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Benjamin J. Burger
Utah State University

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Apathy and Concern over the Future Habitability of Earth: An Introductory College Assignment of Forecasting CO₂ in the Earth's Atmosphere

*By Benjamin Burger, Ph.D.
Utah State University*

Abstract

Non-science, first year regional undergraduate students from rural Utah communities participated in an online introductory geology course and were asked to forecast the rise of CO₂ in the Earth's atmosphere. The majority of students predicted catastrophic rise to 5,000-ppm sometime over the next 3,100 years, resulting in an atmosphere nearly uninhabitable to human life. However, the level of concern the students exhibited in their answers was not directly proportional with their timing in their forecasted rise of CO₂. This study showcases the importance of presenting students with actual data and using data to develop student forecasted models. It also illustrates the challenge in environmental science with the cognitive issue of temporal discounting, in which the consequences of these future predictions tend to be viewed apathetically due to the long durations in which they play out.

Introduction

On April 14th, 1970 at 3:07 Coordinated Universal Time and 200,000 miles from Earth, three men wedged in the outbound Apollo 13 spacecraft heard an explosion (NASA, 2009). A moment later astronaut Jack Swigert transmitted a message to Earth, "Houston, we've had a problem here." One of the oxygen tanks onboard the

Service Module had exploded, which also ripped a hole in a second oxygen tank and cut power to the spacecraft. Realizing the seriousness of the situation, the crew quickly scrambled into the Lunar Module. The spacecraft was too far from Earth to turn around; instead, the crew would have to navigate the spacecraft around the far side of the moon and swing it back to Earth, if they hoped to return alive. The Lunar Module now served as a life raft strapped to a sinking ship (the Service Module). The improvised life raft was not designed to hold a crew of three people for the four-day journey home. Oxygen was conserved by powering down the spacecraft. Water was conserved by shutting off the cooling system, and drinking became rationed to just a few ounces a day. There remained an additional worry: the buildup of CO₂ in the space capsule.

At high concentrations, CO₂ (carbon dioxide) causes asphyxia, in which the blood cannot be replenished with fresh oxygen. In the Earth's atmosphere, there is a balance of 20.9% oxygen, 79% nitrogen, and a tiny fraction of carbon dioxide, usually measured in parts-per-million. With each outbreath, the crew expelled air with about 5% carbon dioxide. This carbon dioxide would accumulate in the lunar module over the four-day journey and result in death by hypercarbia: the buildup of carbon dioxide in the blood. The crew had to determine how long the air would remain breathable in the capsule.

Although the biosphere is much more complex than a sealed space capsule, the Earth finds itself in a similar predicament to that of the Apollo 13 crew. Its resources are stretched to provide food, water, and air to over 7 billion people. In similar fashion as the air in the Apollo 13 space-capsule, the Earth's entire atmosphere is also changing with a dramatic rise in levels of carbon dioxide, which have been building up in the Earth's atmosphere during the last century, along with a rapidly growing population (Newell and Marcus, 1987). The amount of carbon dioxide in the atmosphere today (408 ppm) is by far the highest it has been in over 800,000 years (Lüthi et al. 2008) and has not reached this high of a level since 4.5 million years ago (Pagani et al. 2010). How long will the air remain breathable?

Methods

The students in my introductory science class at Utah State University were asked the same question that faced the crew of the Apollo 13, but applied to the entire Earth. How long will Earth's atmosphere remain breathable, given the recent historical increases in carbon dioxide?

The students face this challenging question after completing a three-chapter module on the Earth's atmosphere, as part of an online introductory physical science course at Utah State University Uintah Basin Campus. The course is an Earth Systems class for non-science majors, utilizing Skinner & Murck's 2011 textbook, entitled "The Blue Planet: An Introduction to Earth System Science" 3rd edition. The students taking the class are non-science majors, with a range of degree programs with education and business dominate fields of study.

The students are directed to the Earth System Research Laboratory, Global Monitoring Division website (ESRL, 2017) run by the National Oceanic & Atmospheric Administration, which currently maintains the long-term carbon dioxide monitoring station on top of Mauna Loa in Hawaii.

