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Key Concepts in Polar Science: Coming to Consensus on the Essential Polar Literacy Principles

BY JANICE MCDONNELL, LIESL HOTALING, OSCAR SCHOFIELD, AND JOSH KOHUT

ABSTRACT

Key concepts in Polar Science emerged as a result of working with both scientists and educators. The goal was to develop a consensus document that would address what the public should know and understand about the Polar Regions. The key concepts were created to enable scientists to construct more effective Broader Impacts projects to engage people in learning about Polar Regions and for educators to integrate information about the Polar Regions into their STEM teaching.

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- Atmospheric Science Literacy (<https://scied.ucar.edu/atmospheric-science-literacy-framework> and Climate Literacy)
- Climate Literacy (<https://www.climate.gov/teaching/essential-principles-climate-literacy/essential-principles-climate-literacy>)
- The Polar Literacy Principles (<https://polar-ice.org/polar-literacy-initiative/>)

Polar Fun and Games

BY MARGIE TURRIN, STEPHANIE PFIRMAN, AND LAWRENCE HAMILTON

ABSTRACT

Reaching students and the general public with the Polar Literacy Principles will require both formal and informal education approaches. The Polar Learning and Responding: Climate Change Education Partnership developed a suite of fun and interactive resources addressing many of the recommended Polar Literacy areas for use in settings, ranging from classrooms to museums and science festivals. Topics for the resources were identified using general-public surveys. Our resources have reached millions of participants through approaches that included direct facilitation by team members and train-the-trainer events, and indirectly through other media. Our audience has encompassed a diverse and broad range including Alaskan leaders, educators and community members, the general public, parents/caregivers and their children, and teachers and educators for grades 5-16 serving a broad socioeconomic range of students.

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Bringing Long-term Ecological Research (LTER) at Palmer Station, Antarctica to your Classroom

BY JANICE MCDONNELL, OSCAR SCHOFIELD, AND CHRISTINE BEAN

ABSTRACT

The Long-term Ecological Program at Palmer Station, Antarctica is developing educational strategies for engaging students and educators in climate science research. In this paper, we share two techniques, including teaching with LTER data and engaging virtually with scientists through video teleconferences (VTCs), as strategies for increasing engagement in scientific data and student's ability to connect with practicing scientists in the field.

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A Whale of a Roller Coaster

BY JOANNA CHIERICI, NANCY FITZGERALD, AND KATIE LODES

ABSTRACT

To most students Antarctica remains a distant location, unconnected to their lives and daily concern. The Polar Interdisciplinary Coordinated Education (Polar-ICE) program creates opportunities for educators and students to get involved in polar research. Facilitating access to polar scientists, their field data, and the story behind their research can connect students to this fragile polar environment, which is under threat from climate change.

Polar scientists are using advanced technologies, such as oceanographic sensors, aerial and marine unmanned vehicles, and GPS tracking devices, to help understand this changing ecosystem. Technological advances such as these allow for enhanced sampling capabilities and reduced logistical costs as well as provide rich datasets, which can tell us a great deal about the Antarctic ecosystem. There is a growing need to create innovative learning experiences which bring real-world datasets, models, and simulations into the classroom (NRC Framework 2012). Long-term data sets generated from research missions such as this, support the larger scientific community, and provide rich resources to support educational and outreach opportunities to engage pre-K through postgraduate classrooms.

Using data in the classroom is an integral component of meeting the Next Generation Science Standards (NGSS) in K-12 STEM teaching nationwide (Manduca and Mogk 2002; Adams and Matsumoto 2009; and Kastens 2010). Early exposure to hands-on science with data-rich activities can enhance learner motivation, investment, and achievement in science (NRC 2000; McGrath 2001; National Center for Education Statistics 2001; Parsons 2006; and Hug and McNeill 2008). Utilizing polar data streams and observations provide unique opportunities to engage students.

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It Takes a 'Superhero' to Uncover the Climate Secrets in Fossilized Arctic Ocean Dinocysts

BY MARGIE TURRIN, ESTELLE ALLAN, JEREMY STOCK, AND LAUREL ZAIMA

ABSTRACT

The ocean is a dynamic system that is teeming with life, and an invaluable resource providing a host of ecosystem services that humans rely on. Yet it also holds messengers of past climate, including past sea ice cover in the Arctic. The ocean is an archive of Earth's history, where hidden in the sediments are tiny fossils, small recordings of past environmental conditions, geologic events, and climate. This information about the past can be used to build predictions of the future. The National Science Foundation-funded Arctic research project, *Snow On Ice*, explores sea ice cover in the Middle Holocene warming—a period warmer than today—by investigating microscopic dinocysts collected from Arctic Ocean sediment cores. The project developed a pre- and post-tested set of educational materials entitled *Scientists are Superheroes* to introduce the science through a unique combination of scientist superhero postcards, posters, and a downloadable curriculum that explores how scientists use proxies to understand past climate in order to build models and predictions of future climate.

