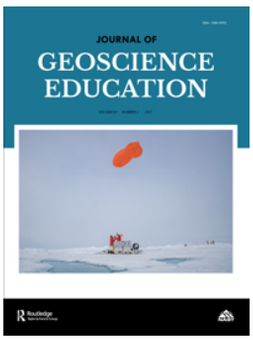

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COMMENTARY

Bringing polar topics into the classroom: Teacher knowledge, practices, and needs

Katya A. Schloesser and Anne U. Gold

Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado 80309, USA

ABSTRACT

Results from a national needs assessment survey advertised through science teacher networks with the title "Polar Education—Teacher Input Needed" showed that the majority (90%) of teachers that responded are teaching about polar topics or polar regions. We received 508 responses from elementary to post-secondary teachers across the United States. The survey assessed in which classes polar topics are being taught (high school environmental science classes had the highest percentages; ≥83%), which polar topics are being taught in classes and which topics teachers would like to teach more, what kind of polar education resources teachers are aware of (the majority of respondents, 66%, did not list more than 2 resources), and whether teachers had received professional development on polar topics (81% of teachers had not). Additionally, teachers' knowledge of polar topics was compared to the public's, using item blocks from representative public surveys. Results showed that teacher respondents' knowledge of polar topics consistently exceeded public knowledge. Based on the findings from the survey, we recommend that the polar education community continue to develop educational resources, offer professional development and conduct outreach to K–12 teachers. Specifically, we recommend a focus on: curating classroom-ready authentic data sets based on current polar research, multidisciplinary curricular materials that build on real world geopolitical issues and the historical importance of polar exploration, and curriculum for teaching ocean acidification, ocean ecosystems, and polar teleconnections to global climate.

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Polar regions; Arctic; Antarctica; teacher; needs assessment

Introduction

As global temperatures increase, rapidly changing weather patterns and ice concentrations in polar regions are impacting the global climate system. Ice sheets in the Arctic and Antarctica are melting at an alarming pace, which is contributing to global sea level rise (Alley, Clark, Huybrechts, & Joughin, 2005; Forsberg, Sørensen, & Simonsen, 2017, Joughin, Smith, & Medley, 2014; Rignot, Jacobs, Mouginot, & Scheuchl, 2013; Thomas et al., 2004). Arctic climate is changing significantly faster than the rest of the planet, with temperatures rising two times faster than global rates (Hansen, Ruedy, Sato, & Lo, 2010). Arctic sea ice extent is declining at historic rates due to rapid warming (Comiso, 2002; Stroeve, Holland, Meier, Scambos, & Serreze, 2007). As a result, the increase of open water in the Arctic Ocean has led to more opportunities for natural resource development, increased options for transportation across the Arctic, increased tourism, changes to geopolitical boundaries and national security concerns (Emmerson & Lahn, 2012).

In lower latitudes, the impacts of a changing Arctic climate have been observed in weather patterns and extreme events (Francis & Vavrus, 2012; Honda, Inoue, & Yamane, 2009; Overland & Wang, 2010, Liu, Curry, Wang, Song, & Horton, 2012). Additionally, coastal cities around the world are dealing with the consequences of rising sea levels. Between 1992 and 2016, 12 mm of sea level rise has been attributed to ice melt from Greenland and 5 mm of sea level rise can be attributed to ice melt in Antarctica (Forsberg et al., 2017). These observations confirm the saying that is popular with polar researchers, "what happens in the Arctic doesn't stay in the Arctic" (Scowcroft, Hotaling, Gingras, & Tuddenham, 2019).

While scientists exhibit high levels of concern regarding the global effects of climate change in polar regions, the poles are not at the forefront of most Americans' minds (Hamilton, 2015). Hamilton (2008) analyzed results from the 2006 General Social Survey (GSS), a nationally representative personal-interview poll of U.S. adults, and found that 40% of survey participants consider themselves somewhat or very informed about the North and South Poles. A large proportion of respondents did not consider themselves informed, though respondents did express concern about the consequences of a warming climate at the poles (Table 1). Table 1 shows GSS results from both 2006 and 2010, which indicates that the highest levels of concern among US adults were about: sea level rise leading to flooding in coastal areas, melting of the northern ice cap, loss of Inuit traditional way of life, and extinction of polar bears

CONTACT Katya A. Schloesser Katya.Schloesser@Colorado.edu c/o CIRES Education and Outreach, University of Colorado Boulder, UCB 449, Boulder, CO 80309, USA

Table 1. Public concern about polar regions, from Hamilton et al. (2012). The survey offered a four point scale, with 1 being "not at all" and 4 being "a great deal" of concern. Percentages reflect answers from survey respondents that expressed a "great deal" of concern.

Polar concern question	% with high concern from 2006 survey (n = 1862)	% with high concern from 2010 survey (n = 697)
"Sea level may rise by more than 20 feet, flooding coastal areas."	70	67
"The northern ice cap may completely melt."	63	67
"Inuit and other native peoples may no longer be able to follow their traditional way of life."	45	47
"By 2020, polar bears may become extinct."	45	49

(Hamilton, Cutler, & Schaefer, 2012). With further analysis, Hamilton (2008) and Hamilton et al. (2012) found that both younger respondents and respondents with greater science knowledge or awareness of polar facts were more likely to be concerned about environmental change in polar regions. Children's concern for climate change has been shown to increase their parents' level of climate concern (Lawson et al., 2019). Concern is warranted, as environmental impacts of rapid climate change at the poles will undoubtedly affect today's students in their lifetimes, if they have not already. Knowledge of the poles positively correlates with concern (Hamilton, 2008 and Hamilton et al., 2012), and so we recommend that teachers teach about polar topics and polar regions in their classrooms so students will be aware of the future impacts of global climate change.

