A STUDY OF K-12 TEACHERS' CLIMATE CHANGE KNOWLEDGE IN THE UNITED STATES

Chong Shimray*

Department of Education in Science and Mathematics
NCERT, New Delhi

Climate change education is increasingly getting streamlined in the schools in the United States. However, studies have shown that teachers are yet to develop a basic understanding about climate change science. At the same time, as climate change continues to be a controversial issue in the United States and political parties are divided on their opinion about the issue and the solutions they propose, it impacts teachers and consequently their knowledge, beliefs and teaching practices. This paper presents the findings of an online survey conducted among teachers in the United States about their climate change knowledge and the factors such as teaching experience in K-12, grade level they teach, subject they primarily teach, educational degree, attendance of professional development on climate change and whether they teach climate change that can influence the same.

Keywords: Climate Change Education, United States, Teachers, Knowledge, Teacher Characteristics

Introduction

Human-induced climate change is a transnational issue which concerns every nation. It began to receive worldwide attention since Greenpeace came out with its report on the issue in 1989 which was soon followed by the first Intergovernmental Panel on Climate Change (IPCC) report in 1990 (Chang, 2015). Since then, the discourses on climate change have escalated in every sphere—politics, economics or education. Following this trend, the number of articles on global warming has also been found to be increasing (Kidman and Papadimitriou, 2012). At the same time, climate change education has become increasingly important in many countries given the increased focus on the need to respond to changing climate (Chang, 2013). Nations also realised the need to come together to tackle this issue of global warming and it did by way of taking collective responsibility through major international treaties such as the Kyoto protocol in 1997 that commits parties (countries that are part of the treaty) to reduce greenhouse gas emissions and more recently in 2015, by adopting the Paris agreement. This agreement aims to restrict increase in the average global temperature by 2 degrees celsius from the pre-industrial level and if possible, restrict increase by 1.5 degrees celsius which surely is an ambitious target but is achievable if countries take stringent measures to tackle global warming by drastically reducing greenhouse gas emissions.

However, it is also universally accepted that climate change is a complex topic with many uncertainties associated with it (Dillon, 2016). This is indicated by the use of the terms such as medium confidence, high confidence, very high confidence, likely, very likely, more likely than not, very unlikely, much evidence and so on to refer to the impacts associated with climate change in IPCC annual reports such as AR4 (IPCC 2008) and AR5 (IPCC 2015), indicating its uncertainties which negatively impacts its implementation in education as it is in taking positive political decision. Chang (2014), terms such complexities associated with climate change as 'epistemological constraints.' Because of the uncertainties associated with climate change science, we have the politics and economics related to climate change driven in different directions with ulterior motives leading to several forms of controversies.

Environmental education has been an integral part of the school curriculum since several decades in the U.S. In fact, climate change education has also begun to receive special focus in the U.S. For example, The Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas prepared by the National Academy of Sciences (NAS) highlights the importance of incorporating global climate change in the curriculum throughout K-12 (NAS 2012). In line with this, the Next Generation Science Standards (NGSS) which was prepared by the collective efforts of partners consisting of members from twenty six states and their broad-based teams with a 40-member writing team and others incorporated climate change related education as part of the middle school and high school curriculum (NGSS Partners 2013). This indicates that the focus is, in effect, shifting towards a concrete climate change education from a more general approach of environmental education. However, inspite of these developments, it is found that teachers are yet to develop a basic understanding about climate change science as found by Plutzer *et al*. (2016), among U.S. teachers and also by Liu *et al*. (2015), in a study among Native American teachers in the U.S. Other studies related to climate change knowledge have been reported by researchers such as Miler *et al*. (2012), on teachers' understanding of climate change with questions focused on how thee climate system works in Czech Republic; Ratinen (2013), pertaining to the concept of greenhouse effect among student-teachers in Finland; Sousa *et al*. (2019), on teachers' understanding about the interconnectedness of soil and climate change in South Africa; Anyanwu and Grange (2017), on climate change knowledge amongst geography teachers in South Africa. Invariably, studies have pointed out the lack of appropriate knowledge about climate change and the processes amongst teachers.

Interesting events have unfolded in the U.S. related to environmental education since the past few years. Efforts have been put forward since 2008 to push the No Child Left Inside Act, the intent of which was to amend the Elementary and Secondary Education Act (formerly, No Child Left Behind) to provide grant funding to states for implementation of a statewide plan for environmental literacy (NAAEE website). More recently in December 2015, the reauthorised Elementary and Secondary Education Act (now, the Every Student Succeeds Act) was passed with key language in support of environmental education, such as— Environmental education and environmental literacy programmes

are eligible for funding under different programmes (U.S. Department of Education website). Besides, the prioritisation of STEM activities including 'hands-on learning' and 'field-based or service learning' to enhance understanding of STEM as a result of this new education law is likely to provide additional opportunities for environmental science education programs. It is to be seen how far this development will contribute toward climate change education. Targeted efforts are also being made regarding climate education by environmentalists, environmental educators and people's representatives as they have succeeded to introduce the Climate Change Education Act in the House of Representatives in 2015. The main objective of this Act is to establish climate change education program (GovTrack.us website). In addition, climate change continues to be a controversial issue and political parties are largely divided on their opinion about the issue itself and also about the solutions proposed to tackle it. Wise (2010) found in a study that teachers acknowledge the existence of public controversy as one strategy in teaching about climate change.