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Bring on the Polar Data: Two Approaches to Connect Students with Polar Data through the Polar-ICE Project

BY KRISTIN HUNTER-THOMSON

ABSTRACT

Leveraging the power of data and storytelling, we tested new ways to connect teachers and students with Polar Regions through two projects with Polar-ICE. We designed short, interactive Data Stories to provide students a glimpse of what happens at the Poles while practicing key data skills. We also developed a year-long immersion experience for students to work with professionally collected polar data to ask and answer their own questions about the Poles. This article highlights our process of developing, implementing, and evaluating these projects as well as the lessons we learned from these two approaches.

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Polar-ICE Data Stories: Putting Real Data from Polar Regions into the Hands of Students

BY HOPE BIGWARFE AND STACEY SEBERT

ABSTRACT

The Polar-ICE Data Stories provide a unique way of connecting students with real-world, phenomenon-based data that addresses multiple topics in New York State Middle School curricula. Since 2017, we have used multiple Polar-ICE Data Stories with middle school students and at-risk high school students—and find the material flexible and engaging for our wide range of learners. In addition, the students enjoy thinking critically about the data and making their claims from the evidence. Here, we share examples of two integrated Data Stories that we implemented in our classrooms as well as the student responses to their experiences.

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Using Polar-ICE Data Stories to Drive Small Group Student Research Projects

BY JULIE WOOD

ABSTRACT

A high-need, urban high school may seem like an unlikely location to utilize polar data; however, students in a Brooklyn school used Polar-ICE Data Stories to structure small group research projects and presented their results during a STEMposium. Students used data in accessible formats to understand and evaluate different aspects of a polar environment. The interactive projects were connected to Earth Science curricula and NGSS and Common Core standards.

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- Plastic Soup Foundation: <https://www.plasticsoupfoundation.org/en/psf-in-action/plastic-footprint-2/>

Empowering Students with Polar Science Through Real-World Data

BY KRISTIN HUNTER-THOMSON, JOSH KOHUT, AND GRACE SABA

ABSTRACT

Since 2011 we have been exploring different ways to advance Polar Science and broader science education. Through various broader impact and education projects, primarily funded by the National Science Foundation, we developed a sequence of educational experiences for teachers and students grounded in partnerships that connect teacher/student audiences to the Polar Regions, and allow them to explore real-world phenomenon. We provide a description of the different projects, discuss how our approach evolved to leverage our successes, and share our lessons learned.

INTRODUCTION

- *How do we move students beyond penguins and polar bears?*
- *How do we engage kids in the United States with science happening at the Poles?*
- *We immerse them in Antarctic science missions!*

Over the past eight years we integrated students, in real time, into various science missions at the Poles. Our process and approaches have evolved, but the objective has stayed the same: connecting students, teachers, and scientists together as partners in science.

A key ingredient creating connections is the utilization of authentic, real-world data to empower students to be scientists alongside the Polar Science teams in the field. Using data in the classroom is an important component of STEM (science, technology, engineering, and mathematics) education for philosophical, pedagogical, and practical reasons (Manduca and Mogk 2002; Adams and Matsumoto 2009; Kastens 2010) and also integral to the Next Generation Science Standards (NGSS) in K-12 STEM teaching nationwide. Research has shown that early exposure to hands-on science with data-rich activities can enhance learner motivation, investment, and achievement in science (NRC 2000; McGrath 2001; National Center for Education Statistics 2001; Parsons 2006; Hug and McNeill, 2008). Therefore, we wanted to create innovative learning experiences that brought real-world datasets, models, and simulations into the

classroom as a means to that end. Utilizing ever expanding polar data streams and observations provides unprecedented opportunities to expand teaching and learning innovations in STEM classrooms that could potentially be the bridge for classrooms to engage and understand how Polar Regions influence their lives.

Here we outline the development path of four previous projects and discuss plans for our next iteration of closing the large geographic, and often conceptual, gap between students and important research conducted in the Polar Regions as a way to connect students with the vital polar ecosystems and empower them to conduct authentic science.

ROSS SEA CONNECTION PROJECT

The Ross Sea Connection (<http://coseenow.net/ross-sea/>) engaged teachers and students as virtual members of a scientific field team aboard the *RVIB Nathaniel B. Palmer* in the Ross Sea, Antarctic during the austral summer season (Dec 2010-Feb 2011; NSF ANT-0839039). It was a ship-based expedition to explore the sources of nutrients and trace metals and their role in the Ross Sea food web. We partnered with Chris Linder, a professional science photographer; and Hugh Powell, professional science writer; and three educators at the Liberty Science Center to develop and implement the Broader Impacts, connecting Polar Science with non-scientist audiences. In addition, the project participants included an outreach team of 4 educators, 18 scientists, teachers from 16 schools, and 400+ students.

During the summer, prior to the Antarctic field season, we convened 6-9th grade teachers from across New Jersey to join our science team and bring our polar research into their classrooms. For a week, we explored the concepts driving our hypotheses and participated in a range of classroom-ready activities. As we were packing up our science equipment to send it south, students all over New Jersey were diving deep into learning about Antarctica. Teachers used a provided bank of lesson plans relating to Antarctica, or developed their own to introduce participating students to the Ross Sea region

and the research area and topics. During January, while the science team was aboard the *R/V Palmer*, Chris and Hugh produced Daily Journal entries on a blog for students to follow along during the research mission. Additionally, each participating school joined in a conference call with multiple members of the research team as well as ship crew to learn about what was happening in real-time and ask their own questions about the science, and what life was like aboard an Antarctic research vessel.

