Students’ Understanding of Climate Change: Insights for Scientists and Educators

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ABSTRACT

Teachers and meteorologists are among the most respected purveyors of scientific information to the public. As such, they can play an influential role in educating the public about basic atmosphere-related phenomena. To better fulfill this educational role, it is necessary to (i) identify and (ii) correct people’s major misconceptions about climatic and atmospheric issues, including global climate change. This paper reports the results of a survey of high school students’ knowledge and attitudes about climate change. The authors use open-ended survey questions to gain a more comprehensive understanding of the range of “mistakes” that are made. The results show misconceptions including inflated estimates of temperature change, confusion between ozone depletion and global warming, the perception of warmer weather and a belief that all environmentally harmful acts cause climate change. Also discussed is the origin of these mistakes from the perspective of current social scientific literature. It is suggested that these misconceptions arise from low levels of information, reliance on the televised news media, use of judgmental heuristics, confusion between weather and climate, and “fuzzy environmentalism,” wherein students perceive disparate environmental harms as significantly interrelated. The study also reveals that students have a very high level of trust in scientists and teachers. This suggests a role for scientists and educators through which they help correct misconceptions about climate change and ensure that people adopt effective environmentally protective measures.

1. Introduction

Over the last decade there has been tremendous concern over the possibility of a “human imprint” on global climate. The principal effects of human actions arise from industrial pollution and fossil fuel use, which have led to a buildup of carbon dioxide and other greenhouse gases in the atmosphere, and deforestation, which has resulted in the loss of carbon sinks that sequester carbon naturally. These human actions are expected to add to the natural greenhouse effect, resulting in global warming. While there continues to be heated debate among scientists on whether anthropogenic or human-related climate change is indeed occurring, new evidence in the recent report of the Intergovernmental Panel on Climate Change (IPCC) seems to support the anthropogenic climate change hypothesis (IPCC 1992, 1996; Nicholls 1996).

The complexity of the science of climate change often places it beyond the understanding of many members of the general public. This is especially true given the general level of “scientific illiteracy” or lack of understanding of scientific phenomena exhibited by many members of the public (Steen 1991; Arcury 1990; Miller 1988; Hausbeck et al. 1992). In the case of meteorological science, Morgan and Moran (1995) have provided evidence of college students’ misunderstanding of the greenhouse effect and the ozone layer. Several other studies have examined whether people understand the concept of climate change and have concluded that people have persistent misconceptions about this topic (Rebetez 1996; Bostrom et al. 1994; Boyes and Stanisstreet 1993; Francis et al. 1993; Read et al. 1994; Kempton 1991; Henderson-Sellers 1990).
The American Meteorological Society (AMS), among other groups, is trying to address this lack of understanding through teacher education programs like DataStreme and Project Atmosphere. Where should such programs focus their educational efforts to produce more scientifically literate students? Morgan and Moran’s article informs us that science education makes a significant difference in literacy on climate-related issues, but it also shows that these messages alone do not eradicate “mistakes.” It would therefore be worthwhile to understand the nature and origin of students’ misconceptions in the hope of devising the most appropriate remedies. This paper aims to explore this issue with the hope that our insights will be valuable to educators and scientists, whether in school or in the news media, in devising better educational programs that will increase popular understanding of the climate change issue.

Sampling and method

What are the common misconceptions students have about climate change? To find out, we conducted a survey of high school students using a questionnaire designed to probe their understanding of basic issues related to climate change. Our sample consisted of 66 ninth grade students from Honolulu, Hawaii, and 33 high school students from Oklahoma, for a total of 99 respondents. We presented these students with a survey instrument designed to elicit open-ended responses representing students’ understanding of climate change-related issues. The open-ended nature of these questions allows for multiple responses, leading to a relatively high number of observations, as well as the emergence of a broader range of responses not evidenced in studies such as Morgan and Moran (1995) and other closed-ended surveys. Therefore, although this sample appears small by traditional standards, it is appropriate for discovering a broader range of misconceptions and obtaining an appropriately large number of observations. To facilitate comparison with other studies, we followed the open-ended questions with a series of knowledge-related questions that students judged to be true or false. Demographic data and data on the sources of information used by students were also elicited.