As we make this recommendation, we ask, what are school-age students learning about the poles in America's classrooms right now? Little is known about the extent to which polar topics are taught in the classroom and how well teachers are prepared to teach about these topics. The mention of polar topics and/or polar regions is largely absent from the Next Generation Science Standards (NGSS Lead States, 2013), as the NGSS do not refer to any specific regions but use a global approach to Earth science concepts. The only references to the Arctic, Antarctica or polar topics in NGSS is a mention of polar ice caps in relation to the water cycle (5-ESS2-2)[1] and the mention of tropical plant fossils found in Arctic areas in relation to the use of fossils (3-LS4-1)[2] as evidence to understand past environments (NGSS Lead States, 2013). Polar regions easily capture the imagination, with the appeal of adventure in extreme cold, dramatic historic expeditions, polar bears and penguins, and indigenous cultures that have learned to thrive in such a harsh environment. Consequently, these regions provide an engaging hook for young learners to access a wide range of science topics. While they are largely absent from the standards, polar regions provide an inspiring opportunity for educators to harness the fascination of their learners in topics that range from science, history and geography to language-arts.

To learn how polar topics are integrated in classrooms across the US, we conducted a national needs assessment among teachers. We attempted to reach a broad range of educators for the survey, but due to our advertising of the survey as "Polar Education – Teacher Input Needed", we realize that teachers who have interest in polar regions may be overrepresented in the sample (as discussed in the Limitations section). Nevertheless we feel these results provide a useful guide for the continued development and expansion of polar education resources. In this commentary we summarize our findings from this needs assessment including which educators are teaching about polar regions and topics in their classroom, what topics they are teaching, what resources they use and what resources they wish they had.

Methodology

The survey instrument consisted of 22 questions with a combination of multiple-choice and open-ended questions. Skip logic facilitated a customized survey flow depending on individual responses (see the survey in Supplemental Materials). The survey was administered online using the Qualtrics survey software. The survey link was available to anyone with the URL. The survey questions asked about respondents' experience teaching, teaching practices around polar topics, information on the resources teachers are using and information on needs that the teachers have in order to teach effectively about polar topics. The survey also included items on polar topics from published public knowledge and attitude surveys; specifically, the five polar knowledge questions from the General Social Survey (GSS; Hamilton, 2008; Hamilton et al., 2012); the four questions from the POLES survey (Hamilton, Wirsing, Brunacini, & Pfirman, 2017) and selected four questions from the Scowcroft, Hart, Hayward, and Gingras (2019) unpublished manuscript. The list of topics that teachers are teaching about or may want to teach about was created through extracting topics from i) a review of the NGSS and all Arctic topics that were listed, ii) the science plan of the year-long Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) research expedition where we looked for important concepts, and iii) a search of topics in syllabi of introductory undergraduate classes on the Arctic. These polar topics can broadly be categorized into *Physical Science* topics (Glacier/ice, climate, ocean circulation, permafrost, polar vortex, feedback, teleconnections, ocean acidification), *Life Science* topics (wildlife, animal migration, ecosystem), *Geography* (polar geography, seasons) and *Social Science* (culture, historic exploration, geopolitics). Respondents spent about 8 minutes completing the survey (median value). Respondents who completed less than 15% of the survey (first two questions) were removed prior to data analysis, leaving a total of 508 responses for inclusion in the analysis.

[1] 5-ESS2-2 Refers to an NGSS 5th grade Earth Science performance expectation.
[2] 3-LS4-1 Refers to a NGSS 3rd grade Life Science performance expectation.

Table 2. Overview of professional organizations that sent out our survey announcement and associated response rate (total valid survey responses n = 508).

Survey Announcement Posted	# responses	% of total response
National Science Teacher Association email lists	273	54%
American Geosciences Institute email list, Facebook	42	8%
American Geophysical Union education board & Geological Society of America email list	29	6%
National Association of Environmental Educators information board	20	4%
National Earth Science Teacher Association Facebook group	10	2%
National Association of Geoscience Teachers newsletter	5	1%
Other national teacher email lists, social media, etc.	129	25%

The average survey completion rate was 95%. The full survey was completed by 88% of respondents.

Sampling method

We distributed the survey notice to science educators across the US through recruitment postings on science teacher email lists, large professional societies in the geosciences, and on social media platforms, and sent out separate survey links to allow tracking of where respondents received the email notice (see Table 2; the email notice text is included in the supplemental materials). We entered participants in a gift card drawing as a survey incentive. Our sampling methodology resulted in a nonrandom convenience sample, in which we likely oversampled educators interested in the polar regions (see discussion under limitations).

Analysis methods

Survey responses were analyzed using descriptive statistics. Open-ended responses were coded using thematic coding (Braun & Clarke, 2006). Instances in which certain themes were mentioned were added and reported by frequency.

