A Cooperative Classroom

Students investigate environmental changes and their impact on penguin communities

Juanita Constible, Luke Sandro, Richard E. Lee Jr.

At the global level, strong evidence suggests that observed changes in Earth's climate are largely due to human activities (IPCC 2007). At the regional level, the evidence for human-dominated change is sometimes less clear. Scientists have a particularly difficult time explaining warming trends in Antarctica—a region with a relatively short history of scientific observation and a highly variable climate (Clarke et al. 2007). Regardless of the mechanism of warming, however, climate change is having a dramatic impact on Antarctic ecosystems. In this article, we describe a standards-based, directed inquiry we have used in 10th-grade biology classes to highlight the ecosystem-level changes observed on the western Antarctic Peninsula. This activity stresses the importance of evidence in scientific explanations and demonstrates the cooperative nature of science.

Warming climate, waning sea ice

Air temperature data indicate that the western Antarctic Peninsula has warmed by about 3°C in the last century (Clarke et al. 2007). Although this relatively short-term record is only from a few research stations, other indirect lines of evidence confirm the trend. The most striking of these proxies is a shift in penguin communities. Adélie penguins, which are dependent on sea ice for their survival, are rapidly declining on the Antarctic Peninsula despite a 600-year colonization history. In contrast, chinstrap penguins, which prefer open water, are increasing dramatically. (**Note:** See "Chinstrap and Adélie penguins," p. 58, for additional information on the penguins.) These shifts in penguin populations appear to

Investigation of Climate Change

be the result of a decrease in the amount, timing, and duration of sea ice (Figure 1; Smith, Fraser, and Stammerjohn 2003).

Why is sea ice so important to Adélie penguins? First, sea ice is a feeding platform for Adélies. Krill, the primary prey of Adélies on the Peninsula, feed on microorganisms growing on the underside of the ice (Atkinson et al. 2004). For Adélie penguins, which are relatively slow swimmers, it is easier to find food under the ice than in large stretches of open water (Ainley 2002). Second, sea ice helps control the local climate. Ice keeps the Peninsula cool by reflecting solar radiation back to space. As air temperatures increase and sea ice melts, open water converts radiation into heat and amplifies the upward trend in local air temperatures (Figure 2; Wadhams 2000). Third, ice acts as a giant cap on the ocean, limiting evaporation. As sea ice declines, cloud condensation nuclei and moisture are released into the atmosphere, leading to more snow. This extra snow often does not melt until Adélies have already started nesting; the resulting melt water can kill their eggs (Fraser and Patterson 1997).

FIGURE 1

Effects of regional warming on sea ice, krill, and penguin communities of the Antarctic Peninsula.

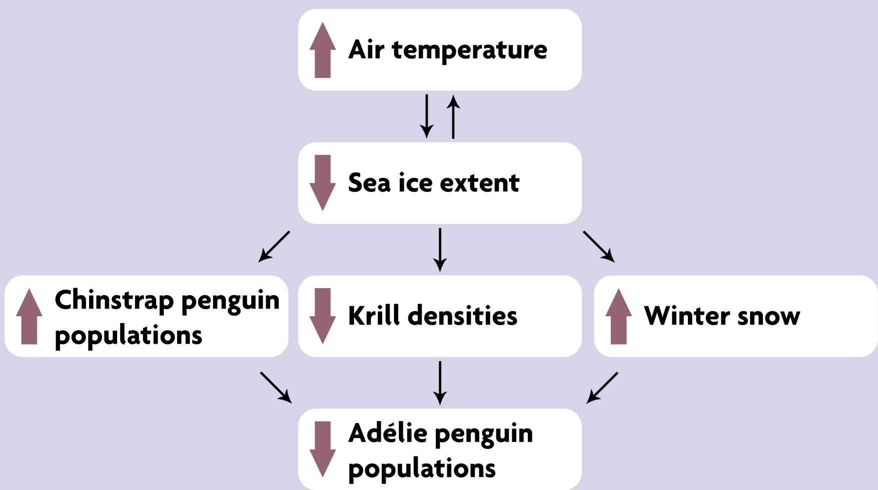
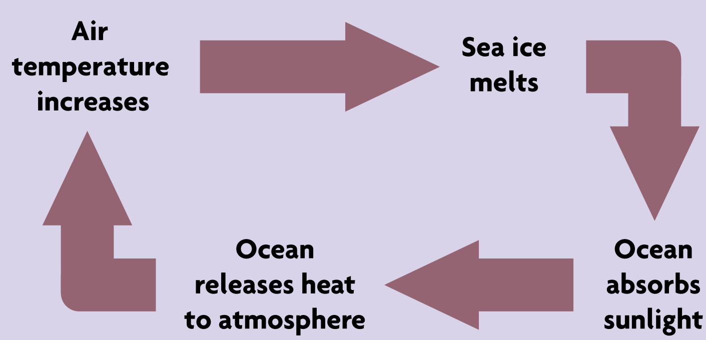