2. Major misconceptions

Although students revealed many correct concepts about climate change, the survey revealed at least five prevalent misconceptions that are good targets for educational efforts. Overall, there were no statistical differences in the types of mistakes made by the Hawaii and Oklahoma samples (although there were some minor differences in their environmental outlooks). So we shall present our findings as a single sample of students. The students’ misconceptions will be detailed below, followed by a discussion of several potential explanations for the sources of these misconceptions.

a. Mistake 1: Inflated estimates of temperature change

The Intergovernmental Panel on Climate Change’s best estimate is that, to date, human activities have increased mean air temperatures by about 0.3°–0.6°C above natural increase (IPCC 1992, 1996). According to their “business as usual” scenario, the IPCC estimates a 0.3°C (0.5°F) change per decade throughout the next century, with an uncertainty range of 0.2°–0.5°C. This translates into a 1.5°C (2.7°F) change over the next 50 years, with an uncertainty range of 1°–2.5°C (IPCC 1992, 1996).

How well do students understand the scope of climate change in comparison? As Fig. 1 indicates, students’ estimates of the increase in average temperature resulting from global warming were much higher than that of adults (Bostrom et al. 1994) and dramatically higher than IPCC scientists (IPCC 1996). Interestingly, the students in our sample “missed” the best estimates by a much larger margin than adults in the Bostrom et al. study.

b. Mistake 2: Confusion between CFCs, the ozone hole, and climate change

Students also exhibited confusion about global climate change and its relationship to chlorofluorocarbons (CFCs) and the “hole” in the stratospheric ozone layer. While CFCs are greenhouse gases and do have some role to play in climate change, they are a significantly smaller cause of global warming than fossil fuel use, industrial air pollution, or deforestation (Read et al. 1994). Nevertheless, students prominently identified CFCs and ozone layer depletion as causes of climate change (see Table 1; erroneous statements are marked with an asterisk).

The range around the temperature estimate shows its inherent uncertainty. To ease comparison between groups in Fig. 1, we use a 0.5°C (0.8°F) point estimate (Read et al. 1994).
The confusion between the ozone layer and global warming also emerged when students were asked how they personally contribute to climate change. As Table 2 reveals, the use of air conditioning, CFCs, and aerosol cans was cited prominently. This error continued when students were asked for evidence that indicated that global warming was actually occurring. As shown in Table 3, the hole in the ozone layer was often cited as evidence of global warming. This pattern of responses corroborates the results of Bostrom et al. (1994), Read et al. (1994), Morgan and Moran (1995), and Kempton (1991), who also found significant conflation of these two atmosphere-related environmental problems.

TABLE 1. Student conceptions of the causes of climate change.

<table>
<thead>
<tr>
<th>Number of responses</th>
<th>% of total mentions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollution in general</td>
<td>45</td>
</tr>
<tr>
<td>Fossil fuel usage; automobiles, etc.</td>
<td>39</td>
</tr>
<tr>
<td>Deforestation and forest fires</td>
<td>29</td>
</tr>
<tr>
<td>*Ozone depletion/ozone layer</td>
<td>26</td>
</tr>
<tr>
<td>Air pollution</td>
<td>20</td>
</tr>
<tr>
<td>Factories</td>
<td>16</td>
</tr>
<tr>
<td>*Chemicals/harmful and unnatural gases</td>
<td>15</td>
</tr>
<tr>
<td>*CFCs</td>
<td>15</td>
</tr>
<tr>
<td>*Garbage/littering</td>
<td>13</td>
</tr>
<tr>
<td>*Changes in weather, seasons</td>
<td>12</td>
</tr>
<tr>
<td>Overpopulation</td>
<td>11</td>
</tr>
<tr>
<td>Greenhouse effect</td>
<td>10</td>
</tr>
</tbody>
</table>

*Represents “mistakes” or misprioritized causes of climate change. n = 330 open-ended responses. “Other” responses omitted from tables

TABLE 2. Student conceptions of personal contributions to climate change.