The students are asked to use the available data to make a prediction of when (years after present) the values of carbon dioxide will reach 5,000 parts per million (ppm). The 5,000-ppm amount was chosen because it is the amount that the Occupational Health Guideline for Carbon Dioxide (1978) lists as requiring workplace ventilation. Although fifty times this amount is fatal to humans (Gill et al. 2002) within a few seconds, a value of 5,000 ppm at the Mauna Loa observatory would indicate that values elsewhere on the planet would be significantly higher, and such high values would be detrimental to long-term human health on the planet¹³. Other than the data, students are not given any step-wise procedures, and it is up to them to devise a forecast and defend their own procedures for their answer. The

¹³ Current understanding of historical levels of carbon dioxide in the atmosphere, using the *Ginkgo* stomata on fossil leaves proxy method, indicate previous ranges in Earth's last 100-million-year history from 176 to 2,285 ppm (Barclay & Wing, 2016). While this method is less sensitive to detecting values above 800 ppm, a value of 5,000 ppm would be unprecedented over the last 100 million years and would lead not only to catastrophic climate change, but mass extinction.

project is developed within the framework of constructivism theory in education, in which learning is the active creation of knowledge from personal experiences. There is a significant body of research about the merits of constructivism theory, and in particular, problem-based learning (Hoover, 1996; Mayer, 1996). Inquiry-based learning has become widely accepted in the teaching of science (Rakow, 1986). One of the biggest criticisms of constructivism theory is whether questions or problems given are defined well enough for the student to actually answer (Land, 2000). This project does not have a definitive answer, but facilitates back-and-forth discussion of the assignment, and the students at this point should have the prior knowledge to present a reasonable forecast.

At this juncture in the semester, students have already been introduced to some of the basic principles of climate and weather. However, the project does not directly address climate change. While climate change can be discussed in the students' forecasted answer, it is the change in Earth's atmospheric composition that is of concern in this assignment. Climate change is covered in the class, but focused on after this assignment and after the students have mastered an understanding of the composition of the Earth's atmosphere.

Student answers over the five semesters I've introduced this assignment have some bearing on the challenges facing today's environmental education. In particular, how does apathy and concern play against better knowledge of the available data? Additionally, how concerned or apathetic are students who forecast a sooner, rather than later, date in the assignment? When first introduced, I predicted that student responses would reflect their forecasted date, such that students who predicted earlier dates would be the most concerned about rising CO₂.

Students were also asked a series of follow-up essay questions:

1. What assumptions did you have to make to come up with this estimate?
2. How confident are you in your answer?
3. What tools or thought processes did you use to come up with your answer?
4. Did this knowledge increase or decrease your concern about increasing levels of CO₂ in the atmosphere?

Results

Responses from 130 students forecasted different rates of increasing CO₂ concentration in the atmosphere from five semesters taught between 2014-2017. Figure 1 shows the histogram of responses. Only 10 percent of the students (n=13) forecasted that levels of CO₂ would either never reach that level, or reach it after 10,000 years. However, the majority of students (90%) forecasted a 5,000-ppm level within the next 10,000 years, and 84% forecasted a 5,000-ppm level within the next 3,100 years. Hence 90% (117/130) of students predicted catastrophic levels of CO₂ in the future.¹⁴

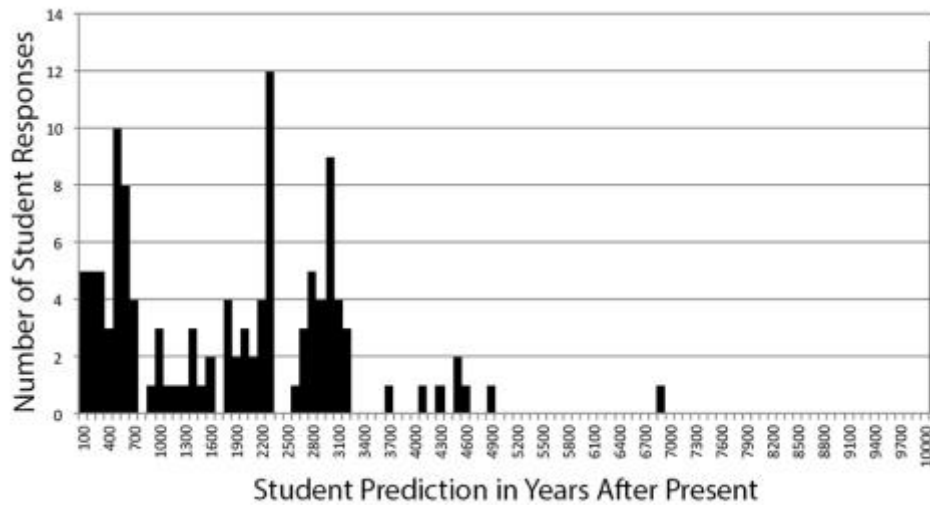


Figure 1: Graph of student responses from 130 introductory geology students enrolled in the class from 2014 to 2017.

