger percent of both groups had partially correct answers consisting of components of the definition. While this is troubling, it may be an artifact of the way that we worded the item, or a tendency to limit one's writing on a survey. Clearly, this warrants further investigation.

Although a larger percentage of FL teachers than PR teachers provided fully correct definitions of climate change, the numbers in each group were quite low—only eight FL teachers and two PR teachers. We believe that this may in part be due to the complexity of climate change, which includes two variables—changes in weather and time. The large numbers of teachers with partially correct definitions in both groups add support to this assertion. The vast majority of teachers wrote that climate change was

related to changes in weather but did not note that the changes needed to be evident over an extended period of time, or vice versa. Interestingly, this is what Millan-Otoya found in his study of middle school students who were taught a unit on sea level rise (Millan-Otoya, 2015).

Causes of Climate Change

As we noted in the "Results" section, large percentages of both the FL and PR teachers in our study correctly identified four out of five survey items as major causes of climate change. However, nearly all the PR teachers and over 70 % of the FL teachers indicated that the depletion of the ozone level, the use of pesticides, and the use of aerosol cans contributed at least in a minor or secondary way to changes in the climate. It is important to note that these results are similar to those of almost every study done on people's beliefs about the causes of climate change.

While the beliefs above are common misconceptions held by most of the teachers that we surveyed, significantly more of the PR teachers responded in this way than did the FL teachers. This difference suggests that FL teachers have more knowledge of climate change science than do the PR teachers whom we surveyed. We believe that this can be accounted for in part by a difference in the two samples. Table 1 shows the subjects taught by the teachers. A simple calculation shows that general science was 9 % of the courses taught by the FL teachers and 30 % of those taught by the PR teachers. Although we do not have information about where and how the teachers obtained their certification, most states and PR require a distribution of introductory-level science courses for general science certification, while requiring a concentration in the content specialization with advanced courses for those certified in subjects such as biology, chemistry, and physics.

We also find it interesting that nearly 90 % of the PR teachers also indicated that the use of nuclear energy contributes to climate change. This is in comparison with a significantly lower percent (41 %) of FL teachers who believe that it at least partially contributes to climate change. No obvious reasons exist for this difference unless one considers that the last operational nuclear power plant in PR was decommissioned in 2007, while FL continues to have two in operation. Regardless, it is important to understand why many of the PR teachers hold these misconceptions, as well as the impact that this has on their students.

In addition, we found that only a small percentage of the teachers in FL and PR indicated that the heating and cooling of their homes is a major contributor to climate change, although a large percentage of both groups see it being at least a minor or secondary cause (FL=93 %, PR=88 %). This suggests that they might not be aware of the total amount of energy that is used for these purposes. It would be interesting to compare these figures with teachers who live in colder climates in which fossil fuels are used directly to heat homes in the winter.

Nature of Climate Change Science

We found that while FL teachers' views about the nature of climate change science were modestly more accurate than those demonstrated by PR teachers, both groups held common misconceptions that would impede their ability to teach students about

how scientists reliably account for climate change. The majority of the teachers investigated here indicated scientists' understanding of climate change is based on valid scientific accounts as a result of sound research and methodology and indicated implementing some to extensive instruction about how climate change evidence is developed. However, most teachers also agreed that climate change science must be based on controlled experiments to ensure validity. Thus, we infer that the teachers profiled here largely believe that the scientific body of knowledge about climate change, while valid, was primarily developed through scientists' controlled experiments.

A look at Table 3 shows that the largest difference between FL and PR teachers was the percent correct on the item related to the use of models. We believe that this could also be due to a difference in content knowledge or possibly in what the NGSS refers to as science practices (NGSS Lead States, 2013), between the two groups. Again, this may be accounted for by the difference in the subject matter knowledge of those teachers certified in general science and those in specific science disciplines.

In any case, while FL and PR teachers in this investigation may, like many teachers (e.g. Sullivan et al., 2014), rely heavily on teaching nature of science (NOS) to confront misinformation and controversy regarding climate change, our findings indicate that their nature of climate change science instruction may actually be *setting students up* to doubt the validity of climate change science when they later encounter claims, often dispensed by climate change naysayers, that knowledge about climate change is speculative because it cannot be verified via prescribed experimental method (Rudolph, 2007). Their understanding of NOS which coincidentally reflects the introductory units of most science textbooks that emphasize the controlled experiment as the optimal way to do *good science* may not only permeate teachers' climate change science portrayals but also be reinforced through cookbook labs and factual memorization that imply scientific investigations result in definitive and proven knowledge. Unfortunately, these views about science have been associated with lower levels of willingness by secondary students to mitigate global warming and climate change (Herman, 2015).