Keeping in view the developments that have taken place in the U.S. with regard to climate change education and with U.S. being one of the highest emitters of greenhouse gas (to the tune of 14.44 t CO2 per capita emission) (IEA, n.d.), this study attempts to find out teachers' knowledge about climate change in the U.S. so as to understand their preparedness. This is because, for a teacher to be able to teach climate change related topics effectively, it is imperative to have a basic knowledge about climate science i.e., climate literate teachers (Miler *et al*., 2012). In addition there are various factors that influence effective teaching. Anyanwu and Grange (2017), through their survey involving 194 high school geography teachers in the Western Cape Province, South Africa, found that teacher characteristics could have an important influence on climate change science literacy, such as gender, age, qualification, specialisation, teaching experience, teaching grade. Hence this study has been undertaken with the following objectives:

Objectives

(i) To study U.S. teachers' knowledge about climate change

(ii) To find out the association between U.S. teachers' knowledge about climate change and teacher characteristics such as teaching experience in K-12, grade level they teach, subject they primarily teach, educational degree, attendance of professional development on climate change, and whether they teach climate change

Methodology

A quantitative survey method was used to collect data from teachers. For recruitment of participants a convenient sampling method was followed. The participants consisted of teachers teaching K-12 in any discipline. A link was generated for the survey on Qualtrics Survey platform and sent through different sources such as:

(i) Emailing list of teachers in different schools in selected Cooperative Educational Service Agency (CESA) in Wisconsin compiled by Wisconsin Center for Environmental Education (WCEE). This list included the

complete list of teachers of the schools irrespective of the subjects they were teaching.

(ii) Victoria Rydberg sent out to her emailing list consisting of teachers.

(iii) Email sent out to Wisconsin Society of Science Teachers (WSST) listserv which would take them to the WSST website leading to the online survey link.

(iv) Email was sent out to the National Science Teaching Association (NSTA) biology teachers emailing list which contained the survey link.

Analysis of data — A descriptive statistics were applied to analyse the quantitative data such as distribution oof the scores, etc., using SPSS.

Tool

The online survey had questions on participants' information, knowledge and opinion about climate change. However, in this paper, questions pertaining to information about the participating teachers and questions on climate change knowledge which includes questions on climate change science, causes and impacts as considered by Stevenson *et al*. (2016), are analysed. The questions can be categorised as:

The items for the tool were prepared keeping in view the following parameters or criteria:

(i) Information about participants: This included seven questions (Q1 to Q7) pertaining to information about the participants on the following variables: state they currently teach, their teaching experience, the level they currently teach, the primary subject they teach, their highest educational degree, whether they have attended any professional development and whether they teach climate change. The questions included the following:

Q1. In which state do you teach? (State)

Q2. How many years have you taught in K-12 to date? (Teaching experience in K-12)

Q3. At what level do you currently teach? (Grade level they teach)

Q4. What subject do you primarily teach? Choose the best answer. (Subject primarily teaching) (Subject primarily teaching was further grouped into two such as 'Science' (the subject science alone) and 'Others' all other subjects except science)

Q5. What is your highest educational degree? (Highest educational degree)

Q6. Have you attended any professional development course of any duration on climate change? (Attended professional development on climate change)

Q7. Do you teach topics related to climate change? (Teach climate change)

For convenience of presentation and discussion, the questions have been reframed into few words which are provided within parenthesis along with the questions. These will be uniformly and consistently used throughout this document.

(ii) Participants' knowledge about climate change: It consists of seventeen questions in the form of statements (Q8 to Q24) that are considered basic and fundamental to understanding climate change as provided below:

Q8. Greenhouse gases in the atmosphere trap the ultraviolet rays reflected from the earth thus, causing global warming.

Q9. Water vapour is a potential greenhouse gas but is not considered seriously because of its short life cycle in the atmosphere.

Q10. Methane has more heat-trapping ability per molecule than carbon dioxide.

Q11. Greenhouse gases are essential to sustain life on earth.

Q12. Chlorofluorocarbon is an ozone layer destructor and also a greenhouse gas.

Q13. The reradiated solar radiation has a shorter wavelength than the incoming solar radiation.

Q14. Increase in greenhouse gases in the atmosphere enhances melting of permafrost, releasing additional carbon dioxide and methane into the atmosphere.

Q15. Albedo effect is a measure of the reflectivity of a surface such as snow, rooftops, buildings, etc.

Q16. Seawater becomes more basic due to the absorption of carbon dioxide.

Q17. Earth's ocean has been able to absorb and hold a majority of the heat from Earth's atmosphere due to its high heat capacity.

Q18. El Nino is a phenomenon caused by global warming.

Q19. Melting sea ice has the potential to raise sea level by several feet.

Q20. Reflectivity of ice caps and ice sheets are reduced due to algae formation thereby, increasing the atmospheric temperature.

Q21. Thermohaline circulation refers to deep-ocean currents driven by differences in the water's density, which is controlled by temperature and salinity.

Q22. Changes in plate tectonics, changes in earth's orbit and changes in the sun's strength are the natural causes of climate change.

Q23. Thermal expansion of sea water along with glacier melting causes sea level rise.

Q24. Oceans are important carbon sinks.

For the knowledge-based questions, the participants had three options to choose from—'Yes', 'No' and 'Not Sure'. The participants had the choice to skip any of the questions. The tool was tested among a select group of educators and practitioners for its internal consistency and validity, and necessary changes made accordingly.

The online survey had consent letter with it. Standard protocol of the University of Wisconsin-Stevens Point, United States was followed to obtain approval from the Institutional Review Board of the University to administer the above-mentioned research tool.

Results

The result of the online survey conducted for K-12 teachers is discussed below.

1. Information about participants

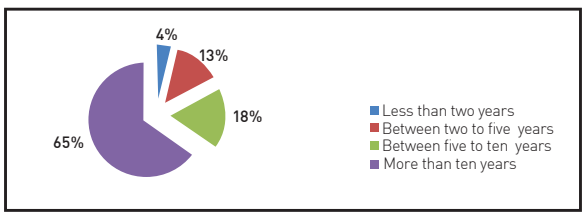
A total of 362 responses from 35 states were recorded, of which majority, i.e., 265 (73.2%) were from Wisconsin, 24 from Minnesota, 8 from New Hampshire, 7 from New York and 5 or less responses were recorded from rest

of the 31 states grouped as others (Table 1). Regarding the teaching experience K-12, of the 322 that responded, 210 (65.2%) had more than ten years of teaching experience (Fig. 1). Majority of the participants, i.e., 175 were high school teachers (Fig. 2). With regard to subject primarily teaching, of the 253 that responded, 122 (48.2%) were science teachers while those teaching other subjects were comparatively very low (Fig. 3). In terms of highest educational degree, out of the 321, more than half i.e., 187 (58.3%) have master's degree and 10 (3.1%) possess doctoral degree (Fig. 4). In response to attended professional development on climate change, of the 322 teachers that responded to this question, only 80 (24.8%) responded in the affirmative (Fig. 5). Regarding teach climate change, out of the 322 teachers that responded this question, 180 (55.9%) responded positively, while 142 (44.1%) responded in the negative (Fig. 6).