Exit surveys with participating teachers indicated that throughout the project the teachers and students grew attached to and invested in the science mission and science team. Many teachers even reached out to the education team to inquire about the safety of the scientists following the 2011 Christchurch earthquake as the students were worried knowing “their scientists” were flying home through New Zealand. The project ended with students energized about “their” polar scientists; and the science professionals excited to participate in more outreach efforts, according to our evaluation surveys and follow-up conversations. The teachers also communicated through exit surveys, suggesting things to consider doing differently in future projects. For example, participating teachers reported that the general Antarctic lesson plans bank, which were not specifically related to the research project, did not fully help students make sense of the ins-and-outs of the research mission. Instead, teachers were interested in using lesson plans specifically aligned with the hypotheses and approach of the research mission. Additionally, teachers reported that they felt the end of the field season brought an abrupt end to the partnership as there were no connection points between the research team and the schools following the end of the intensely, interconnected field season.

PROJECT PARKA (PLANTING ANTARCTICA IN KANSAS)

Building off of the momentum from the Ross Sea Connection and the suggestions of those participating teachers, we developed another year-long immersion experience for Kansas high school students during the 2013-14 academic year in conjunction with a research mission to study the impacts of ocean acidification on organisms instrumental to the Antarctic food web: Project PARKA (<http://coseenow.net/project-parka/>; NSF #1246293). The project participants included an outreach coordinator, 6 scientists, teachers from 19 high schools, and 500+ students. Here, our goals were to connect students to the complex multi-disciplinary scientific research and to demonstrate a broader sense that as students in a landlocked state their actions had impacts on organisms and the ecosystems thousands of miles away in Antarctica. We addressed



Figure 1. Students collecting data in a hands-on demonstration of the process of ocean acidification. Courtesy of Ruth Hutson

these aims through a teacher training workshop, unique lesson plans, student group research projects, video conferencing between scientists and the participating schools, and a spring student research symposium.

We first developed the connection between the participating teachers and scientists through a kick-off three-day training workshop in July 2013. First the lead scientist (Saba) presented the background information about the Antarctic research that would be happening in the field. Then Saba and the outreach coordinator (Hunter-Thomson) facilitated the teachers to participate in each of the provided lesson plans as learners themselves and then discuss strategies for teaching each. Rather than a suite of general Antarctic related lessons, we developed unique lessons that specifically addressed aspects of the hypotheses of the science team or mimicked the work the scientists would be doing. Teachers integrated these four provided lesson plans into their curriculum in the fall and early winter of 2013 to better provide all participating students with a sense of what was happening during the research field season (Figure 1).

Each lesson plan included the scientific background information needed to prepare the students and all necessary materials. To compliment the lessons, the students worked in small groups (3-4) to conduct an independent research project, on a topic of their choosing, that they worked on during the school year. These projects were designed with limited and shared resources, but the teachers, outreach coordinator, and scientists worked together to ensure each project was logistically feasible.

Similar to the Ross Sea Project, we connected all participating students with the scientists through video conferences while the scientists were in the field in January 2014. This allowed students to meet the scientists, experience their laboratory set-up in Antarctica, and focus some of their questions on the activities surrounding the scientific team in real-time. However, we built upon this connection between students and scientists by adding a culminating experience for all to connect in person. At the end of the project year following the research field season, we hosted a symposium that was attended by most of the participating high school students and teachers at the Washburn University campus in Topeka, Kansas on April 15, 2014. We modeled this symposium after a scientific conference with three components: 1.) oral presentations by the scientists describing preliminary research findings during their field season; 2.) poster presentations used by high school students to communicate outcomes from their group research projects to several participating scientists and each other for feedback; and 3.) a career panel with five scientists who briefly described their path to science followed by an open-discussion forum for student questions.

Again, participating teachers and students developed a strong bond with the science team and their work as indicated on post-project surveys. According to teacher and student survey responses, students gained a broader understanding of Antarctica as well as a thorough understanding of the scientists' research and how they were going about it via the developed lesson plans. The culminating experience was a highlight for many participating students as they got to present their original research to "real" scientists. The event also served as a celebration of the teachers, students, and scientists working together for the year. This project was a success, and the participating teachers offered suggestions to consider in designing future programs. For example, while many enjoyed the diversity of the student research projects, others communicated the research projects did not relate to Antarctica and; thus, felt disjointed from the project overall, creating a bit of a mismatch at the culminating event. These teachers expressed an interest in supporting their students to conduct polar research in the future, similar to the research team their students had connected with during the project.