FIGURE 2

Melting sea ice amplifies the effects of atmospheric warming.



RICHARD E. LEE JR.

FIGURE 3

Specialist fact sheet.

Each Home Group contains five different specialists.

Ornithologist: A scientist who studies birds. Uses visual surveys (from ship or on land), diet analysis, and satellite tracking to collect data on penguins.

Oceanographer: A scientist who studies the ocean. Uses satellite imagery, underwater sensors, and manual measurements of sea ice thickness to collect data on sea ice conditions and ocean temperature.

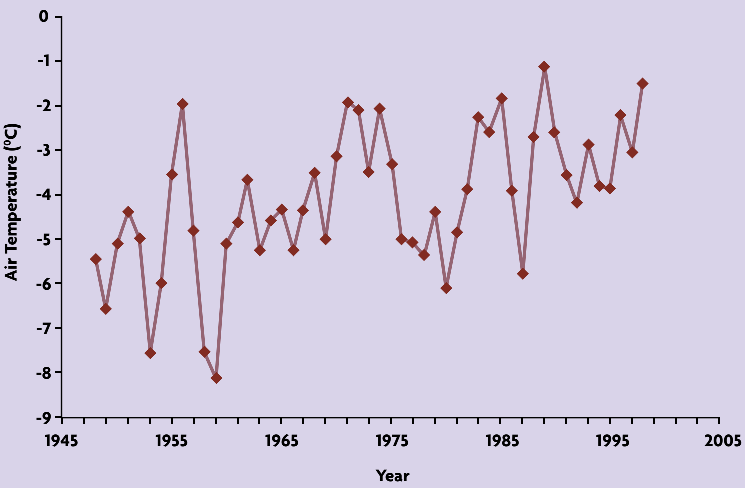
Meteorologist: A scientist who studies the weather. Uses automatic weather stations and visual observations of the skies to collect data on precipitation, temperature, and cloud cover.

Marine ecologist: A scientist who studies the relationship between organisms and their ocean environment. Uses visual surveys, diet analysis, and satellite tracking to collect data on a variety of organisms, including penguins.

Fisheries biologist: A scientist who studies fish and their prey. Collects data on krill during research vessel cruises.

FIGURE 4

Climatologists: Air temperature data set.



Data source: Palmer LTER Data Archive *(http://pal.lternet.edu/data/dataset_catalog.php)*, supported by NSF Grant No. OPP-96-32763.

Chinstrap and Adélie penguins.

Chinstrap penguins *(Pygoscelis antarctica)* are primarily found on the Antarctic Peninsula and in the Scotia Arc, a chain of islands between the tip of South America and the Peninsula. Their name comes from the black band running across their chins. Adult chinstraps stand 71–76 cm tall and weigh up to 5 kg.