<table>
<thead>
<tr>
<th>Number of responses</th>
<th>% of total mentions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use automobiles</td>
<td>30</td>
</tr>
<tr>
<td>Waste natural resources</td>
<td>15</td>
</tr>
<tr>
<td>*Aerosol cans</td>
<td>16</td>
</tr>
<tr>
<td>*Improper trash disposal</td>
<td>12</td>
</tr>
<tr>
<td>*Air conditioning/CFCs</td>
<td>11</td>
</tr>
<tr>
<td>Use environmentally harmful products</td>
<td>10</td>
</tr>
</tbody>
</table>

*Represents “mistakes” or misprioritized causes of climate change. n = 138 open-ended responses. “Other” responses omitted from tables

Clearly greater educational focus is needed here. This mistake is significant because people’s perceptions regarding causes help dictate their responses to the problem. If citizens believe they are decreasing CFC concentrations by cutting down their use of aerosol spray cans (which no longer contain CFC propellants, at least in the United States), then they may have the false impression that they are doing a significant amount to prevent global warming, while actually having no effect.
c. **Mistake 3: Perceived evidence—Warmer weather focus**

How do students know that climate change is under way? To find out, students were asked if they believed there was evidence for climate change. If they answered yes, they were asked to identify the evidence for this conclusion and to identify the source from where they received such evidence. Forty-three percent of the students believe there was evidence of climate change. As Table 3 shows, among those students who believed this, the most often cited source of evidence was television. Of the 75 sources of evidence students cited, 34 were from television; 14 were from books, magazines, or newspapers; 12 were from teachers; and 11 were from personal experience.

Those who claimed to personally witness evidence of climate change tended to believe that they could personally sense rising climatic temperatures, changes in long-term weather patterns, or the ozone hole. This is the type of mistake that can be either enhanced or abated by news stories and the comments of television meteorologists. Research has shown that people frequently claim to perceive climate change even when it is not supported by climatological evidence (White 1985). These conceptions can arise from memorable weather events such as frequent or severe storms. Of course, such occurrences are common in midlatitude regions where a high level of temperature and storm variation is prevalent. Hence, one hot summer’s day or week does not necessarily equate with global temperature increase. Rebetez (1996) showed that the Swiss believed a lack of snow at Christmastime was evidence of global warming. Yet climatological evidence for the region shows little change over time: Christmases never were predominantly white (depending upon the altitude). Instead, people hold an unsubstantiated yet socially desirable myth that Christmases used to be and should be white. Of course, this tendency is likely exacerbated by frequent television reports about global warming, leading people to believe that they, too, can sense climate change.

While another potential indicator of climate change is increased storm frequency, students did not report a change in storm frequency per se, but they did believe there had been an unspecified “change in weather.” Furthermore, although two-thirds of the sample consisted of Hawaiian students, there was no concern expressed about sea level rise or about the potential increase in the frequency and severity of tropical storms. This is interesting because, even though Hawaii is a “high” island, sea level rise would still have profound effects on the state and its prosperous, dominant tourism industry, and students should have some awareness of this aspect.

d. **Mistake 4: All environmental harms cause climate change**

Students tend to confuse multiple unrelated environmental harms. As Fig. 2 (and Table 1) indicates, students believe that climate change is caused by a broad variety of environmentally harmful actions. Again, the use of aerosol spray cans is prominent in the students’ minds. Even the improper disposal of garbage is given as a cause of global warming. It is apparent that students exhibit a good deal of confusion between the proximate causes of climate change and other less-related environmental harms.

e. **Mistake 5: Confusing weather and climate**

One final fundamental problem that seems to underlie many of the students’ mistakes is a general con-
Often school curricula reflect traditional disciplines and are not multidisciplinary enough to provide coverage of topical, controversial, environmental problems that straddle disciplinary boundaries.