Climate Change Content Coverage

The FL and PR teachers investigated here reported that they teach only a subset of climate change-related topics, all of which are related in some ways to those topics usually taught in earth science, such as sea level, weather and climate, and water resources, or as part of a focus on ecology in biology. The majority of the teachers in both groups do not provide explicit and extensive focus on subjects tangential to their specialized scientific discipline such as the social or political aspects of climate change. The lack of focus on these topics in secondary curricula may prevent students from connecting climate change to their everyday lives and that of others' and in engaging in well-reasoned climate change-mitigating decisions.

The largest difference between FL and PR science teachers was in the teaching of the carbon cycle. We believe that this may also be accounted for by the differences in the courses taught by the teachers. The carbon cycle is usually taught as part of biology or other life science courses at the high school level. This is evident in the NGSS in

which the carbon cycle is only found in one standard, HS-LS2-5 Ecosystems, Interactions, Energy and Dynamics (NGSS Lead States, 2013), which is high school life science.

Overall, we believe that for the most part the differences that we saw between the FL and PR teachers whom we surveyed may be understood as differences in science content knowledge due to differences in the samples. This suggests that science teachers in both regions might be similar in their knowledge and teaching of climate change science. It also suggests that in order to be able to adequately teach climate change science, teachers need to have more in-depth science content knowledge than what is found in traditional university courses. This is supported by literature that indicates science teachers generally feel their science content coursework insufficiently prepared them to instruct about climate change (Wise, 2010). This is in part due to post-secondary science content courses being taught from a traditional approach and teachers specializing in core disciplines (e.g. biology, chemistry, or physics) or, as in the case of general science teachers, introductory courses, with little connection to other scientific fields or even NOS. Consequently, teachers leave preparation lacking the cross-disciplinary knowledge required to effectively teach about climate change and instead draw from the public media sources (e.g. the Internet, television, magazines, and newspapers) that superficially or inaccurately portray climate change science (Choi, Niyogi, Shepardson & Charusombat, 2010; Hestness, McDonald, Breslyn, McGinnis & Mouza, 2014; Sullivan et al., 2014).

It may be that when science teachers draw from public media sources, it may cause them to believe that they are more deeply informed about climate change science than they actually are (Herman, 2013). In the literature review, we described how Monroe et al. (2011) showed a large proportion of secondary science teachers from the same region as this study self-reported having at least a moderate understanding of climate change and being somewhat to very comfortable teaching this subject. Taken in context with our investigation, while teachers may feel competent and claim to teach about climate change, they hold a plethora of misconceptions regarding this issue. Perhaps many science teachers, as Dunning, Johnson, Ehrlinger and Kruger (2003) would describe, are "unskilled and unaware" regarding their climate change science knowledge and pedagogy and are unknowingly embellishing their understanding and competence to teach about this important subject. Overestimations of occupational knowledge and proficiency have been empirically shown to exist among various professionals including medical doctors (Hodges, Regehr & Martin, 2001), and similar investigations may be needed in science education in order to promote accurate self-assessment and metacognition among science teachers.

Implications

The findings from this and other studies hold many implications for science teaching and science teacher education. People need to be taught and understand the content, practices, and nature of climate change science, including the pertinent economic, social, and moral considerations, to be convinced that they need to actively support climate change mitigation. If K-12 teachers are to help make that happen, then these topics must also be an explicit focus of both pre- and inservice science teacher

education. Our findings suggest that many science teachers may not have sufficient knowledge of these aspects of climate change science to be able to enable their students to effectively engage climate change and its impacts.

While our findings suggest that teachers lack knowledge, we do not believe that they ought to be required to take more traditional university-level science courses. Rather, we advocate that science teacher preparation programs require multi-disciplinary science courses devoted to climate change that are taught utilizing research-based pedagogical approaches. Importantly, these courses should address both the scientific concepts underpinning climate change and the nature of climate change science and the historical, political, and social dimensions associated with climate change. These courses would prepare preservice and inservice teachers, so that they can incorporate the nature of science, as well as social, economic, and political dimensions, into climate change instruction in a manner that elicits cognitive and emotive responses that favor climate change understanding and engagement (see: Herman, 2015; Lombardi & Sinatra, 2013; Lombardi, Sinatra & Nussbaum, 2013; and Teed & Franco, 2014). This could be done, for example, with science methods courses that focus on authentic local climate change issues as a context for modeling research-based practices such as inquiry, questioning, and argumentation that they could use in their teaching. This would facilitate their students using evidence-based reasoning to consider possible climate change-mitigating solutions from socioscientific perspectives. Such teaching approaches reflect the democratically motivated visions of science education of promoting civics and environmental stewardship needed for engaging complex scientific issues such as climate change (Hodson, 2009).

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