Adélie penguins *(Pygoscelis adeliae)* breed on the coast of Antarctica and surrounding islands. They are named after the wife of French explorer Jules Sébastien Dumont d'Urville. Adult Adélies stand 70–75 cm tall and weigh up to 5 kg.

Activity overview

For our directed inquiry, we use the *jigsaw technique,* which requires every student within a group to be an active and equal participant for the rest of the group to succeed (Colburn 2003). To begin, students are organized into "Home Groups" composed of five different specialists. (**Note:** See "Procedure" in the next section for specific instructions on how each student assumes the identity of a different specialist.) Specialists from each Home Group then reorganize into "Specialist Groups" that contain only one type of scientist (e.g., Group 1 could include all of the Ornithologists and Group 2 all of the Oceanographers). Each Specialist Group receives a piece of the flowchart in Figure 1 (p. 57), in the form of a data table. With only a few facts to guide them, the Specialist Groups create graphs from the data tables, brainstorm explanations for patterns in their data, and report results back to their Home Groups. Finally, Home Groups use the expertise

FIGURE 5

Ornithologists: Adélie penguin dataset.

Year	# Breeding pairs of Adélie penguins
1975	15,202
1979	13,788
1983	13,515
1986	13,180
1987	10,150
1989	12,983
1990	11,554
1991	12,359
1992	12,055
1993	11,964
1994	11,052
1995	11,052
1996	9,228
1997	8,817
1998	8,315
1999	7,707
2000	7,160
2001	6,887
2002	4,059

MICHAEL ELNITSKY

- Adélie penguins spend their summers on land, where they breed. They spend winters on the outer extent of the sea ice surrounding Antarctica, where they molt their feathers and fatten up.
- Adélies are visual predators, meaning they need enough light to see their prey. Near the outer part of the pack ice, there are only a few hours of daylight in the middle of the winter. There is less sunlight as one moves further south (closer to land).
- On the western Antarctic Peninsula, Adélie penguins mostly eat krill, a shrimplike crustacean.
- Several countries have been harvesting krill since the mid 1960s.
- Adélie penguins need dry, snow-free places to lay their eggs. They use the same nest sites each year and at about the same time every year. Heavy snowfalls during the nesting season can bury adult Adélies and kill their eggs.
- Female Adélies lay two eggs, but usually only one of those eggs result in a fledged chick (fledged chicks have a good chance of maturing into adults). The two most common causes of death of eggs and chicks are abandonment by the parents (if they cannot find enough food) and predation by skuas (hawklike birds).
- In the water, Adélies are eaten mostly by leopard seals and killer whales.
- Adélies can look for food under sea ice because they can hold their breath for a long time. They are not as good at foraging in the open ocean, because they cannot swim very fast.
- Adélie penguins have lived in the western Antarctic Peninsula for at least 644 years.

Data source: Smith, Fraser, and Stammerjohn 2003.

of each specialist to reconstruct the entire flowchart (Figure 1, p. 57).

Before starting this activity, students should have at least a rudimentary knowledge of Antarctica. Teachers can find a collection of links to our favorite Antarctic websites at *www.units.muohio.edu/cryolab/education/AntarcticLinks.htm.* Teachers also can engage student interest in this inquiry by showing video clips of penguins, which are naturally appealing to students of all ages. We also have short movies of Adélies feeding their young and battling predators on our website at *www.units.muohio.edu/cryolab/education/antarcticbestiary.htm.*

The activity

Materials

- Specialist fact sheet (Figure 3; one for each student or one overhead for the entire class)
- Temperature data (Figure 4; one overhead for the entire class)
- Datasets for each Specialist Group (Adélie penguins [Figure 5], sea ice [Figure 6, p. 60], winter snow [Figure 7, p. 61], chinstrap penguins [Figure 8, p. 62], and krill [Figure 9, p. 63])
- Specialist Group report sheets (found online at *www.nsta.org/tst0907*; one for each student)
- Sheets of graph paper (one for each student), or computers connected to a printer (one for each Specialist Group)
- Sets of six flowchart cards (one complete set for each Home Group); Before the inquiry, teachers can make flowchart cards by photocopying Figure 1 and cutting out each box (e.g., "Air Temperature," "Sea Ice Extent," etc.)
- Paper, markers, and tape for constructing flowcharts

Procedure: class period 1 (45 minutes–1 hour)

1. Split the class into Home Groups of five students each. Assign the name of a different real-life research agency to each group (see *www.units.*

FIGURE 6

Oceanographers: Sea ice dataset.