### b. News media as a source of information

Students’ misconceptions also may arise because of students’ reliance on the news media for information about climate issues. The media may provide skewed or incomplete information about such topics because of the constraints and incentives affecting its operation. The media is impelled by business considerations to use news reports to attract viewership in order to sell newspapers or increase television ratings. This leads to the framing of media stories in a manner designed to attract people’s attention, thereby directing the focus to dramatic, controversial, attention-grabbing news. The media justifies this by arguing that its mission is to inform rather than to educate (Dunwoody 1992). On this front, Morgan and Moran (1995) and others show that people who rely on print media do better than those who rely on television reports in terms of their understanding of climate issues, presumably because print media can cover issues in more depth than television can. The lack of time to adequately discuss complex issues such as climate change is another reason for persistent misunderstandings. Singer and Endreny (1993) show that almost all news reports about scientific studies contain factual mistakes, so it follows that reports about

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**3. Why misconceptions arise**

Now that we have identified several major misconceptions, it is important to consider why some of these mistakes arise. Identifying their possible origins is critical if we want to design better educational materials and programs. Below we discuss several prominent social scientific explanations for why these mistakes may arise.

#### a. Information availability

It is clear from our sample that students are only rarely exposed to extensive academic information on climate change. As Table 3 indicates, teachers were mentioned much less frequently as a source of information than the news media. Classroom time devoted to a current issue like climate change is limited.

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**Fig. 2. Major causes of global climate change. Asterisks indicate mistakes.**

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**Fig. 3. Knowledge about weather and climate. Asterisks indicate mistakes.**

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the complex nuances of science might also contain many mistakes.

Dunwoody (1992) suggests that in order to attract and sustain viewer attention, journalists often feel the need to personalize stories with people, anecdotes, and vivid information. The need to achieve balance also leads journalists to try to devote equal space to competing interpretations about an issue, which results in both sides (both scientists and and nonscientists) being accorded equal validity on a scientific question. Although media organizations do often attempt to give equal time, Wildavsky (1995) argues that this balance did not exist in early speculative reporting about the possibility of global warming. Global warming was highlighted as an environmental problem when the media reported on National Aeronautics and Space Administration scientist J. Hansen’s congressional testimony concerning human actions causing climate change. Wildavsky argues that the media failed to emphasize Hansen’s caveats about the lack of scientific evidence to support his claim and the media also ignored scientists’ doubts about the evidence in support of global warming. Wildavsky contends that the media tended to quote predominantly supporters of the hypothesis rather than its critics. News coverage can thus lead students to obtain a less than balanced understanding of climate change, its uncertainties, and its complex causes and effects.

c. Judgmental heuristics

Fischhoff and Furby (1983), called for a research program to address the psychological dimensions of climate change in order to better understand the heuristics, or mental shortcuts, that people use to make sense of complex and uncertain threats like climate change. These heuristics, which are used by both experts and lay people, often lead individuals to make erroneous judgements about complex phenomena. These mistakes can be exacerbated by dramatic, unbalanced, or inaccurate media coverage. Slovic et al. (1979) showed that people are particularly vulnerable to using heuristics in the context of environmental risks.

One example is the availability heuristic, whereby people judge the frequency of a problem by the ease with which evidence comes to mind. Another example is the representativeness heuristic, whereby people generalize on the basis of limited evidence, in violation of basic statistical principles such as regression to the mean. These two heuristics can work together to cause people to believe that global warming has begun. For example, heat waves are typically memorable events. Media personalities often discuss or joke about global warming during these episodes, thus making the link to global warming more available. Representativeness can then lead people to infer from instances of hot weather that global warming is under way.