PROJECT CONVERGE

We were able to roll our lessons learned from and build on suggestions from those teachers in Project PARKA straight into another opportunity to implement a year-long Polar Science Broader Impacts project during the 2015-16 academic year. We were fortunate to be awarded a grant for an interdisciplinary project looking at the connections

between the physical oceanography and top predators (Adélie penguins) off the Western Antarctic Peninsula (WAP). This research required a diverse team of scientists and engineers from across the Western Hemisphere to review the data and communicate in real-time to make decisions about the project. This provided an opportunity to invite the students to be contributing members of our science and engineering team. The access to our real-time datastreams allowed the students to get a first look at the data, even before the teams deployed in Antarctica had a chance to analyze it! The project participants in this project included 7+ scientists, Chris Linder, Hugh Powell, 3 educators from the Liberty Science Center, an outreach coordinator and team, 22 teachers, and 1100+ students.

We ran Project CONVERGE (<http://coseenow.net/converge/>) with 6-9th grade classrooms from throughout New Jersey and New York. Prior to the summer workshop, we developed data-based lessons that taught students about the concepts driving the research mission's hypotheses. Three of the lessons explored the physical oceanography, ecology and food web dynamics, and engineering aspects of the project to help students understand the research mission (Figure 2).

Through the fourth lesson we transitioned the students from spectators of the science to contributing participants in the science. The students had to make sense of data similar to what the scientists would be looking at in the field and work in teams to determine which scientific instruments they would use, and propose how they would deploy the



Figure 2. Teachers participating in the hands-on activity regarding convergence zones before looking at wave data from around the Palmer Research Station in Antarctica.

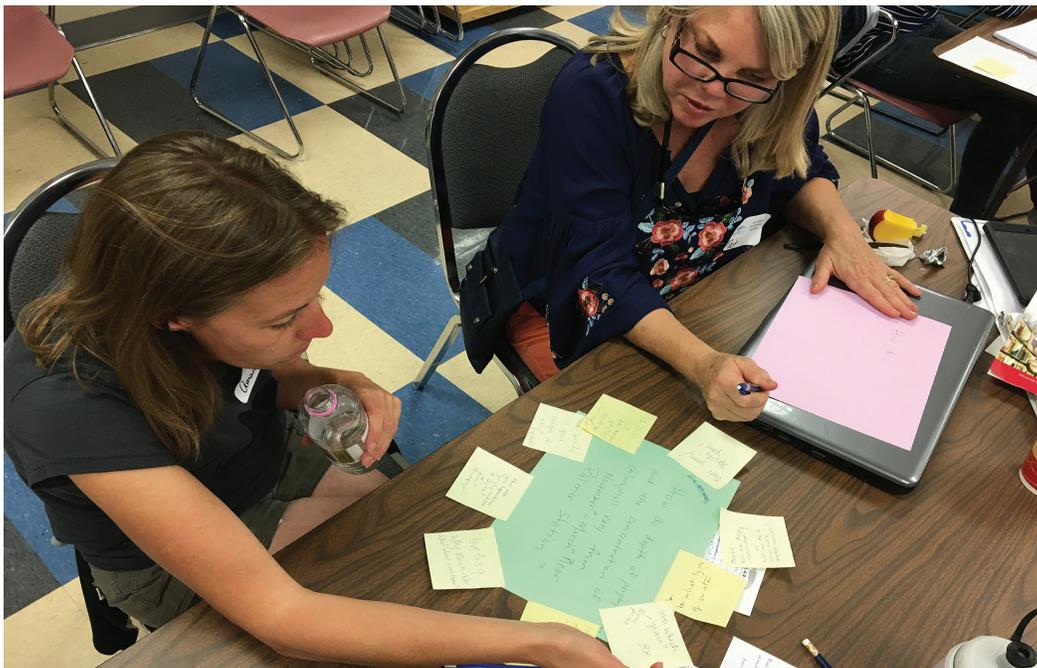


Figure 3. Teachers at the 2017 Summer Institute working to refine their testable question to explore during their investigation based on feedback from their peers in a gallery walk.

instruments in the field (directly modeling what the scientists would be doing during their field season). Additionally, we were fortunate to be able to work with Chris and Hugh again, so while the science team was in Antarctica there was a daily blog posted by professional science communicators. The students also participated in video conference calls with the science team when they were in Antarctica. Building off of the success of the culminating event for Project PARKA, the students were asked to develop their own ocean- and/or polar-theme investigations using data to present at the Student Research Symposium at the Liberty Science Center.

The students' projects were sophisticated in their use of data to answer their investigation questions. Teachers commented that two aspects of the project that most supported their students use of data were the data-based lessons and the data primer. The unique lessons developed for this project each contained data and asked the students to make sense of the data as they were learning the concepts. Additionally, we developed a Data Primer to explain all of the different datastreams being produced by the project, and how to access and use the data (as anyone could access the research mission's data in real-time with the scientists). In fact, more than half of the participating students in the project elected to use data collected by the science team for their own projects. The students and teachers were not only

connected to the science team, but also became connected to the WAP ecosystem as they explored the data to answer their own science questions. Through post-project surveys and a focus group, participating teachers communicated with us that they were surprised with how much their students had struggled to develop testable questions and make sense of the large professionally collected datasets through the project. Many asked us for additional resources to better support their students develop these skills.