Year	Area of sea ice extending from the Antarctic Peninsula (km^2)
1980	146,298
1981	136,511
1982	118,676
1983	88,229
1984	85,686
1985	78,792
1986	118,333
1987	142,480
1988	90,310
1989	44,082
1990	79,391
1991	111,959
1992	110,471
1993	94,374
1994	103,485
1995	95,544
1996	86,398
1997	100,784
1998	73,598
1999	79,223
2000	79,200
2001	69,914

- In the winter (August), sea ice covers over 18 × 106 km^2, or 40%, of the Southern Ocean (an area larger than Europe). In the summer (February), only 3 × 106 km^2 (about 7%) of the ocean is covered by sea ice.
- Sea ice keeps the air of the Antarctic region cool by reflecting most of the solar radiation back into space.
- Open water absorbs solar radiation instead of reflecting it and converts it to heat. This heat warms up the atmosphere.
- Sea ice reduces evaporation of the ocean, thus reducing the amount of moisture that is released to the atmosphere.
- As sea ice melts, bacteria and other particles are released into the atmosphere. These particles form condensation or freezing nuclei, which grow into rain or snow.
- Rain helps to stabilize the sea ice by freezing on the surface.
- Sea ice can be broken up by strong winds that last a week or more.
- An icebreaker is a ship used to break up ice and keep channels open for navigation. Icebreakers were first used in the Antarctic in 1947.

MARIANNE KAPUT

Data source: Palmer LTER Data Archive *(http://pal.lternet.edu/data/dataset_catalog.php)*, supported by NSF Grant No. OPP-96-32763.

muohio.edu/cryolab/education/AntarcticLinks.htm#NtnlProg for examples).

2. Instruct students to read the Specialist fact sheet (Figure 3, p. 58). Within a Home Group, each student should assume the identity of a different specialist from the list.
3. Introduce yourself: "Welcome! I'm a climatologist with the Intergovernmental Panel on Climate Change in Geneva, Switzerland. In other words, I study long-term patterns in climate. My colleagues and I have researched changes in air temperatures on the Antarctic Peninsula since 1947. We have observed that although air temperatures on the Peninsula cycle up and down, they have increased overall (show Figure 4, p. 58). We think this might be occurring because of an increase in greenhouse gases, but we are unsure of the impacts on the Antarctic ecosystem. Your team's job is to describe the interconnected effects of warming on Antarctica's living and nonliving systems."
4. Direct the specialists to meet with their respective Specialist Groups. Specialist Groups should *not* interact with one another.
5. Distribute the datasets and Specialist Group report sheets to each Specialist Group. The specialists should graph their dataset and interpret the graph.

Procedure: class period 2 (45 minutes–1 hour)

6. Hand out a complete set of flowchart cards to the reconvened Home Groups. Each specialist

FIGURE 7

Meteorologists: Winter snow dataset.