Research has also shown that people have difficulties dealing with probabilistic information, especially when the probabilities are very small. People tend to overweight small probabilities and underweight high probabilities when they arrive at judgments about uncertain events (Slovic et al. 1979). We suspect that something similar may be at work in the climate change context. Students and adults may expect a high range of absolute temperature change in a short time frame because it is hard to believe that a catastrophic phenomenon like global warming could result from minute increases in mean temperatures over a long time horizon. This coupled with a general confusion between weather and climate may lead people to believe they can directly sense climate change. Further, while scientists attempt to convey the uncertainty involved in climate change forecasts using confidence intervals and competing scenarios, lay people may not be exposed to these complexities or may ignore them and focus instead on worst-case estimates.

d. Fuzzy environmentalism

In general, students’ responses to questions about their environmental values revealed a significant “pro-”environmental orientation. We asked students to note their levels of agreement or disagreement with a series of statements expressing environmental values (1 = strongly disagree, 4 = strongly agree). Mean responses indicated that students strongly agreed that (i) it is important to preserve the environment for future generations (\( \bar{x} = 3.70 \)), (ii) nature is divine and should be treated respectfully (\( \bar{x} = 3.40 \)), and (iii) nature is fragile and we should be careful not to harm or disrupt it (\( \bar{x} = 3.53 \)). Students strongly disagreed that (i) there is nothing we can do to change environmental conditions (\( \bar{x} = 1.57 \)), (ii) nature is wild and should be tamed to serve mankind (\( \bar{x} = 1.51 \)), (iii) it is all right to sacrifice other species in order to satisfy human needs (\( \bar{x} = 1.54 \)), and (iv) harm to the environment is justified if it brings an economic benefit (\( \bar{x} = 1.58 \)).

While this “green ethic” among students suggests a strong foundation for environmental concern, it may lead students to lump together all environmentally harmful acts, which results in fuzzy environmentalism. From the perspective of our discussion of judg-
mental heuristics above, fuzzy environmentalism is a heuristic that can be easily used when students are uncertain about cause and effect. They can simply “guess” that all environmental harms could lead to global climate change. In many students, these concepts are not yet fine-tuned enough to enable a sophisticated consideration of cause and effect, resulting in confusion over critical issues related to climate change. Thus, fuzzy environmentalism can lead students toward inappropriate responses like avoiding aerosol spray cans in order to remedy global warming. As Bostrom et al. (1994) suggest, fuzzy environmentalism also leads to incorrect reasoning chains, such as the conclusion that the “hole” in the ozone layer is leading to more solar radiation, which then causes global warming.

4. Trust in scientists and its implications

The effectiveness of educational messages is often dependent on the trust in the source of the information. Thus, we asked students to rank who they most trust to give them correct information about climate change (rank = 1) and who they trust the least (rank = 8). As Fig. 4 indicates, scientists emerged as the group students trusted most (mean ranking 2.99), followed by teachers (mean ranking 3.01), and then environmental groups and the news media (mean rankings 3.94 and 3.96, respectively). Government officials, family, and friends had mean rankings on the low trust side of the scale.

The enormous level of trust placed in scientists bestows both an opportunity and a responsibility on the scientific community to play an active role in enhancing students’ knowledge about climate change and about actions that students can take to help prevent it. Together with educators, who are also highly trusted, scientists can help increase students’ understanding and especially help them avoid the significant misconceptions identified in this and other studies. This may involve initiatives inside and outside of the traditional classroom setting.

But when scientists venture outside the traditional classroom setting, they are entering an arena where political or other agendas intervene. Scientists attempting to reach a broader audience through media outlets may find it frustrating when their statements are reported in an incomplete manner or where uncertainties in their discussions are ignored in favor of bold, attention-grabbing headlines. Scientists are typically not trained to deal with these arenas and some caveats about scientists’ potential role are in order.

The public may have a more absolutist perspective on the scientific process, believing that scientists have all the answers and that such answers are final. People may have difficulty grasping the concept that science is evolutionary, and that there is considerable controversy at the frontiers of knowledge, for instance, in the context of climate change. If people do have such misunderstandings about the scientific process, then they will be confused by public controversy among scientists on matters such as climate change. Therefore, scientists should exercise great care to avoid transgressing the boundary from education to advocacy in public arenas. Otherwise, the high level of trust in scientists may be affected. As Slovic (1993) points out, trust is fragile and asymmetric, meaning that it takes just a few actions to destroy trust, while developing and sustaining trust require continuous action.