SCIENCE INVESTIGATIONS (SCI-I) PROJECT

An opportunity to put more focus on building process of science and data skills through polar data materialized through the Polar-ICE (Polar Interdisciplinary Coordinated Education) project (NSF #1525635). We wanted to leverage our lessons learned from the past three projects of year-long immersion experiences that joined teachers, students, and scientists in Polar Science while also providing more targeted support around data skills as requested by previous teachers. Therefore, we wanted to test a model that put a larger emphasis on building out students' data skills when working with professionally collected data than on the content of any one particular research project. As a result, the Sci-I (Science Investigations) Project (<https://polar-ice.org/educator-resources/sci-i-workshops/>) was developed. During the 2016-17 and 2017-18 academic years, we worked

with students in grades 6-9 from New Jersey, Ohio, Missouri, Colorado, Utah, and California (see Hunter-Thomson within the journal [*Current*, Volume 34, Number 1, Winter 2020] for a more complete description of the project).

Students developed and conducted authentic science investigations using freely available, online, professionally collected data from the Polar Regions, many looking at data from the Palmer Long Term Ecological Research (<https://pallternet.edu/>) project. The students conducted an observational investigation by developing their own questions, looking for patterns within existing data (a new experience for many students), and communicating their findings to their peers, teachers, and scientists. While the Sci-I Project did not include any specific lesson plans for the students, we did cover a wide range of activities with the teachers at a week-long summer institute prior to each implementation year. During the institute, the teachers conducted investigations using polar data as well as discussed implementation strategies (Figure 3).

During the year, the students were required to submit mini-proposals of their project ideas so that we could provide suggestions and feedback. Each year we hosted a student research symposium within each state at a central university for the students with the top projects from each participating school to attend, present their work, and meet polar scientists. According to student and teacher surveys, the students were empowered by their ability to ask and answer questions that no one else had asked previously from the real-world data. Additionally, the teachers and students reported using data and process of science skills developed through the Sci-I Project in other aspects of the curriculum.

NEXT STEPS

Through these four projects, we have learned invaluable lessons about connecting students with scientists in the Polar Regions as they undertake their field work and; afterwards, enhancing students understanding of the process of science, and increasing students' ability to and confidence in working with data to answer their own scientific questions. More specifically, we have learned that the following components of programs driven to connect students, teachers, and scientists together as partners in science should include:

- Inviting researchers to participate in summer trainings so that the teachers have a chance to ask their own questions about the science and meet the scientists.
- Conducting teacher professional development workshops that are centered around supporting teachers completing for themselves what they are asking their students to do,

fostering a sense of a professional learning community among participants, and providing ample time to discuss and plan how to implement the program into their classrooms.

- Developing lesson plans that align with grade-level standards and utilize data from, or at least similar to, the research project to help students understand the specific components of and hypotheses in the research mission.
- Providing suggested online data portals and support resources for how to access and download the data to teachers and students, so they feel successful in searching freely available, professionally collected data to use.
- Utilizing online video conferencing technology to connect scientists in the field with students in their classrooms, so the students can meet the scientists, see where and how the research is happening, and ask the scientists questions.
- Encouraging students to develop mini-proposals of their research projects to receive feedback from scientists prior to completing their research projects, so that they can learn about the iterative process of science and adjust while working on the project.
- Host a culminating experience for teachers, students, and scientists to attend that facilitates one-on-one communication between the stakeholder groups and highlights the successes of the students in their science research.

While these projects led to communicated and measurable impact on the scientists, teachers, and students who participated in each project, we found that the impact of the project largely stayed within the classroom of individual participating teachers. In other words, through these four projects we were able to identify components that resulted in change for the particular teachers and students participating. But, we were not able to identify ways to share or scale the model so that more teachers and students could benefit from our lessons learned.

We received the news that a follow-up research mission to CONVERGE was funded in the fall of 2018 and; thus, began to think about how we could build on the momentum to date and develop a broader impact approach that scaled our successes to more teachers and students. We kicked off Project SWARM (<https://polar-ice.org/swarm-workshop-2019/>) in the summer of 2019. The emphasis of this project is similar to previous projects of connecting teachers, students, and scientists as well as enhancing students' awareness and understanding of Polar Regions, the process

of science, and how to make sense of lots of data. However, we are building this effort as a train-the-trainer model so that the approach can reach more teachers and students. Teachers who have participated in these past projects were invited to apply to be Teacher Leaders in their local areas. As a community, we are working to develop a way to lead professional development trainings within our local communities to encourage and support more teachers to integrate data and Polar Science into their classrooms.

Through this latest project and others yet to come, we look forward to seeing how these efforts sustain and scale over time so that more students feel confident in using data, feel connected to the Polar Regions, and identify as scientists.