Answers from two of the essay questions on student confidence, as well as increased or decreased concern based on new knowledge, were quantified by the instructor using a five-point Likert scale for the final three semesters, based on

¹⁴ If interested there are a number of published carbon dioxide models that give differing predictions of forecasted CO₂ levels. Using the more linear Chambers (2017) equation yields an answer of 550 years in the future that CO₂ levels will reach the 5,000-ppm mark, while the exponential equations of Bourne (2009) equation yield an answer of 166 years in the future. My own forecast suggests between 413 (which assumes 1 ppm rate increase every 25 years) to 1,531 years (assuming rates remain held at 3 ppm per year). These predictions are within the ranges of those given by students at Utah State University.

student essays (n=90). The levels of concern that students expressed in these essays were scored base on their essay answer as: 1) not concerned; 2) somewhat concerned; 3) concerned; 4) concerned and we should take action; 5) gravely concerned and/or frightened by numbers. These scores were open-coded based on the student’s response, rather than directly scored by the student.

Regression plots show no strong correlation between students’ forecasted rise in CO₂ in the atmosphere and their own confidence or concern about rising CO₂ in the future (Fig. 2, top). In other words, the level of the students’ concern or apathy in their own calculations of rising CO₂ in the atmosphere does not correspond greatly to their own forecasts. Students who predicted a slow rise of CO₂ in the atmosphere were equally concerned as those who predicted an extremely fast rise of CO₂ in the atmosphere. There is a slight shift in the mean value of the predictions, as a function of this scale, if students with predictions longer than 10,000 years are removed. With this change, those who showed the greatest concern manifest slightly shorter predictions than those with the least concern (Fig. 2, bottom).

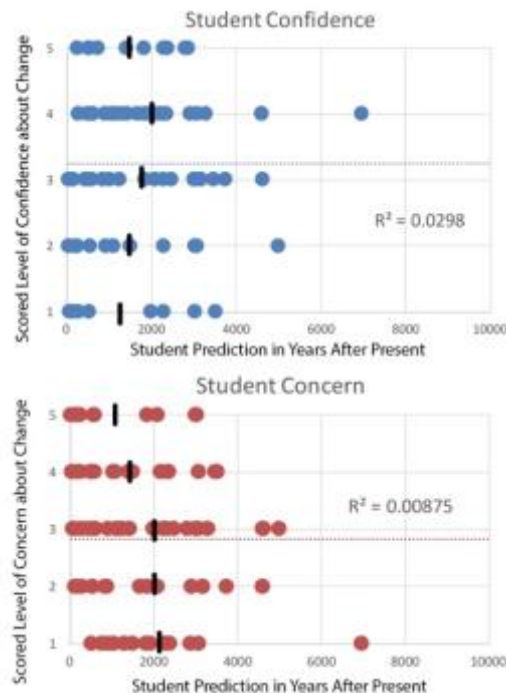


Figure 2: Graph of 90 student essay responses scored to a 1-5 Likert scale, with 5 high and 1 low, showing the level of student confidence in their prediction, as well as the level of the student’s concern resulting from their prediction. Black lines indicate the mean student prediction in each category (calculated after removing student answers longer than 10,000 years in the future).

Discussion of Student Forecasts of Rising CO₂

Overall, most of the students (90% or 117/130 students) predicted catastrophic levels of CO₂ in the future within the next 10,000 years. Students were not given any analytical procedures to solve this problem and were required to devise their own procedures to justify their answers. Overall, student forecasts can be grouped into three major approaches. The first is a simple linear extrapolation, often done by drawing a line on a graph or using a given rate for the most recent year, or average rate over the last decade. The second is more complex and uses an exponential curve to either plot data on a spreadsheet or calculate a formula from the different rates as they increase each year. The third involves a more conceptual approach, including in calculations like societal changes in the near future, the availability of fossil fuel resources, and possible government regulations on CO₂ emissions. Most students answer this question through a simple linear approach, which tends to result in a slower rate of increase when compared to exponential forecasts. The physicist educator Albert Bartlett spent his career documenting the well-known educational phenomenon in which students have difficulty understanding exponential growth in forecasting the future (Bartlett, 1978). This seems to have played out in our exercise, with most forecasts tending to be linear.