Table 1: Number of Participants from Different States

Sl. No.	States	No. of participants	Percentage
1	Minnesota	24	6.6
2	New Hampshire	8	2.2
3	New York	7	1.9
4	Wisconsin	265	73.2
5	Others	58	16.0
	Total	362	100.0

Fig. 1. Distribution of Respondents Based Teaching Experience in K-12



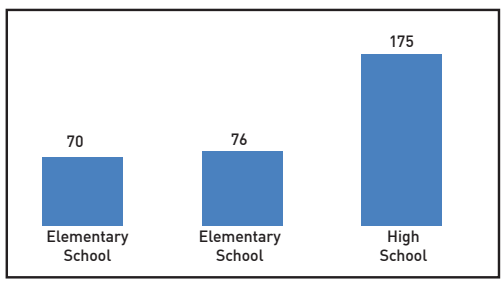


Fig. 2. Distribution of Respondents Based on Grade Level Teaching

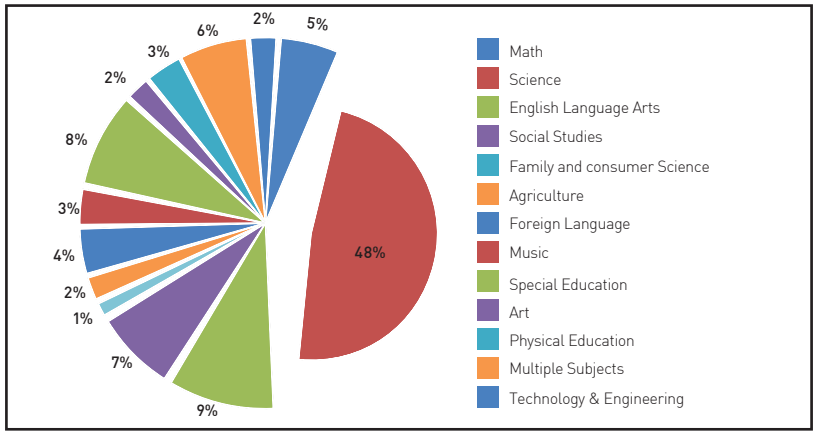


Fig. 3. Distribution of Respondents – Based on the Subject Primarily Teaching

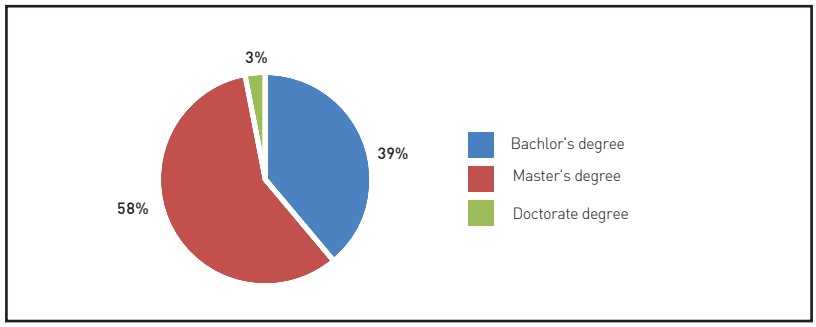


Fig. 4. Distribution of Respondents – Based on Highest Educational Degree

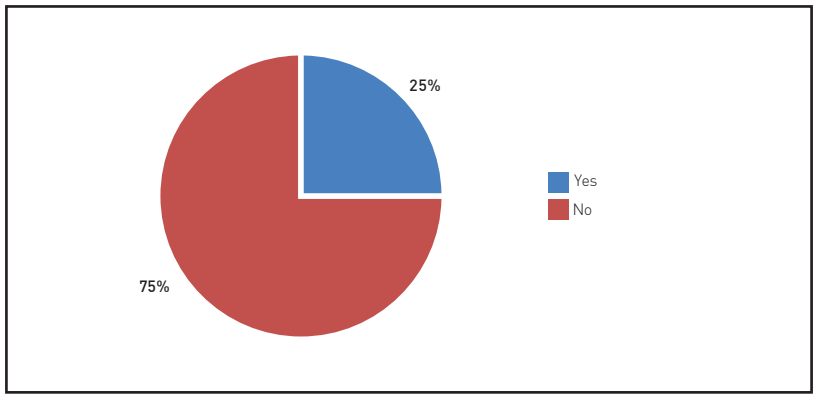


Fig. 5. Distribution of Respondents – Based on Attended Professional Development on Climate Change