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Using Long-Term Data From Antarctica to Teach Ocean Acidification

BY PATRICIA S. THIBODEAU

ABSTRACT

Ocean acidification (OA) results from the addition of carbon dioxide (CO₂) to seawater and is an applicable topic when discussing the general concepts of seawater chemistry as well as broader topics including climate change and human impacts (much of the CO₂ input into the atmosphere is anthropogenic). Global oceans have absorbed approximately a third of the CO₂ produced by human activities, such as burning of fossil fuels, over the past decade, and this accumulation of CO₂ in the ocean has lowered average global ocean pH and; thus, impacted many marine organisms. This lesson plan uses OA as a method to apply more traditional chemistry concepts (i.e., solubility, acids-bases) within the context of global climate change. The lesson focuses on a case study in Antarctica, and the potential effects of OA on an open-ocean plankton, the pteropod (tiro-pod) species *Limacina helicina*, whose shell is easily dissolved in ocean acidification conditions. Through this lesson plan, students will learn ocean chemistry processes, synthesize scientific information, graph and record real scientific data, and make predictions about future trends based on graphical information. Data were collected as part of the Palmer Antarctica Long Term Ecological Research program (PAL LTER) that conducts annual research cruises along the western Antarctic Peninsula 1993-present. Content is intended for grades 9-12 but can be modified for use in grades 6-8. By learning about important scientific concepts related to oceans and utilizing real scientific data, students will better understand the processes governing our oceans and be practiced in answering important scientific and societal questions.

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Bringing the Ends of the Earth to Your Classroom

BY KATHLEEN COUCHON AND MEGAN MCCALL, PH.D.

ABSTRACT

The Polar Regions are sometimes difficult for students to make connections with because they are so remote. This statement cannot be farther from the truth. Two teachers from different regions of the U.S. have been working together for 15 years on various programs to bring Polar Science into the classroom and have created lessons and resources for students of all ages. Polar Science and conservation issues have never been more critical to implement into science classrooms. Providing engaging educational activities that portray accurate Polar Science will help make students better-informed decision makers and advocates for the Polar Regions.

INTRODUCTION

Teachers often struggle to make curricular connections with Polar Regions for their students because these are remote areas that do not seem to have direct impact on their lives. Yet processes at the Poles affect global ocean currents and climate for the entire planet and are the fastest warming areas (EU-PolarNet 2017). This combination is reason alone to relate the Arctic and Antarctic to our students' daily lives through innovative teaching experiences in K-12 classrooms. Being able to connect with scientists is one of the most enriching ways to bring real world science to students. There are several ways to incorporate scientists into the classroom, either in real time or with archived materials. The following are suggested resources with editorial opinions about using the resources in the classroom.

ARMADA Project

The ARMADA Project (www.armadaproject.org) was a research and mentoring program funded by the National Science Foundation and organized by the Office of Marine Programs at the University of Rhode Island Narragansett Bay Campus. For seven years, the ARMADA Project enabled teachers to join scientists on research expeditions and mentor new teachers in the research process. Resources on the ARMADA website include blogs that describe in detail a wide variety of scientific research experiences from both Poles. These blogs provide a rich depository which students can mine for evidence of climate change in the Polar Regions, can use as evidence in Claim-Evidence-Reasoning writing

(NSTA 2014), or to compare and contrast the differences between the Arctic and Antarctic. Comparing the two Poles is a great launching pad for rich conversations and learning in the classroom. The ARMADA website contains a selection of lesson plans developed from research experiences, such as one that explores global climate change, *The Impact of Sea Level Rise on a Local Coastal Community*. In this activity, students utilize topographic maps of their coastal town to illustrate three different scenarios of sea level rise, discuss the impacts, and make suggestions for mitigation. While the lesson is especially impactful for the 40% of students living on the coast (NOAA 2018), it can be eye-opening for inland students as well. Useful skills such as map interpretation, evaluating map data, and data discussion are imbedded in this activity. These skills are valuable across the curriculum. The blogs in this resource are useful to address common misconceptions held by students about the Poles and to allow students to compare and contrast research experiences at both Poles.

EARTH

Another valuable resource for teachers is the EARTH (Educating and Research: Testing Hypotheses) website sponsored by the Monterey Bay Aquarium Research Institute (MBARI) at <https://www.mbari.org/products/educational-resources/earth/>. This site has many teacher-developed lessons. Each summer teachers from across the country come together to learn the latest developments in marine science research. Marine scientists share near real-time data with teachers who then collaborate and use the data to create engaging student lessons. After using the lessons during the school year, teachers evaluate and peer review the lessons. This feedback ensures a high-quality lesson plan. These resources also offer evaluation and extension suggestions. The EARTH Lesson Plan Finder is easily searchable for polar lessons; while some are "in development", many are "published lessons" that have been tested in the classroom and have received high rankings for use.

A popular polar lesson found on the MBARI EARTH website is "Polar Play," which incorporates a game and Polar-ICE Data Stories (<https://polar-ice.org/focus-areas/polar-data-stories/>). Students learn facts about Arctic and Antarctic regions as they



What's the Bigger Picture? Narragansett High School and Narragansett Elementary students creating artwork from climate change graphs. Courtesy of Kathleen Couchon

move along a game board. Real world scenarios are built in to help students understand the unique predicaments that researchers experience in Polar Regions. For example, the research ship can hit an iceberg and players have to move back three spaces in the game. As they complete the game, students are directed to a particular Polar-ICE data story to investigate interviews with scientists and learn more about polar research. In the third and final portion of the lesson, the students create a "Fund My Research" page to pitch their research plan and secure funding just as real scientists do with funding agencies. Through short pre- and post-tests, the students demonstrated an increased knowledge of Polar Regions and an improved attitude about the importance of better understanding these areas.