Year	% of precpitation events that are snow
1982	49
1983	67
1984	72
1985	67
1986	81
1987	80
1988	69
1989	69
1990	68
1991	72
1992	70
1993	70
1994	83
1995	77
1996	74
1997	81
1998	81
1999	83
2000	77
2001	90
2002	82
2003	76

- In the winter, most of the precipitation in the western Antarctic Peninsula occurs as snow. There is an even mix of snow and rain the rest of the year.
- It is difficult to accurately measure the amount of snowfall in the Antarctic because strong winds blow the snow around.
- The Antarctic Peninsula has a relatively warm maritime climate, so gets more rain and snow than the rest of the Antarctic continent.
- Most of the rain and snow on the Peninsula is generated by cyclones from outside the Southern Ocean. Cyclones are areas of low atmospheric pressure and rotating winds.
- When there is less sea ice covering the ocean, there is more evaporation of the ocean and therefore more moisture in the atmosphere.
- As sea ice melts, bacteria and other particles are released into the atmosphere. These particles form condensation or freezing nuclei, which grow into rain or snow.

LUKE SANDRO

Data source: Antarctic Meteorology Online, British Antarctic Survey *(www.antarctica.ac.uk/met/metlog/)*.

should make a brief presentation to his or her Home Group approximating the format on the Specialist Group report sheet. Home Groups should then construct their own flowchart using all the flowchart cards. Remind the students throughout this process that they should use the *weight of evidence* to construct the flowcharts. In other words, each idea should be accepted or rejected based on the amount of support it has.

7. Consider these discussion questions at the end of the period as a class, by Home Group, or as homework for each student:

- How has the ecosystem of the Antarctic Peninsula changed in the last 50 years? What are the most likely explanations for these changes?
- Is there sufficient evidence to support these explanations? Why or why not? What further questions are left unanswered?
- Did your Specialist Group come up with any explanations that you think are not very likely (or not even possible!), based on the complete story presented by your Home Group?

Assessment

To assess student learning, we use a simple performance rubric that can be found online at *www.nsta.org/0907*. The rubric focuses on group work and the nature of science. Depending on the unit of study in which this inquiry is used, a variety of specific content standards also may be assessed. For example, in an ecology unit, teachers may wish to determine student knowledge of interactions among populations

FIGURE 8

Marine ecologists: Chinstrap penguin dataset.

Year	# of breeding pairs of chinstrap penguins
1976	10
1977	42
1983	100
1984	109
1985	150
1989	205
1990	223
1991	164
1992	180
1993	216
1994	205
1995	255
1996	234
1997	250
1998	186
1999	220
2000	325
2001	325
2002	250

- Chinstrap penguins breed on land in the spring and summer and spend the rest of the year in open water north of the sea ice. The number of chinstraps that successfully breed is much lower in years when the sea ice does not melt until late spring.
- Chinstraps mostly eat krill, a shrimplike crustacean.
- Whalers and sealers overhunted seals and whales, which also eat krill, until the late 1960s.
- Chinstraps primarily hunt in open water, because they cannot hold their breath for very long.
- The main predators of chinstraps are skuas (hawklike birds), leopard seals, and killer whales.
- Chinstraps will aggressively displace Adélie penguins from nest sites in order to start their own nests, and may compete with Adélies for feeding areas.
- Although chinstrap penguins have occupied the western Antarctic Peninsula for over 600 years, they have become numerous near Palmer Station only in the last 35 years.

MICHAEL ELNITSKY

Data source: Smith, Fraser, and Stammerjohn 2003.

and environments; in an Earth science unit, teachers could check student understandings about weather and climate.

Modifications

Some students have initial difficulties with the construction and interpretation of flowcharts. Once students have connected their flowchart cards with arrows, it may be useful to have them label each arrow with a verb. For instance:

↑ sea ice extent **causes** → ↓ winter snowfall

Teachers can shorten this lesson by starting immediately with Specialist Groups, rather than with Home Groups. Another option is to provide graphs of the data rather than having Specialist Groups create their own.

To make this lesson more open-ended, students may do additional research on the connections between sea ice, krill, and penguins. Instructors should keep in mind, however, that the majority of resources on this topic are articles in primary scientific journals. If teachers have access to a university library, they might wish to make a classroom file of related journal articles. A more engaging extension would be for students to generate ideas for new research studies that would address questions left unanswered by the current inquiry. This type of activity could range from asking students to formulate new hypotheses to asking students to write short proposals that include specific research questions and plans to answer those hypotheses.