Description of respondents

We received 508 responses from teachers in 47 states - all but Arkansas, Hawaii, Oregon and West Virginia. We had on average ten responses per state (range responses per state: 1-52, SD 9.8, see appendix for details). Almost two-thirds of educators who completed the survey (69%) teach in states that have adopted the NGSS (30% this study; NSTA reports students taught with NGSS nationally: 41%) or adapted the NGSS (39% this study, NSTA reports students taught with adapted NGSS nationally: 43%).

Table 3 summarizes the teaching experience of respondents and shows that the majority of responses came from K-12 teachers. Many fewer responses came from informal science educators, higher education/college level educators and preservice teachers. Nineteen educators reported that they currently are not teaching, but have taught in the past. Six respondents indicated that they never taught before, so these respondents were directed to leave the survey. As seen in Table 2, two-thirds of the respondents have experience teaching high school, more than half have taught middle school and about one-third taught elementary school. When we asked teachers what subjects they were teaching, middle school teachers reported a fairly even distribution across

Table 3. Summary of survey respondents' teaching experience. The percentage of teachers that have taught specific subjects are beneath the high school and middle school headers, and describe only the teachers that have taught that age level. For example, 91% of teachers that have high school teaching experience have taught environmental science.

Survey respondent professional experience	% of respondents
K-12 teachers	80
High school teaching experience	61
Environmental Science teaching experience	91
Biology teaching experience	77
Physical science teaching experience	57
Chemistry teaching experience	39
Middle school teaching experience	56
Earth science teaching experience	84
Life science teaching experience	80
Physical science teaching experience	76
STEM teaching experience	29
Elementary school teaching experience	27
Informal science educators	9
Higher education/college level educators	4
Preservice teachers	1
No teaching experience (directed to leave the survey)	1

Life Science, Physical Science, Earth Science, while about one-third indicated having taught STEM in general. The responses from the high school teachers showed that almost all teachers who responded had taught Environmental Science before, two-thirds have taught biology, over half have taught physical science and over a third taught chemistry at the high school level. We included Physics in Physical Science responses. The majority of educators, 81%, self-report that they are experienced classroom teachers with more than six years of experience, 14% of respondents taught for 3-6 years and only 5% of respondents indicated that they have less than 3 years of teaching experience.

Limitations of study

This study is based on a nonrandom convenience sample of science teachers across the country who were recruited through email lists and social media channels. It is therefore not possible to estimate a response rate to the survey. In order to reach the broadest possible sample of teachers, we worked with professional societies and organizations that serve science teachers across the country, thus, we were able to reach a large sample of teachers representing almost all states (47 of 50 states) with a fairly even distribution across the states. Our sample also is representative with respect to the number of teachers who align their teaching with NGSS to the national average. The survey was advertised to list serves with the title "Polar Education – Teacher Input Needed", with the top of the email reading "Teaching about the Arctic, Antarctica, sea ice, ocean, glaciers, polar bears or

penguins? Take our short anonymous online survey." This language presumptively encouraged self-selection of teachers based on their interests, resulting in a likely oversampling of educators interested in polar regions and polar topics. Thus, findings from this survey likely overrepresent teaching practices and teacher knowledge around polar topics across the U.S., however, it is likely accurate about existing needs and where gaps exist in the available resources for teachers, as the respondents are likely aware of the available resources.

Results

Who is teaching about polar topics and polar regions? What are they teaching?

The majority of teachers who responded to our survey indicated that they do teach about polar topics in their classrooms. Of the respondents that said they do teach about polar topics or regions, 59% of teachers indicated that it was "sometimes" part of their teaching, and 31% said it was a "regular part" of their teaching. Teachers who responded teach a wide range of topics and ages, from elementary school through higher education (Figure 1).

We asked teachers in which subjects they taught about polar topics. In order to correct for the different number of teachers who teach each subject, we normalized the responses by subject. As shown in Figure 2, classes with the highest percentage of teachers reporting they taught about polar topics were AP Environmental Science and High School Environmental Science. Classes with the lowest percentage of teachers reporting they taught about polar topics were AP Chemistry, high school Chemistry, middle school Physical Science, and high school Agriculture/Animal Sciences.

Polar topics range from Earth science concepts to physical science concepts, and can fit in a variety of science standards. Teachers were given a list of possible polar topics, and asked to select which topics they are currently teaching or have taught in their classes. As shown in Figure 2, of the respondents that "sometimes" or "regularly" teach polar topics (n = 442), the most common topics taught were glaciers or ice sheets, climate change in polar regions and ocean circulation. The least commonly taught topics were geopolitics or national security, history of exploration of polar regions and Arctic culture or indigenous populations. This is not surprising given that the survey was distributed to networks of science teachers, and not to social studies teachers.