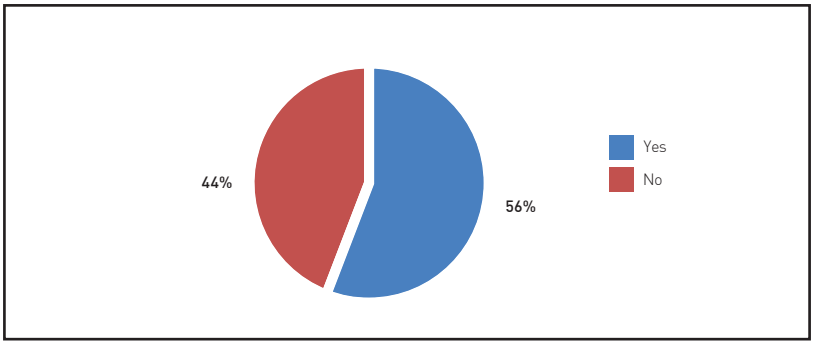


Fig. 6. Distribution of Respondents-based on Teach Climate Change

2. Participants' knowledge about climate change (17 questions: Q8 to Q24)

The results of the responses to the above mentioned knowledge-based questions are provided in Table 2 and fig. 7. The results revealed that a staggering majority of respondents, i.e., 240 (78.8%) and 259 (80.9%) gave incorrect answers to two questions, i.e., "Q8. Greenhouse gases in the atmosphere trap the ultraviolet rays reflected from the earth thus, causing global warming" and "Q19. Melting sea ice has the potential to raise sea level by several feet", respectively; also, a good number of respondents i.e., 88 (27.5%) also gave incorrect answer to the question "Q18. El Nino is a phenomenon caused by global warming" (Table 2). However, a huge chunk of respondents were found to answer correctly to some questions such as "Q24. Greenhouse gases are essential to sustain life on earth. (64%)", "Q14. Increase in greenhouse gases in the atmosphere enhances melting of permafrost releasing additional carbon dioxide and methane into the atmosphere. (70.9%)", and "Q23. Thermal expansion of sea water along with glacier melting causes sea level rise. (67.8%)" Another interesting finding was that more than half of the respondents chose "Not sure" for "Q13. The reradiated solar radiation has a shorter wavelength than the incoming solar radiation. (66.3%)" "Q20. Reflectivity of ice caps and ice sheets are reduced due to algae formation thereby increasing atmospheric temperature. (56.6%)" and "Q21. Thermohaline circulation refers to deep-ocean currents driven by differences in the water's density which is controlled by temperature and salinity. (55.6%)"

Table 2: Performance of Respondents on Knowledge Based Questions

Questions	Correct	Not sure	Incorrect	Total
Q8. Greenhouse gases in the atmosphere trap the ultraviolet rays reflected from the earth thus, causing global warming.	37 (11.5%)	44 (13.7%)	240 (78.8%)	321 (100%)
Q9. Water vapour is a potential Greenhouse gas but is not considered seriously because of its short life cycle in the atmosphere.	132 (41%)	130 (40.4%)	60 (18.6%)	322 (100%)

Q10. Methane has more heat-trapping ability per molecule than carbon dioxide.	184 (57%)	128 (39.6%)	11 (3.4%)	323 (100%)
Q11. Greenhouse gases are essential to sustain life on earth.	206 (64%)	91 (28.3%)	25 (7.8%)	322 (100%)
Q12. Chlorofluorocarbon is an ozone layer destructor and also a Greenhouse gas.	180 (55.9%)	110 (34.2%)	32 (9.9%)	322 (100%)
Q13. The reradiated solar radiation has a shorter wavelength than the incoming solar radiation.	45 (14.1%)	212 (66.3%)	63 (19.7%)	320 (100%)
Q14. Increase in Greenhouse gases in the atmosphere enhances melting of permafrost releasing additional carbon dioxide and methane into the atmosphere.	227 (70.9%)	85 (26.6%)	8 (2.5%)	320 (100%)
Q15. Albedo effect is a measure of the reflectivity of a surface such as snow, rooftops, buildings, etc.	147 (46.2%)	169 (53.1%)	2 (0.6%)	318 (100%)
Q16. Seawater becomes more basic due to absorption of carbon dioxide.	119 (37.3%)	156 (48.9%)	44 (13.8%)	319 (100%)
Q17. Earth's ocean has been able to absorb and hold a majority of the heat from Earth's atmosphere due to its high heat capacity.	164 (51.6%)	131 (41.2%)	23 (7.2%)	318 (100%)
Q18. El Nino is a phenomenon caused by global warming.	167 (51.6%)	67 (20.7%)	88 (27.5%)	322 (100%)
Q19. Melting sea ice has the potential to raise sea level by several feet.	32 (10%)	29 (9.1%)	259 (80.9%)	320 (100%)
Q20. Reflectivity of ice caps and ice sheets are reduced due to algae formation thereby, increasing atmospheric temperature.	87 (27.4%)	180 (56.6%)	51 (16%)	318 (100%)
Q21. Thermohaline circulation refers to deep-ocean currents driven by differences in the water's density which is controlled by temperature and salinity.	134 (42.5%)	175 (55.6%)	6 (1.9%)	315 (100%)
Q22. Changes in plate tectonics, changes in earth's orbit and changes in sun's strength are the natural causes of climate change.	138 (43.4%)	115 (36.2%)	65 (20.4%)	318 (100%)

Q23. Thermal expansion of sea water along with glacier melting causes sea level rise.	215 (67.8%)	86 (27.1%)	16 (5%)	317 (100%)
Q24. Oceans are important carbon sinks.	174 (54.5%)	139 (43.6%)	6 (1.9%)	319 (100%)

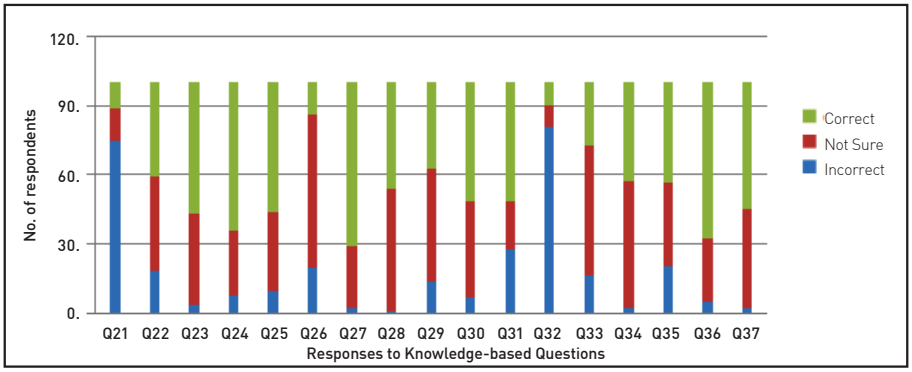


Fig. 7. Performance of Respondents on Knowledge – Based Questions

The responses were then given a score of -1 for an incorrect answer and 0 for not sure and 1 for those who respond correctly. The scores were then grouped into four such as Poor (-ve to 5), Fair (6 to 9), Satisfactory (10 to 14) and Good (15 to 17). The result revealed that a huge chunk of the respondents fall under the category 'Poor' with 199 (61.6%) while 81 (25.1%) under 'Fair', 39 (12.1%) under 'Satisfactory' while only 4 (1.2%) fall under the category 'Good' (Table 3 and Fig. 8).