Public controversies among scientists may also result in different types of reactions. Studies from the field of risk perception indicate that conflict among scientists typically results in people concluding that the risks must be substantial if they generate such controversy. In contrast, such conflicts also can lead policymakers to argue that any risk about which there is no scientific consensus should be ignored. This argument was put forward by the Bush administration when faced with the climate change discussions at the Rio de Janeiro Earth Summit in 1992.
5. Recommendations

The significant misconceptions that students display in the context of climate change suggest the need for better educational materials focused on these major misconceptions. The AMS is one body that can significantly help in this regard, because it already places strong emphasis on its educational role, as evidenced by the annual symposium on education (Smith et al. 1995) and several other educational programs. This fact, coupled with the enormous trust bestowed in scientists, suggests that the meteorological community can play a key role in correcting misconceptions and enhancing environmental literacy regarding climate phenomena.

Although news reporting of scientific phenomena can distort people’s understanding of complex phenomena, those in the media also can do much to correctly inform the public about these issues. Meteorologists, especially, can help television audiences better understand climate-related issues through informal educational messages during weather forecasts. Likewise, they can give more extended educational messages during live public presentations and school visits. These efforts will not only help citizens dispel some of the misconceptions identified, they will also enable the public to better understand the information given them by meteorologists and climatologists.

In the educational setting, the multidisciplinary nature of these environmental problems poses a challenge to curricula constrained by traditional disciplinary boundaries. Schools must be able to overcome these barriers in order to address emerging multidisciplinary issues such as climate change. Innovative curricula devoted to correcting popular misconceptions, such as those identified in this article, could provide a significant return in a short time period.

The AMS has taken the lead in establishing educational initiatives that provide opportunities to enhance student knowledge about climate change. One example is the DataStreme program that the AMS runs with assistance from the National Weather Service and the State University of New York at Brockport. The DataStreme program trains teachers to promote the teaching of weather in schools and has students and teachers work with weather data. Similarly, the Project Atmosphere initiative of AMS trains teachers to encourage the study of weather as a means of teaching science and mathematics. These initiatives can benefit from the lessons learned in our study to build educational modules that correct students’ misconceptions about climate-related concepts.

There are also other government-funded research programs that involve students in data collection as a way of involving them with the scientific process and introducing in them an appreciation for environmental issues. One example is the SPaRCE program (Schools of the Pacific Rainfall Climate Experiment) run by meteorologists S. Postawko and M. Morrissey at the University of Oklahoma. These scientists have equipped a series of high schools in the tropical Pacific with rain gauges and other meteorological equipment, and integrate student measurements with the Comprehensive Pacific Rainfall Database. Student data thus enables scientists to ground truth satellite estimates of rainfall in the data-sparse Pacific Ocean region. In return, the SPaRCE program provides educational materials and a monthly talk-back radio program for the students—an excellent venue for educational messages. The GLOBE program (Global Learning and Observation to Benefit the Environment) is a federal government initiative similar to SPaRCE that attempts to involve students worldwide in its efforts.

The close interaction of scientists, teachers, and students in all these programs provides many opportunities to help educate students about climate and climate change in accessible and nonformal settings. Hopefully, starting with a fuller understanding of students’ mistakes and why they occur will help scientists and educators develop messages that correct and overcome these common misunderstandings.

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References

With the development of meteorological science and the continual refinement of the technologies used in its practical application, the need to produce a new edition of the International Meteorological Vocabulary (IMV) became evident (the original edition was published in 1966). This volume is made up of a multilingual list of over 3500 terms arranged in English alphabetical order, accompanied by definitions in each of the languages (English, French, Russian, and Spanish) and an index for each language. This new edition has been augmented with numerous concepts relating to new meteorological knowledge, techniques, and concerns. It should help to standardize the terminology used in this field, facilitate communication between specialists speaking different languages, and aid translators in their work.