Just under 10% of total respondents (n = 47) indicated that teaching about polar topics or polar regions is "never part of their teaching". Table 4 shows that the primary reasons for not teaching about polar topics were: polar topics

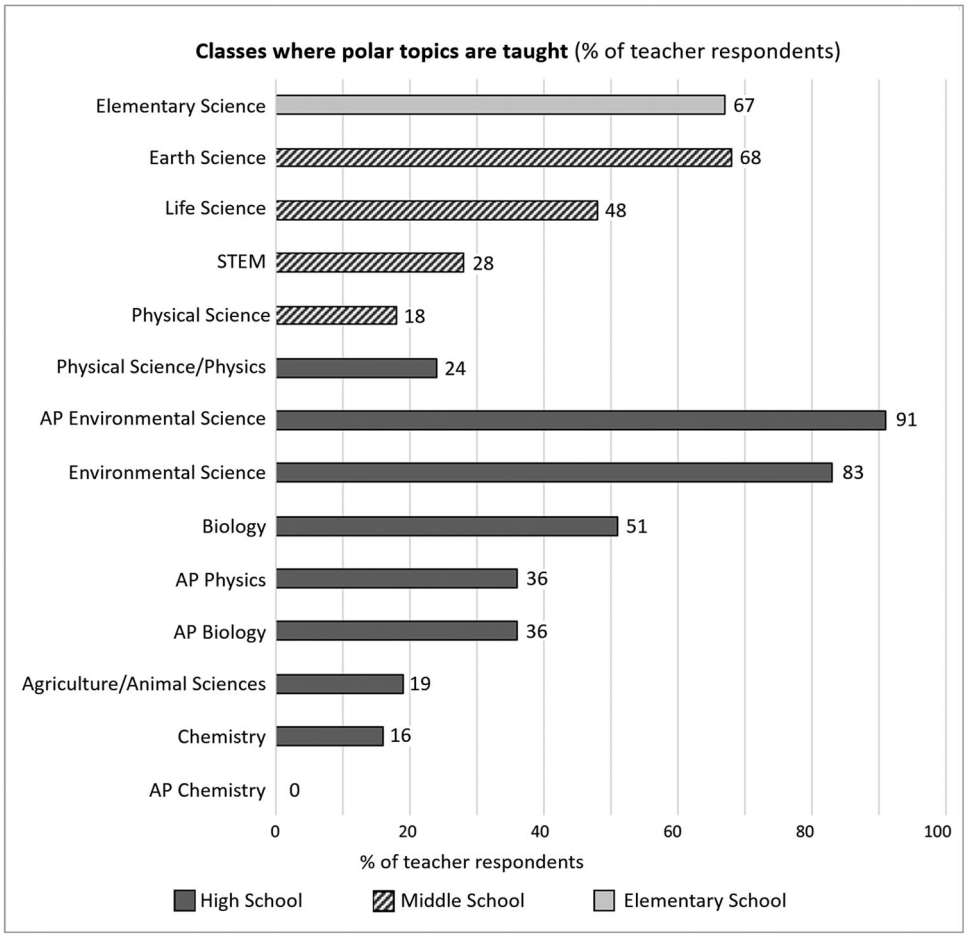

Figure 1. Percentage of classes where polar topics are taught (n = 442). The Number of classes in which polar topics are taught was normalized to the number of teachers teaching each class.