Table 3: Knowledge Groups Based on Scores

Knowledge Groups	Frequency
Poor	199 (61.6%)
Fair	81 (25.1%)
Satisfactory	39 (12.1%)
Good	4 (1.2%)
Total	**323 (100%)**

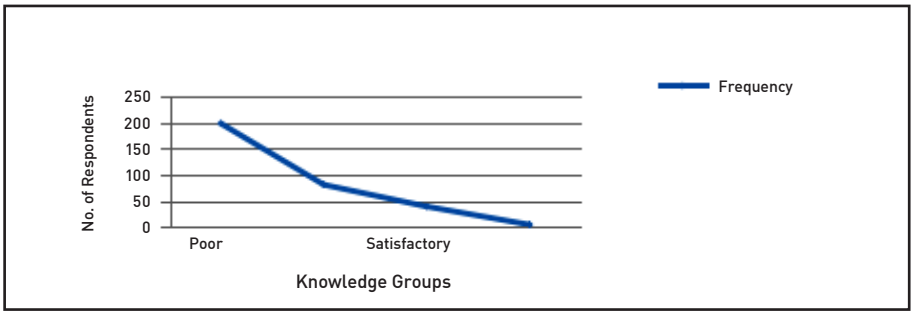


Fig. 8. Categorisation of Respondents Based on Groups

3. Association between knowledge groups and teacher characteristics

An attempt was made to find out the association between knowledge groups and teacher characteristics, such as teaching experience in K-12, grade-level teaching, subject primarily teaching, highest educational degree, attended professional development on climate change and teaching climate change (Fig. 9, 10, 11, 12, 13, 14 and 15). Subject primarily teaching was further grouped into two such as 'Science' (the subject science alone) and 'Others' (all other subjects except science). Therefore, the null hypothesis is—"There is no association between U.S. teachers' knowledge about climate change and teacher characteristics, such as teaching experience in K-12, grade level they teach, subject they primarily teach, educational degree, attendance of professional development on climate change and whether they teach climate change."

It was found that except for teaching experience in K-12, all other knowledge groups based on scores were found to be significantly different as evident from Chi square test results at 0.05 level of significance (Table 4). It can be concluded that the relationship between the two categories of variables (knowledge groups and teacher characteristics except for teaching experience in K-12) are statistically significant. Therefore, the null hypothesis is rejected except for the association between knowledge groups and teaching experience in K-12. An alternative hypotheses stating that there is association between U.S. teachers' knowledge about climate change and teacher characteristics, such as grade level they teach, subject they primarily teach, educational degree, attendance of professional development on climate change and whether they teach climate change is accepted.

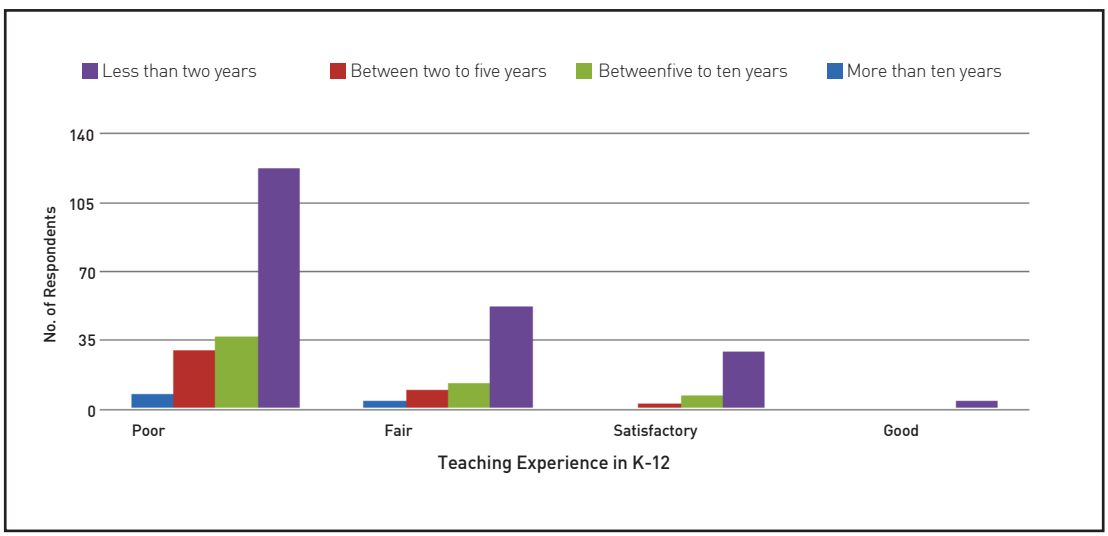


Fig. 9. Distribution of Respondents Under Knowledge Groups Based on Teaching Experience in K-12