Many students have trouble comprehending how just a few degrees of atmospheric warming (in this case, 3°C) could make a difference in their lives. The decline of a charismatic species such as the Adélie penguin is an example of how a seemingly minor change in climate can pose a major threat to plants and animals. Beyond the effects of climate change, however, the activity illustrates the multidisciplinary, international, and above all cooperative nature of science. We want social teenagers to realize that they do not have to sit alone in a lab to do science. ■

FIGURE 9

Biologists: Krill dataset.

Year	Density of krill in the Southern Ocean (no./m^2)
1982	91
1984	50
1985	41
1987	36
1988	57
1989	15
1990	8
1992	7
1993	22
1994	6
1995	9
1996	31
1997	53
1998	46
1999	4
2000	8
2001	31
2002	8
2003	3

Data source: Atkinson et al. 2004

- Krill are a keystone species, meaning they are one of the most important links in the Antarctic food web. All the vertebrate animals in the Antarctic either eat krill or another animal that eats krill.
- Krill eat mostly algae. In the winter, the only place algae can grow is on the underside of sea ice.
- Several countries have been harvesting krill since the mid 1960s.
- Ultraviolet radiation is harmful to krill, and can even kill them. Worldwide, ozone depletion is highest over Antarctica.
- Salps, which are small, marine animals that look like blobs of jelly, may compete with krill for food resources. As the salt content of the ocean decreases, salp populations increase and krill populations increase.

RICHARD E. LEE JR.

Juanita Constible (constijm@muohio.edu) *is a science education writer at Miami University in Oxford, Ohio; Luke Sandro* (luke.sandro@gmail.com) *is a biology teacher at Springboro High School in Springboro, Ohio; Richard E. Lee Jr.* (leere@muohio.edu) *is a distinguished professor of zoology in the Department of Zoology at Miami University in Oxford, Ohio.*

Acknowledgments

The authors would like to thank personnel at Palmer Station, especially W. Fraser, for valuable background information related to this article. M. Kaput, S. Bugg, S. Waits, S. Metz, S. Nuttall, A. Carlson, and an anonymous review panel provided constructive criticism on previous drafts of this article. This project was supported by NSF grants No. OPP-0337656 and No. IOB-0416720.

References

Ainley, D.G. 2002. *The Adélie penguin: Bellwether of climate change*. New York: Columbia University Press.

Atkinson, A., V. Siegel, E. Pakhomov, and P. Rothery. 2004. Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature* 432:100–103.

Clarke, A., E.J. Murphy, M.P. Meredith, J.C. King, L.S. Peck, D.K.A. Barnes, and R.C. Smith. 2007. Climate change and the marine ecosystem of the western Antarctic Peninsula. *Philosophical Transactions of the Royal Society B* 362: 149–166.

Colburn, A. 2003. *The lingo of learning: 88 education terms every science teacher should know*. Arlington, VA: NSTA Press.

Fraser, W.R., and D.L. Patterson. 1997. Human disturbance and long-term changes in Adélie penguin populations: A natural experiment at Palmer Station, Antarctic Peninsula. In *Antarctic communities: Species, structure and survival*, eds. B. Battaglia, J. Valencia, and D.W.H. Walton, 445–452. Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). 2007. *The physical science basis: Summary for policy makers*. Working Group I Report. *www.ipcc.ch*

Smith, R.C., W.R. Fraser, and S.E. Stammerjohn. 2003. Climate variability and ecological response of the marine ecosystem in the Western Antarctic Peninsula (WAP) region. In *Climate variability and ecosystem response at Long-Term Ecological Research (LTER) sites*, eds. D. Greenland, D. Goodin, and R.C. Smith, 158–173. New York: Oxford Press.

Wadhams, P. 2000. *Ice in the ocean*. The Netherlands: Gordon and Breach Science Publishers.