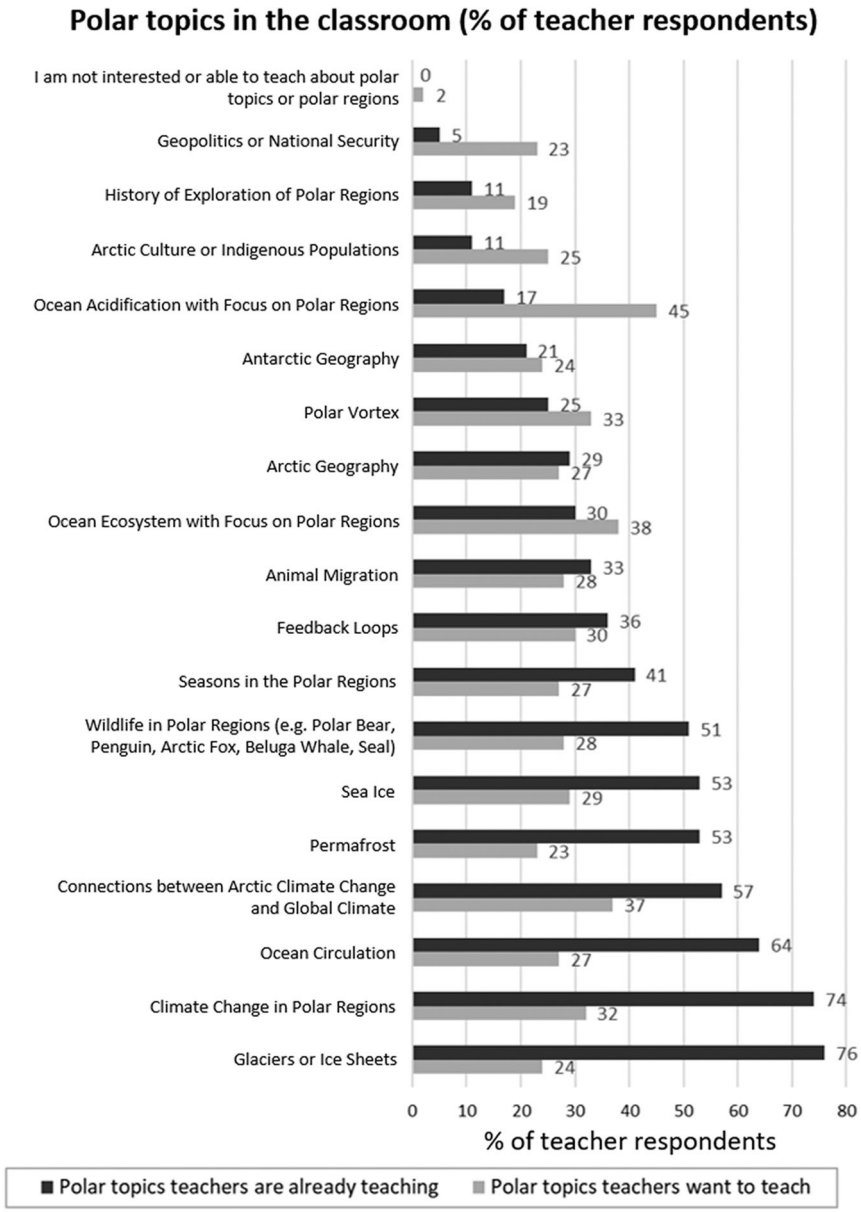

Figure 2. Polar topics being taught in the classroom (n = 442) and polar topics teachers would like to be teaching in the classroom (n = 475).

or regions do not fit into their standards or curriculum, they lacked personal knowledge on the subject matter, and/or they did not have enough teaching resources. Additional reasons for not teaching polar topics were that the teachers did not have enough time and that polar topics do not have enough connection to students' lives.

What polar topics would teachers like to teach that they are not already teaching?

We asked all survey respondents which polar topics they would like to teach in their classroom (Figure 2). The most popular choices for topics they would like to teach include: ocean acidification with a focus on polar regions, ocean ecosystems with a focus on polar regions, connections between Arctic climate change and global climate, the polar vortex, and climate change in polar regions. The topics that were selected the fewest times include: the history of exploration of polar regions, geopolitics or national security, permafrost, Antarctic geography, glaciers or ice sheets, and Arctic culture or indigenous populations. Respondents indicated that they taught the physical science topics most frequently (likely because they are part of the standards), but the topics that are not being taught that teachers would like to teach about are fairly evenly distributed among Physical Science, Life Science and Geography. The social science and history aspects of polar topics are not taught much and teachers did not express wanting to teach about them; a finding that may reflect the fact that most respondents are science teachers.

Do teachers have access to resources to teach about polar topics?

Professional development increases the likelihood that teachers will teach a subject, and improves the quality of their teaching (Supovitz & Turner, 2000). Of the total

respondents, only 19% of teachers have participated in a professional development training around polar topics or polar regions. Of those that had taken a professional development training, the majority indicated that they participated in professional development through teacher workshops (45%, given by institutions like the Byrd Polar Research Center, AMS DataStreme, GLOBE), conferences (14%, such as NSTA, AGU, PolarPalooza) or webinars (10%, such as Planet Stewards, Tundra Connections), while others learned about polar topics as part of degree-relevant coursework (14%). Twenty-two educators had participated in an expedition for educators to polar regions, such as Polar TREC or a National Geographic Grosvenor Teacher Fellowship.

A multitude of excellent, free educational resources on polar topics are available online from a variety of sources, and we wanted to know whether teachers are aware of them. We asked survey respondents to list educational resources on polar topics they were aware of. There was a drop off in response rate at this survey question, with a decrease of 38 responses (8%) from the preceding question. If we include those dropped responses as "zero resources" listed, the percentage of respondents who did not or were unable to list a single resource for teaching about polar topics jumps to 35% (n = 490). It may be that respondents who dropped from the survey at this point did not know of any resources to list. Without taking the drop off respondents into account (n = 452), 30% of respondents did not list a single resource, 36% of respondents listed 1-2 resources on polar topics, 25% of respondents listed 3-4 resources, and 9% of respondents listed more than 4 resources.

We were interested to know which of the resources that teachers listed were most popular. Table 5 shows the most frequently listed resources from the 318 resources that were listed, including the number of times the resource was listed first and the number of times the resource was mentioned at all. Top resources included the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, National Geographic, PolarTREC and the National Science Teaching Association. Resource collections that were mentioned multiple times (less than n = 7, not shown in Table 4) were GLOBE, CK-12, American Geophysical Union (AGU), PhET simulations, National Science Foundation (NSF), Byrd Polar and Climate Research Center, Polar Educators, Public Broadcasting Services (PBS) and many different textbooks.

Table 4. Reasons that teacher respondents cited for not teaching about polar topics (n = 47). Only teachers that responded that "Polar Regions or Polar Topics are never part of my teaching", 10% of total survey respondents, responded to this question.

Reason why teaching about polar topics or polar regions are not part of teachers' regular teaching	% of respondents
Doesn't fit in my standards	51
Lack of personal knowledge	43
Don't have enough teaching resources	40
Not enough time	26
Not enough connection to students' lives	21

What types of resources would teachers like to improve their teaching on polar topics?

We asked what type of resources teachers would like to have access to in order to improve their teaching about polar regions or polar topics, a question that is particularly relevant as the majority of respondents indicated that they have not received professional development training on polar topics, and/or listed no more than two educational resources on polar topics. The majority of respondents said that they would like classroom activities and lesson plans focused on polar topics or polar regions (84%), data on polar regions for students to work with and/or visualize (80%), video or other multimedia resources (67%), and professional development training (56%). Only 29% of teachers said they would like to join an online community of practice with other teachers. Under the "Other" needs, a few teachers (n = 6) said they would like to have the opportunity for their students to connect directly with polar scientists, others described the need for simulations or ways to teach models (n = 4) and their interest in getting involved in authentic polar research (n = 4). Other examples were requests for NGSS-aligned storylines, maps and videos.