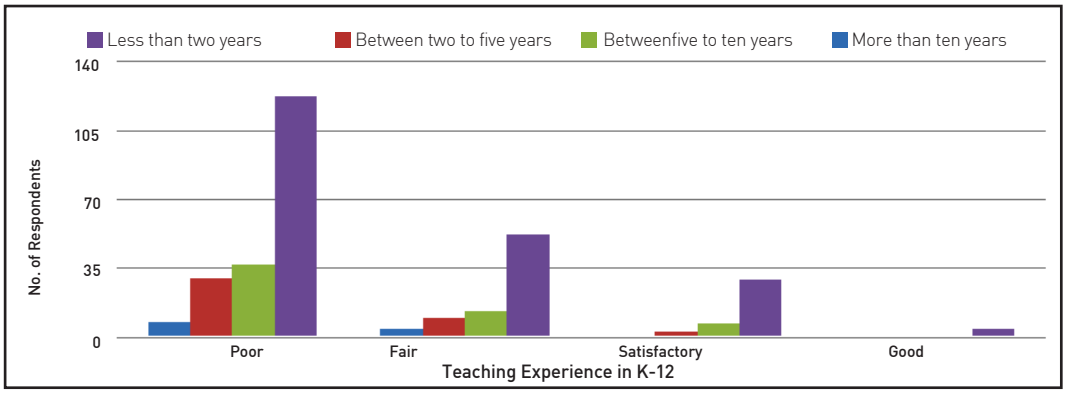


Fig. 10. Distribution of Respondents Under Knowledge Groups Based on Grade Level at Which Teaching

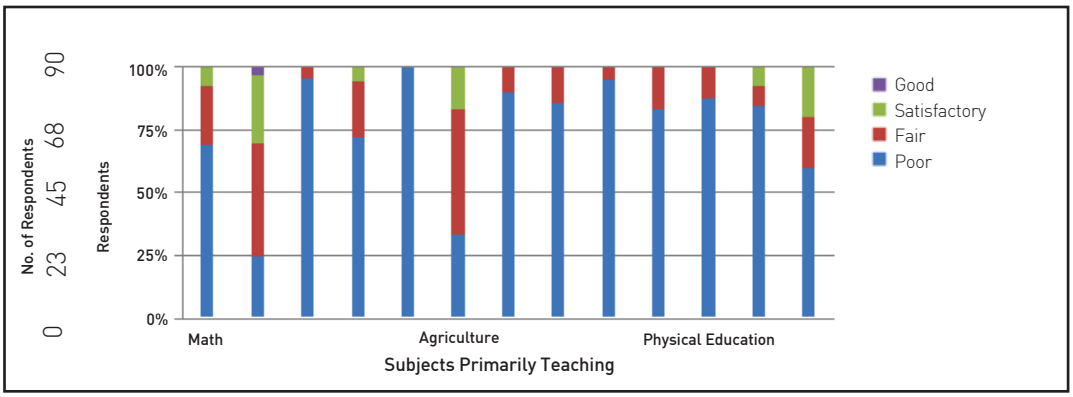


Fig. 11. Distribution of Respondents Under Knowledge Groups Based on Subject Primarily Taught by Respondents

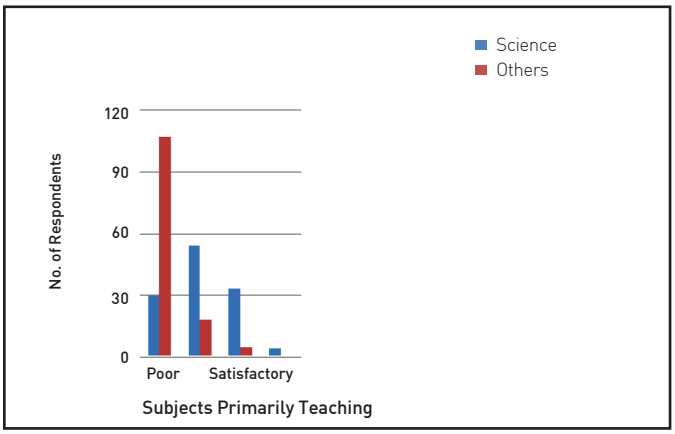


Fig. 12. Distribution of Respondents Under Knowledge Groups Based on Subject Primarily Teaching

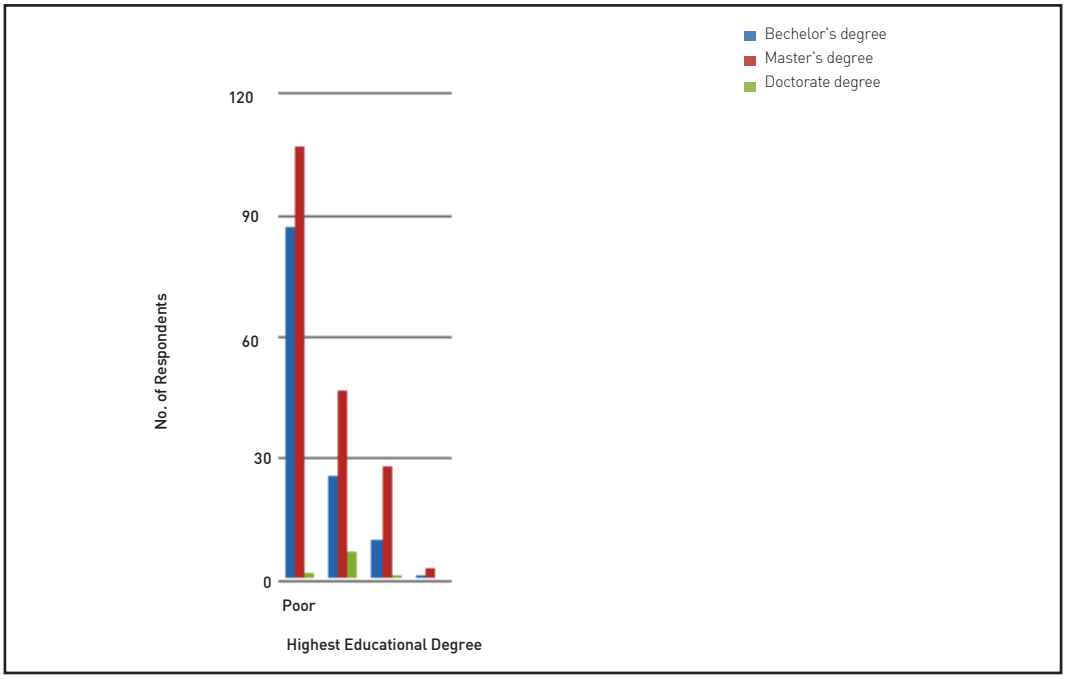


Fig. 13: Distribution of Respondents Under Knowledge Groups Based on Highest Educational Degree