While not necessarily comparable, surveys on climate change indicate that rural communities in Utah tend to feel less concern than other regions of the country. For example, independent surveys by Howe et al. (2015) and Marlon et al. (2016) found that only 67% of rural Utah respondents indicated that CO₂ should be regulated as a pollutant, compared to a national average of 74% (Howe et al. 2015; Marlon et al. 2016). Differences between students in this class and general survey results are likely related to several factors. One of them is that students were shown actual data and asked to formulate a model to predict changes over time, whereas general surveys just asked a single question without introducing or showing data to support or refute the claim. Studies where survey participants are introduced to the scientific consensus on atmospheric change show an increased acceptance compared to those that are not (Van der Linden et al. 2017). The results demonstrate that when students are given data and are required to use it to extrapolate or forecast, they tend to come to a consensus that CO₂ levels in the atmosphere are rising at alarming levels. Helping students to critically analyze such data and draw rational conclusions from them are an important part of environmental education.

Discussion of Student Concern or Apathy

Results from this study demonstrate that even when students forecasted a very quick rise in CO₂ levels, they were not necessarily correspondently alarmed or worried about this rise. In reading through the student essays, common themes for this disconnection become apparent.

First, a segment of the apathetic students voiced some relief that their forecasted answer would not happen within their own lifespan. Indeed, the threshold of this apathy is around the length of a single human life of 75 years. Once students calculated that this threshold would not occur in their own lifetimes, they tended to be more apathetic in interpreting their results. This is likely related to a well-known phenomenon in human cognition called temporal discounting (Hershfield, 2011). It is one of the reasons people have trouble planning for retirement. This phenomenon is a result of how the human brain views future events and disproportionately worries about more immediate or current crises. It is closely related to how delayed monetary rewards are devalued from immediate awards (Green et al. 1997). The greater an event's distance in the future, the more disconnected from it people tend to feel. If this extends beyond their own lifespans, they are much more disengaged. A much smaller segment of the apathetic students voiced a religious belief that the human species would be saved through a miracle or divine intervention, and an equally similar segment voiced that science and new technology would reduce CO₂, thereby giving humanity time to devise a solution.

It is important to note that 79% of the students had some level of concern about the rise of CO₂, and that these more apathetic students represent a minority. However, only 6% of students were gravely or highly concerned about rising CO₂, even after completing the assignment.

One possible way to prevent temporal discounting in environmental studies would be with a follow-up assignment in which students imagine what the world would look like when CO₂ levels reach these high levels in the atmosphere. Some research, such as that by Hershfield (2011), has shown that by viewing aged augmented self-portraits, subjects tended to have less temporal discounting when it comes to saving for retirement in old age. A follow-up assignment, in which students plan out what the world would look like and how human lives would be impacted (such as respiration required for traveling outdoors and CO₂ scrubbers in most

homes) could serve as an interesting future study to see what impact it might have on attitudes regarding rising CO₂ concentrations in the atmosphere.

Conclusion

Challenges abound on how to deal with the changing atmosphere, energy resources, population growth, and ensuring that the earth remains a habitable place for humans far into the future.

With the aid of mission control, the crew of Apollo 13 solved the problem of the rising CO₂ in the air of the Lunar Module as it returned to Earth. Using plastic bags, cardboard, and tape, the crew managed to attach lithium hydroxide canisters from the Service Module inside the Lunar Module. These lithium hydroxide canisters scrubbed the rising CO₂ in the air in the spacecraft enough to get them home to Earth safely.

As it voyages through space, Earth has a grave problem, similar to that of the damaged Apollo 13 space capsule. Rising CO₂ in the atmosphere will present a clear danger to future generations. If we are to survive as a species, we will need to find a solution in the decades to come. As educators, we also need to teach rising generations of students the importance of understanding the available data and using them to forecast the future. We must also be aware of the temporal discounting in monitoring the low level of concern among the general public.

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