How does teachers' knowledge of polar topics compare to the public's knowledge?

Several nationwide studies have been conducted to assess the knowledge of the general public on polar topics and assess the level of concern the general public has regarding environmental changes occurring at the poles (Hamilton, 2008; 2016; Hamilton et al., 2017). In this survey, we asked some of the same questions Hamilton analyzed to describe the understanding of polar topics among the general public, and compared the results. We realize that the teachers who chose to respond to our survey may have a greater knowledge of the poles based on self-selection. Nonetheless, we

Table 5. Educational resources on polar topics or polar regions that teachers were aware of.

Educational Resource	# of times listed as the first resource	# of total mentions
National Oceanic and Atmospheric Administration (NOAA)	43	99
National Aeronautics and Space Administration (NASA)	19	75
National Geographic	20	47
PolarTREC	13	27
National Science Teaching Association (NSTA)	10	22
National Snow and Ice Data Center (NSIDC)	0	17
United States Geological Survey (USGS)	0	13
University Corporation of Atmospheric Science (UCAR)	0	11
Science Education Resource Center at Carleton College (SERC)	0	9
Climate Literacy and Energy Awareness Network Collection (CLEAN)	0	7

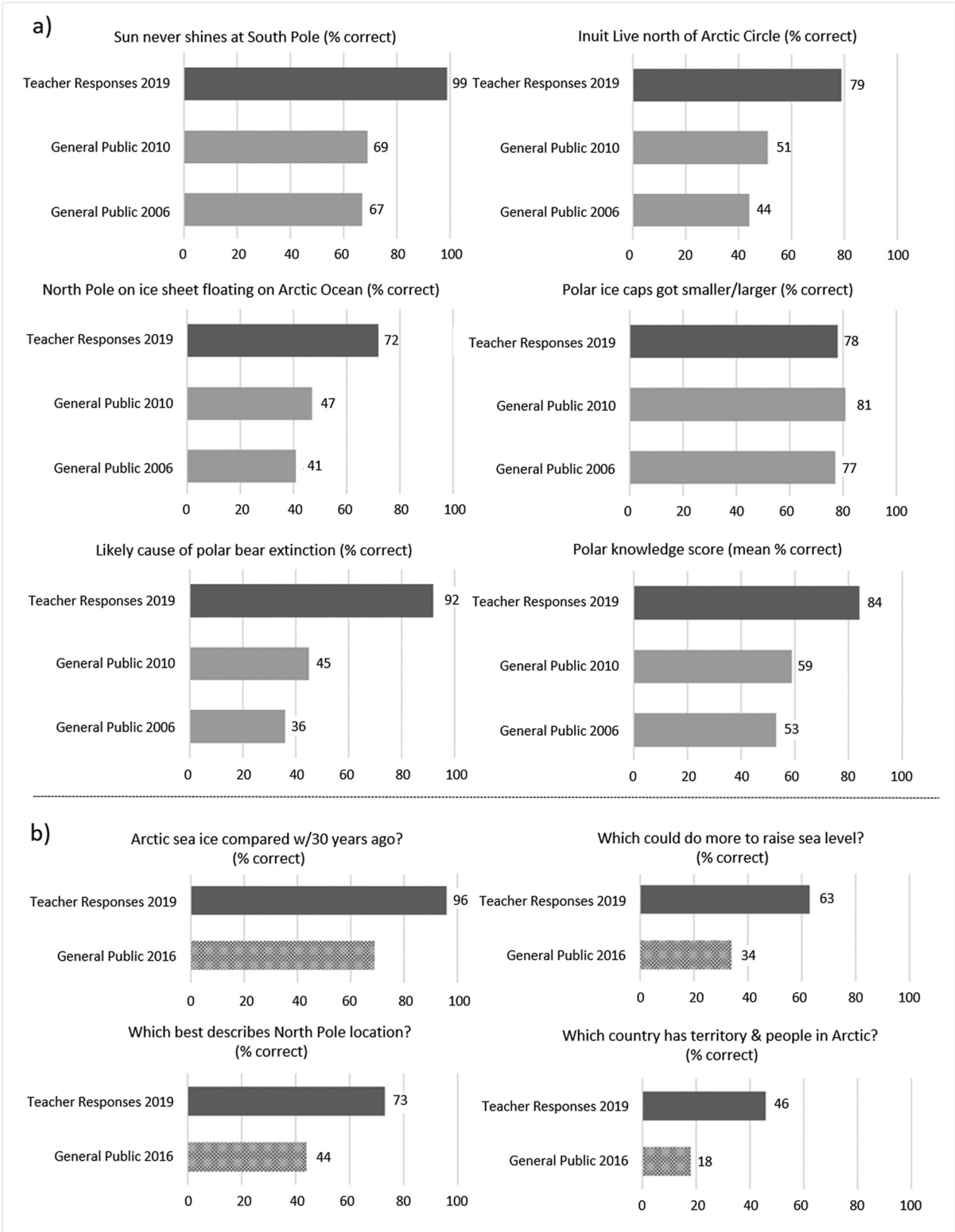

Figure 3. Graphs in section (a) show the comparison of correct teacher responses (this study, n = 450) with general public responses, approximated from the General Social Survey, Hamilton (2008) and Hamilton et al. (2012) (GSS 2006 n = 1,862, GSS 2010 n = 1,006). The polar knowledge score is calculated by finding the mean number of correct responses from each of the five questions. Section (b) show the comparison of correct teachers responses (this study, n = 450) to correct responses from the general public, measured by the Polar, Environment, and Science (POLES) survey, analyzed in Hamilton et al. (2017) (POLES 2016, n = 1,407). To find the original wording of the questions in the surveys, refer to Hamilton et al. (2012) for the GSS survey questions, and Hamilton et al. (2017) for the POLES survey questions.