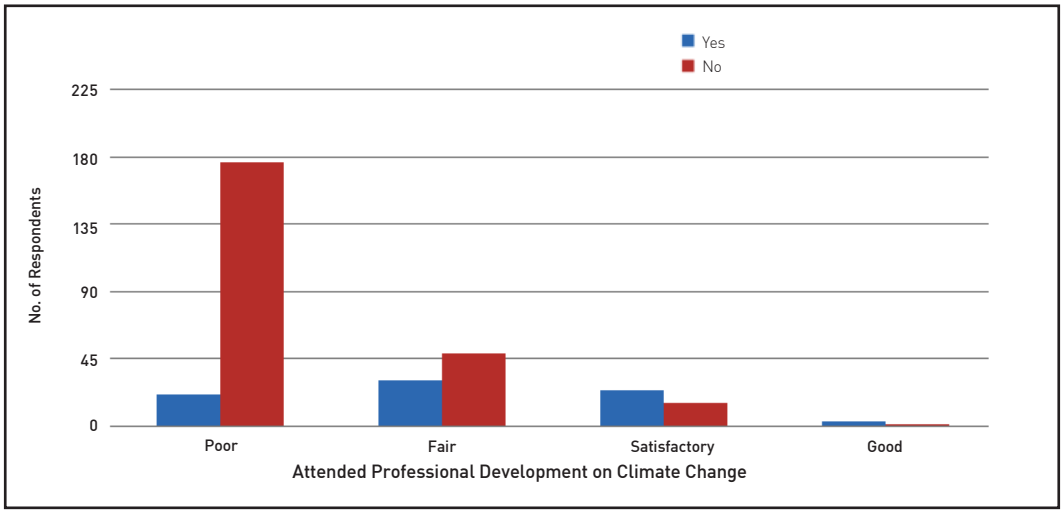


Fig. 14: Distribution of Respondents Under Knowledge Groups Based on Attended Professional Development on Climate Change

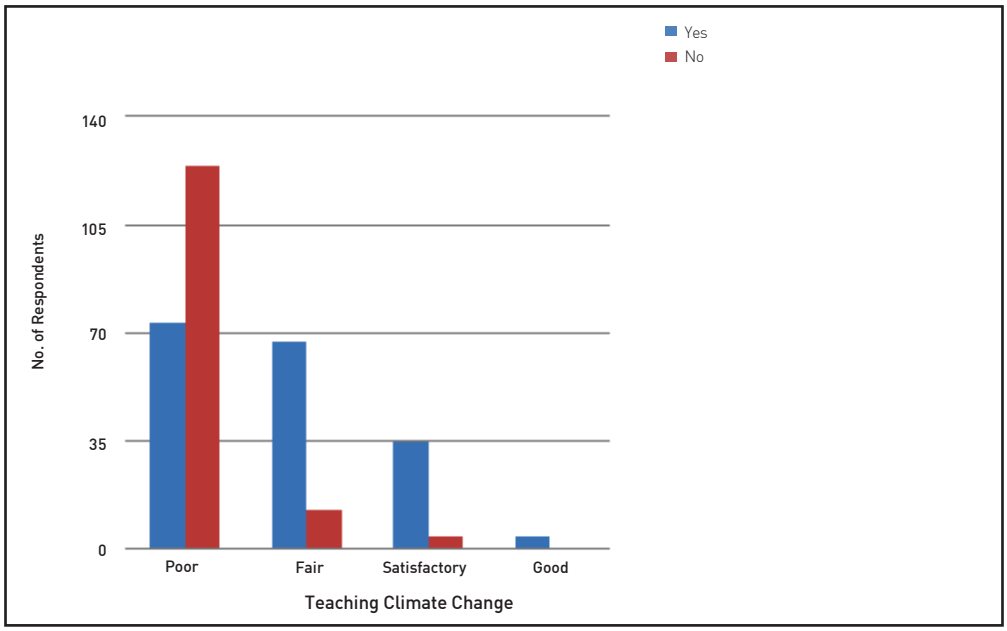


Fig. 15: Distribution of Respondents Under Knowledge Groups Based on Whether Teaching Climate Change

Table 4: Association Between Knowledge Groups and Teacher Characteristics

Variables	Chi-Square Test		
	Value	df	P-Value (p <0.05)
Knowledge groups* Teaching experience in K-12	6.404	9	0.698902
Knowledge groups* Grade-level teaching	36.485	6	< 0.00001
Knowledge groups (all subjects included)* Subject primarily teaching	98.863	36	< 0.00001

Knowledge groups* Subject primarily teaching ('Science' & 'Others')	85.696	3	< 0.00001
Knowledge groups* Highest educational degree	17.211	3	< 0.00064
Knowledge groups* Attended professional development on climate change	63.289	3	< 0.00001
Knowledge groups* Teaching climate change	74.837	3	< 0.00001