The STEAM (science, technology, engineering, arts, and mathematics) activity, *What's the Bigger Picture?* (<https://www.mbari.org/what-is-the-bigger-picture/>) is an engaging science and art project accessible to K-12 students. This lesson encourages students to communicate the data of global climate change by creating art from graphs. In one demonstration of this activity, high school freshmen teamed up with elementary students in the same district. The high school students explained the science behind the graph to the first graders and they collaborated to create a piece of artwork based upon the graphical data. This cross-grade-level integration activity encouraged data discussion, collaboration, and the correcting of Arctic/Antarctic misconceptions. Subsequent reflections revealed clearer and more concise communication of Polar Science by both the elementary and high school students. While this activity illustrates the benefits of multi-grade level collaboration, challenges exist in

coordinating class schedules and transportation. Supportive administrators facilitated this collaborative effort as a pilot program to bring students from the neighboring schools together to continue to share science experiences.

Another valuable resource encourages students to use near real-time data from Argo floats to examine relationships in water chemistry data through the Adopt a Float program at MBARI (<https://www.mbari.org/products/southern-ocean-carbon-climate-observations-modeling-soccom/>). Argo floats are profiling floats deployed across the Earth's ocean to observe temperature, salinity, currents, and bio-optical properties of the surrounding water. The real-time data provided by the floats is available for use by research scientists to students in K-12 classrooms.

One lesson in the MBARI lesson collection is about Antarctic icefish (*Chaenocephalus aceratus*), the only known vertebrate species that as an adult, does not contain hemoglobin in the blood (O'Brien and Mueller 2010). By plotting oxygen and temperature data collected from the float, students make connections between the extremely cold water and fish evolving without the need for hemoglobin. Using data collected directly from the Southern Ocean, in context with their classroom lessons on climate change, students can build their own hypotheses. The students feel like real scientists while discussing data, observing trends, and communicating findings—all skills they need to be successful problem solvers. The SOCCOM project also offers an opportunity for students to name their own float before it is deployed, thereby giving students an immediate connection to the scientists and the equipment. Adding in a telepresence with scientists can bring the scientific process to life for the students, while igniting a curiosity about an otherwise inaccessible part of the world.

Northwest Passage Project

Most recently, the authors collaborated during the summer of 2018 on the NSF-funded Northwest Passage Project (NPP) High School Institute (<https://northwestpassageproject.org/>). The Institute brought together six teacher-student teams from across the country to the Narragansett Bay Campus of the University of Rhode Island (URI) (<http://innerspacecenter.org/education-outreach/projects/northwest-passage-project/>) to learn about the extreme Arctic environment of the Canadian Arctic Archipelago. In addition to learning about the impending expedition by the vessel, *Akademik Ioffe*, students and teachers heard from URI researchers and staff scientists about Arctic ecosystems, seabirds, and animals; sea ice and ocean circulation; the role of plankton in the Arctic; and ocean chemistry. Integrating



Bayside Academy students at SOCCOM float telepresence. Courtesy of Megan McCall

game play into the learning cycle, teams of students challenged each other in the Polar Play activity. The game board activity reinforced the newly learned Polar Science content and the complexity of planning a research expedition to the Polar Regions. Students also learned firsthand the art of science communication by participating in a live broadcast by URI's Inner Space Center (<http://innerspacecenter.org/>). To expand the reach of the project to other high school students, each NPP student crafted a personal Arctic message, describing their vision for the future of the Arctic. The culminating activity occurred when the students returned to their high schools where each team hosted a live video conference with NPP scientists, highlighting the project and their personal Arctic message. Students in any school or classroom could conduct a similar activity and choose a personal message from research and organize their own community presentation.

CONCLUSION

Integrating polar and climate science into the existing curriculum is an oft-cited challenge for teachers. However, the current climate crisis demands that students understand and appreciate the unique environments of the Arctic and Antarctic. These resources are important because they support and promote Polar Science content. They also incorporate the 20th century skills of critical thinking, creativity, collaboration, and communication which gives them added value in a science curriculum. These activities are simply starting points for teachers to help students on their journey of discovering these vital regions. One of the most rewarding results of these Polar Science resources was seeing students make unique connections with the Poles. Learning was evident when high school students took the information from a polar workshop and turned it into an impactful



Northwest Passage Project High School Academy students playing the Polar Play game. Courtesy of Kathleen Couchon

telepresence experience that was then shared with their school community. This is where the true value of opening the doors to the Arctic and Antarctic in our classrooms is found. Once students are exposed to the Polar Regions in the classroom, they become advocates because of the wonders they discover and embrace.

As teachers, we have embraced and enjoyed our adventures together discovering more and more about polar research and developing opportunities that bring science to life in a special way for our students. The students who took part in these activities showed they are capable of learning and sharing Polar Science, whether first graders composing polar data artwork, sixth graders investigating water chemistry data, or high school students hosting polar presentations for their

communities. Students are hungry for this information from their positive reactions and reflections to the lessons shared, and it is the responsibility of teachers to bridge the distance between the classroom and these special polar locations.