Table 6. Comparison of public opinion data (Scowcroft, Hart, et al., 2019) and teacher responses (this study) around their awareness for polar topics (total survey responses for this study n = 450).

	Scowcroft, Hart, et al. (2019)				This study
Statement	I doubt this is true	Maybe true but I didn't know	Heard about this	Know a fair amount	Teacher Response (Correct)
Shipping activity through the NW Passage has increased dramatically in recent years due to changing ice conditions (*Changing sea ice extent impacts shipping activity above the Arctic Circle*).	10%	55%	27%	8%	94%
Polar bears are starving because there is less sea ice from which to hunt.	11%	36%	38%	15%	91%
The Arctic environment is warming faster than other places on earth.	11%	27%	46%	16%	89%
The Arctic contains huge reserves of oil and minerals.	8%	42%	38%	13%	86%

found that the teachers who took the survey had a much higher knowledge of polar topics than the general public.

Hamilton (2008) and Hamilton et al. (2012) analyzed several polar knowledge questions from the General Social Survey (National Science Board, 2008, 2010) that aimed to assess impacts of the International Polar Year (IPY) on the public understanding of polar topics, administered in 2006 and 2010. The GSS is an annual survey which is a nationally representative personal-interview poll of U.S. adults. Using five questions on polar facts, Hamilton created a composite score, the "Polar Knowledge Score", based on the mean number of correct responses for the five questions. As shown in Figure 3, compared to the general public, a higher percentage of teachers answered four questions correctly, knowing that the "Inuit live north of the Arctic Circle", the "sun does shine at the South Pole", the "North Pole is located on an ice sheet floating on the Arctic Ocean" and that "climate change is more likely than hunting to cause polar bear extinction". On the fifth and final question, teachers and the general public responded similarly with the majority correctly marking that the "polar ice caps have gotten smaller in the last 30 years". Overall, teachers scored higher than general public respondents in both 2006 and 2010 with a polar knowledge score of 84%, compared to 59% (2010) and 53% (2006).

Hamilton et al. (2017) conducted another survey, called the Polar, Environment, and Science (POLES) survey in 2016. The objective of the survey was to assess the general public's understanding of the Arctic, with an emphasis on the knowledge of Alaskan residents (28% of respondents in the POLES survey). The survey asked four knowledge questions about the Arctic, different from the GSS surveys, and comparison with our survey results again showed that teachers had more accurate knowledge of the poles than the general public (Figure 3). Almost all teachers correctly responded that "Arctic sea ice coverage has declined in 30 years", fewer teachers knew that "melting land ice from Greenland and Antarctica could have the highest effect on rising sea levels", three-quarters of teachers knew that the "North Pole is located over a deep ocean", and almost half knew that the "US has territory where thousands of people live north of the Arctic Circle". As seen in Figure 3, teachers answered more accurately than the public by 27 to 29 percentage points.

In the third comparison of teachers' knowledge to surveys conducted with the general public, we compared teachers' knowledge of polar topics to the self-assessed awareness of topics assessed through an online questionnaire sent to a representative sample of U.S. households (n = 720; Scowcroft, Hart, et al. [2019]). In Scowcroft's survey, respondents were asked to rate their awareness of several topics. We used the same topics (topic 4 was reworded, see italics in Table 6), and asked teachers to rate them true or false. We wanted to know where teachers' knowledge fell in relation to the general public's awareness of topics. As seen in Table 6, the high correct response rate from teachers (>85% correct on all questions) shows that teachers have high awareness of these topics, compared with the majority of general public respondents indicating that they did not know, or had not heard of the topic (>73%). Results are consistent with the Hamilton comparisons, showing that the science teacher respondents by and large had higher knowledge of polar topics than the general public did.

Discussion

Survey results showed that the K-12 teachers who took the survey are teaching about polar topics and polar regions in their classrooms and have continued enthusiasm to increase the amount they are teaching about polar topics. Only 5% of the entire survey sample said that they did not teach about polar topics and/or polar regions because they don't fit into their curriculum or standards, suggesting that respondents are finding ways to teach polar topics to meet the NGSS. There are many entry and connection points between polar topics and disciplinary core ideas, such as polar phenomena or data from polar regions. For example, when teaching atmospheric and oceanic circulation (MS-ESS2-6)[3], teachers could use the polar vortex as a current topic to connect to students' experiences of anomalous weather patterns. Indeed, the topics that teachers reported teaching the most, listed in Figure 2 (glaciers or ice sheets, climate change in polar regions, and ocean circulation) all provide substantial connections to NGSS standards. Polar phenomena provide excellent entry points to NGSS, and we encourage both teachers and curriculum developers to continue to seek these out. Furthermore, an expressly stated goal of NGSS, listed first in the list of goals outlined in the framework for new K-12 Science education standards, is for "all students (to) have some appreciation of the beauty and wonder of science" (NRC, 2011). The poles provide ample

[3]MS-ESS2-6 refers to a middle school NGSS performance expectation.

opportunities to engage students with the beauty and wonder of our planet, from the variety of ice crystals that form in sub-zero temperatures and the marvel of the northern lights, to the extreme conditions that scientists must face to collect data from the polar regions and the ability of the Inuit to live in harmony with the extreme changes of seasons above the Arctic Circle.