Discussions and Conclusion

As revealed by the result of the data as presented in Tables 2 and 3 and Figs. 7 and 8, teachers' knowledge on climate change for different questions were found to be majorly poor with 61.6 per cent falling under the 'Poor' category and only 1.2 per cent respondents falling under the 'Good' category. This is consistent with the findings of Liu *et al.* (2015), wherein they found that teachers' explanations of the scientific processes of global climate change were non-existent or limited and that they were invariably unaware of the mechanisms of the full-scale of the impacts of global climate change. Plutzer *et al.* (2016) also found in their study that many teachers in the U.S. repeat scientifically unsupported claims in class and notably 30 per cent of teachers emphasise the recent global warming 'is likely due to natural causes' and 12 per cent do not emphasise human causes (half of whom do not emphasise any explanation and thereby avoid the topic altogether). They pointed out that combination of limited training and uncertainty about the scientific consensus affects teachers' acceptance of anthropogenic climate change. Of teachers who teach climate change, 31 per cent report sending explicitly contradictory messages, emphasising both the scientific consensus that recent global warming is due to human activity and that many scientists believe recent increase in temperature is due to natural causes. This, they suggest, could be because first, teachers might experience overt pressure from parents, community leaders or school administrators not to teach climate change. Only 4.4 per cent of teachers reported such pressure (6.1% reported pressure to teach it, mostly from fellow teachers). Wise (2010), also found that teachers experienced

at least some sort of pressure to teach or not to teach global warming from parents, teachers, administrators, acquaintances and family members. Second, teachers may not be knowledgeable about a wide range of evidence Plutzer *et al.* (2016). Findings of Berger *et al.* (2015), from research on a nine-week elective course, Climate Change Pedagogy, taught for the first time in the Bachelor of Education programme at Lakehead University in winter 2014 also found that only a few of the students could describe the basic science behind anthropogenic warming. While Papadimitriou (2004), found that it is not only students but also teachers who have misconceptions and misunderstandings about climate warming. Ratinen (2013), also found that the primary student-teachers' factual knowledge and their conceptual understanding of the greenhouse effect are incomplete and even misleading. Other studies which found inadequate knowledge include that of Sousa *et al.* (2019), where the study revealed that the teachers in this case study struggled to understand the interconnectedness of soil and climate change; Anyanwu and Grange (2017), in their paper referenced several researches, such as Chang and Pascua 2016; Ochieng and Koske, 2013; Olatumile, 2013; Olufemi *et al.*, 2014; Reinfried *et al.,* 2012 which found that both students and teachers have gaps and misconceptions in their knowledge and understanding about climate change; Monroe *et al.* (2017), also mention that some educators feel that they lack the necessary skills and knowledge to adequately deliver instruction regarding climate change based on studies conducted by different researchers; Bozdogan (2011), also found knowledge gaps and certain misconceptions about the reasons underlying global warming among preservice elementary teachers.

With regard to the association between teachers' knowledge and different variables (teacher characteristics), as provided in the result, it was found that except for teaching experience in K-12, all other knowledge groups based on scores were found to be significantly different as evident from Chi square test results at 0.05 level (Table 4). This means that there is no relationship between knowledge groups and teaching experience in K-12, while there is relationship between different knowledge groups and all other variables, such as grade level they teach, subject they primarily teach, educational degree, attendance of professional development on climate change and whether they teach climate change. Similar studies have been undertaken by other researchers to study the relationships between such variables and climate change science knowledge although different statistical analyses were employed. In a study conducted by Anyanwu and Grange (2017), on 'The influence of teacher variables on climate change science literacy of geography teachers in the Western Cape, South Africa' where they had considered variables, such as gender, age, qualification, specialisation, teaching experience and teaching grade. The last four variables are relevant to the present study. As mentioned earlier, in the present study, there is a relationship between educational degree or qualification and teachers' climate change knowledge, while Anyanwu and Grange (2017), found that qualification has no significant influence on climate change science literacy. Similarly, Boon (2010), also observed similarities in the knowledge and understanding of climate change among secondary students and pre-service teachers who had science and environmental studies as their focus of study.

The findings of the present study on the association between teachers' knowledge and subject they primarily teach (their specialisation), also do not corroborate the findings of Anyanwu and Grange (2017), where they found no significant difference in the knowledge between teachers teaching geography and another subject. Boon (2010), also found no significant difference in the knowledge as a result of specialisation. However, Miler *et al.* (2012), found that physics teachers showed significantly better knowledge compared to the rest of the teachers indicating that the subject teachers teach do have a relationship with their knowledge.

The present study established a relationship between knowledge and teaching experience. This corroborates the findings by Anyanwu and Grange (2017), where they found that teaching experience had a significant influence on climate change science literacy of geography teachers. This also corroborates the findings by Baker and Loxton (2013), who reported that the number of years of teaching experience has an important influence on teachers' knowledge and understanding of climate change.

The findings of the present study about the relationship between knowledge and grade-level teaching validates the findings of Anyanwu and Grange (2017), wherein they found teaching grade significantly influenced climate change science literacy of geography teachers. The result also validates the findings of Baker and Loxton (2013), where secondary teachers showed slightly higher knowledge of climate change compared to elementary teachers. Similarly, Miler *et al.* (2012), found that the upper-primary teachers performed significantly better than the lower-primary teachers.

The present study also found that teachers' attendance of professional development has association with their climate change knowledge. This validates the findings of Bozdogan (2011), where it was found that preservice teachers were more successful in rectifying the gaps and misconceptions after intervention. Similar positive impact was found by Chang (2013), from a workshop conducted for geography teachers in Singapore; Liu *et al.* (2015), based on workshop of nineteen teachers from Native American communities; Drewes *et al.* (2018), in a case study.

In the present study, an association was found between knowledge of teachers and whether they taught climate change. However, no studies have been found to be undertaken to corroborate this finding.

Although the sample size of the present study is small, it provides a useful baseline information. Based on the findings of the present study, as well of findings of other researchers, the need to improve climate change knowledge among teachers is clearly evident. Hence, appropriate professional development programmes need to be developed which could be for pre-service or in-service teachers. There is a need to reorient environmental courses for teachers in India as suggested by Shimray (2016), so that students are able to contribute effectively in solving environmental problems. Curriculum developers in India and elsewhere may consider the findings of this research while preparing of courses or resources for professional development. There are also other aspects that may be considered which are not part of this study yet important. For example, Plutzer et al. (2016),

suggested that, in addition to greater attention to teachers' knowledge, addressing values is also critical.

Limitations and future research directions

The sample size was small. All states could not be covered for the online survey. The number of participants who responded were also skewed. This was expected for a research where participation is voluntary. Future research may take into consideration during sampling, the number of participants from each school district, state, type of school, subject and grade they teach.

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