RESOURCES

The NPP gave the authors the opportunity to share lessons developed at prior EARTH summer workshops. One favorite activity of the students was the creation of personal artwork based upon a scientific graph in *What's the Bigger Picture?* This lesson is based upon the imaginative artwork of scientist and artist, Jill Pelto and encourages student scientists to combine science and art to illustrate graphs that convey the "bigger picture" of climate change. The full lesson can be found in the lesson plan resources of the MBARI EARTH website (<https://www.mbari.org/what-is-the-bigger-picture/>). The other was the previously mentioned Polar Play game (<https://www.mbari.org/polar-play/>).

POLAR LITERACY PRINCIPLES ADDRESSED IN THE LESSONS

(https://polar-ice.org/wp-content/uploads/2018/02/PLP_Brochure_Oceans18_final.pdf)

What's the Bigger Picture?

- 2C Sea ice naturally shrinks and expands with the seasons. However, this natural dynamic cycle of ice growth and loss is affected by increasing air and water temperatures occurring at the Poles due to climate change.
- 3A Polar oceans play a key role in global circulation of ocean water and air masses that keep the Earth temperate.
- 3B Ice and snow (white surfaces) reflect sunlight back into space. Ocean and land (dark surfaces) absorb more solar energy. As ice and snow disappear, heat is absorbed by exposed surfaces, which accelerates melting of additional snow and ice.
- 4B Sea ice cover, water and air temperature change with the seasons.
- 5A Arctic sea ice is declining at a rapid rate.
- 5B Antarctica is experiencing less sea ice loss than in the Arctic – for now.
- 6B Polar systems affect humans in a variety of ways.
- 6C Climate change is affecting Arctic residents (about 4 million), including 40 different indigenous groups (about 10% of Arctic residents) through impacts to their environments, food webs, and infrastructure.
- 7E Scientists measure the ice and snow levels over many decades to observe the impact of climate change in the Arctic landscape.

Polar Play

- The Arctic and Antarctic regions are unique because of their location on Earth.
- 1A The Arctic and Antarctic are both cold environments but have different geographical features.
- 1B Earth's tilted axis affects polar seasons – summer and winter. During summer (Arctic - June, July, Aug; Antarctic - Dec, Jan, Feb) the sun does not set, and during winter (Arctic -Dec, Jan, Feb; Antarctic - June, July, Aug) the sun does not rise.
- 1C The physical characteristics of the environment (weather, climate, topography, geology) are significantly different.
- 1D Polar climates create different living conditions
- 6A Humans have inhabited the Arctic for thousands of years. There is evidence of human Arctic presence from over 40,000 years ago. Humans continually adapted to inhabit the unique environment.
- 6B Polar systems affect humans in a variety of ways.
- 7B Today scientists use satellites, drifting buoys, tethered buoys, subsea observatories, unmanned submersibles, and automated weather stations to constantly and remotely study the Poles.

SOCOM Floats

- 6B Polar systems affect humans in a variety of ways.
- 7B Today scientists use satellites, drifting buoys, tethered buoys, subsea observatories, unmanned submersibles, and automated weather stations to constantly and remotely study the Poles.

NEXT GENERATION SCIENCE STANDARDS (NGSS) ADDRESSED IN THE LESSONS

(<https://www.nextgenscience.org/>)

What's the Bigger Picture?

- MS-PS3-4 Energy: Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.
- MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem
- MS-LS2-4 Ecosystems: Interactions, Energy, and Dynamics: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- MS-ESS3-5 Earth and Human Activity: Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

Polar Play

- MS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics: Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem
- MS-LS2-4 Ecosystems: Interactions, Energy, and Dynamics: Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.
- MS-ESS3-5 Earth and Human Activity: Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

SOCCUM Floats

- MS-ETS1-4 Engineering Design: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
- MS-ESS2-6 Earth's Systems: Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.
- MS-LS2-5 Ecosystems: Interactions, Energy, and Dynamics: Evaluate competing design solutions for maintaining biodiversity and ecosystem services.*

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KATHLEEN COUCHON is a National Board Certified Teacher and recipient of the Presidential Award for Excellence in Math and Science Teaching (2005). She has been a high school teacher in Narragansett, RI for 21 years. A teacher-researcher on two Arctic cruises, her passion is sharing Polar Science with her students.

MEGAN MCCALL, PH.D., has been a science teacher for 18 years and has been a STEAM Coordinator for the last 3 years at Bayside Academy in Daphne, AL. She has received several prestigious awards including a Fulbright Distinguished Award in Teaching (2015-16), Presidential Award for Excellence in Math and Science Teaching (PAEMST 2009), and is passionate about sharing authentic marine science lessons with her students. In 2017, she completed her Ph.D. in Instructional Design and Development from the University of South Alabama with her dissertation, "The Effects of Individual versus Cooperative Testing in a Flipped Classroom on the Academic Achievement, Motivation toward Science, and Study Time for 9th Grade Biology Students." This past summer (2019) she was also part of the NOAA Expedition, Journey into Midnight: Light and Life Below the Twilight Zone, in which Dr. Edith Widder made history with the first video of a giant squid in U.S. waters in the Gulf of Mexico.