Specific opportunities we found to engage students with polar topics in the classroom, through needs stated by teachers, require continued development of resources on polar topics. As shown in Figure 2, topics that were highly requested include: ocean acidification w/focus on polar regions, ocean ecosystems w/focus on polar regions, and connections between Arctic climate change and global climate. We encourage the polar education community to use these survey results to develop resources on the above topics, provide professional development opportunities around newly developed resources and continue to expand outreach to teachers to make sure they are aware of existing resources.

Several large-scale polar research expeditions are underway in 2019, including the Northwest Passage Project, and the year-long Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition - both of which are aiming to develop lasting educational resources similar to the education efforts around the International Polar Year (IPY). The International Polar Year (IPY) 2007-2008 included significant collaboration between polar scientists, educators and communities, and prioritized education, outreach and science communication as a supplement to the diverse science program, engaging more than 14 million people in 70 countries (Provencher et al., 2011, p. 4). The IPY education community developed many classroom activities in collaboration with IPY scientists and projects. IPY activities still constitute the majority of available online teaching resources about polar topics and many would benefit from alignment with the NGSS, and an update of the science and/or data used in these activities. Expeditions and international efforts such as the Northwest Passage Project, MOSAiC and the IPY provide remarkable opportunities to engage K-12 students and the general public with compelling and authentic scientific research.

NGSS emphasizes connections of students with authentic research, and such connections are one of the requests teachers shared in this survey to have more access to scientists and real data. As classroom technology use expands, several real-time opportunities are available to make connections between classrooms and scientists, through live webcasts with scientists (e.g., PolarTREC, Joides Resolution), virtual reality expeditions using 3D glasses, and through frequently updated blogs from researchers in the field (e.g., PolarTREC, Polar Field Services). However, analog resources are similarly useful and highly desired by teachers, including lesson plans, classroom activities based on authentic science, and authentic data sets for classroom use (84% indicated a need for lesson plans).

Of the top three resources teachers requested, data on polar regions for students to work with was high on the list (80%), second only to classroom activities and lesson plans (84%). Polar research produces an abundance of authentic geoscience and geophysical data, yet teachers often do not have the time and/or the data analysis skills to break down large datasets into manageable chunks for classroom use (Ledley et al., 2011, Ledley, Prakash, Manduca, & Fox, 2008; Taber, Ledley, Lynds, Domenico, & Dahlman, 2012). The National Snow and Ice Data Center (NSIDC) and the Arctic Data Center are two examples of polar data powerhouses with the mission of making polar datasets available. Yet more work is needed from curriculum developers to create classroom ready data sets for teachers. Data Nuggets, created by Michigan State University, provide an excellent example of manageable datasets from real, cutting-edge research designed to help students meet quantitative learning goals (Schultheis & Kjelvik, 2015). Another curriculum development model example that expressly explains how to develop engaging lessons that incorporate authentic polar data is the Arctic Climate Connections Curriculum (Gold et al., 2015). We encourage curriculum developers and broader impacts projects to continue to create manageable datasets using polar datasets for classroom use.

In addition to an emphasis on authentic scientific research connections, NGSS also encourages cross disciplinary curricular connections, alignment with other subjects, and an emphasis on real world phenomena (NRC, 2011). In the Arctic, a rapidly changing climate has led to less ice and more open water in the Arctic Ocean, which has opened up pathways for natural resource development, transportation, and national security interests in the Arctic. Polar science and geopolitical issues are inextricably linked in the Arctic, and are gaining increasing visibility in the global psyche. The complexity of the Arctic provides an excellent opportunity for cross curricular study. Out of all of the polar topics currently being taught in classrooms, teachers selected geopolitical and social science topics the least, with 5% of all respondents selecting Geopolitics or National Security, 11% of respondents selecting History of Exploration of Polar Regions, and 11% selecting Arctic Culture or Indigenous Populations. Yet, about a quarter of all respondents would like to teach these topics more in their classroom. We encourage curriculum developers and teachers to think beyond the science classroom for teaching about the poles. Many opportunities exist in the social sciences (geopolitics, anthropology, archeology), history (historic expeditions), math (abundant, especially when working with authentic data), engineering (infrastructure design challenges around permafrost, sea ice, ship design of ice breakers) and language arts (diaries of explorers, writings of indigenous peoples, speeches of scientists to propose funding) and many more.

Conclusion and recommendations

In conclusion, we commend the polar science community for creating excellent educational resources for K-12 classrooms that are clearly being used. Yet, there is more work for us to do. Survey results showed that teachers' hunger for educational resources on polar topics has not been satisfied and that many opportunities exist to develop new materials and communicate about existing materials. We recommend the continued development of curricula based on current

research, including classroom ready datasets and multidisciplinary lessons that reach beyond the science classroom and the use of classroom technology to connect with researchers in the field.

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ORCID

Katya A. Schloesser http://orcid.org/0000-0001-5530-582X
Anne U. Gold http://orcid.org/0000-0002-5309-0762

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