Educatore are increasingly exploring ways to improve the quality of undergraduate education through active learning methods such as “interactive engagement,” “learner-centered environments,” and “teaching for understanding” (Hake 1998; Wiggins and McTighe 2006; Doyle 2008; Freeman et al. 2014). In active learning, the instructor moves the focus of instruction from “delivering the material” to engaging students in the learning process. While quantifying the effectiveness of these methods poses challenges and the results can be uneven, studies show support for all forms of active learning (Prince 2004). Public concern that national prosperity and economic competitiveness based on science and technology depends on effective Science, Technology, Engineering, and Mathematics (STEM) education throughout K–12 and higher education has driven much of the debate about the use of these methods (National Academies 2007, 2010). In meteorology, the need for effective STEM is further demanded by the need for the public to understand and respond to a changing climate (IPCC 2013, 2014a,b,c).

Alaskans are particularly concerned about climate change, as Alaska, like the rest of the Arctic, continues to warm more rapidly than other regions on Earth and is experiencing declining sea ice, earlier snowmelt, and new record high temperatures (Jeffries and Richter-Menge 2015). Given this rapid change in their local environment, Alaskans and other Arctic residents have increasingly advocated for inclusion of local and indigenous participation, experience, and knowledge in addressing these challenges to their communities (Cochran et al. 2013; Krupnik et al. 2011). Here, we present results from an introductory undergraduate science class for nonscience majors. Weather and Climate of Alaska (course ATM101X)
COURSE DESIGN AND CURRICULUM.
Weather and Climate of Alaska is designed around the fact that Alaska encompasses several climate regions because of its vast size, high-latitude location, proximity to oceans, and complex topography (Shulski and Wendler 2007). Alaska has 13 climate divisions that range from the North Slope on the Arctic Ocean with a polar tundra climate to the South Panhandle on the Gulf of Alaska with a marine climate (Bieniek et al. 2012). The course has been offered five times, starting in the spring of 2012 and continuing each spring, with only one offering in the fall of 2012. The spring semester provides a wider seasonal range of the weather and a higher likelihood of snow at all sites across Alaska than the fall semester. We report on the course through spring 2015. Over these five semesters, 119 students from 25 communities have completed the course. In each semester the students have represented between three and six separate climate divisions (Fig. 1). The National Weather Service (NWS) maintains 146 weather stations across the state that post their observations in near–real time to a public website. Thus, for each student location, there is a local NWS site that provides hourly data for comparison with their measurements.

The goals of Weather and Climate of Alaska are 1) to have students better understand weather and climate based on weather they have experienced; 2) to have students connect meteorological processes at local, regional, and global scales; and 3) to have students reflect with their peer group on their individual and collective investigation. The roles and responsibilities we give the students are typical of those found in learner-centered classes and include working as a team, participating in discovery learning, evaluating learning, presenting publicly, developing problem solving strategies and skills, solving authentic problems, reflecting, demonstrating use of feedback, and taking risks (Doyle 2008). The course incorporates instructional scaffolding in both the design of the individual investigations and the sequencing of the investigations (Reiser and Tabak 2014). The course is designed to support learner–learner, learner–instructor, and learner–content interaction (Shearer 2007).

The curriculum follows the American Meteorological Society’s (AMS) Weather Studies. The course is offered completely by distance using online resources hosted on a Blackboard-based website. The class operates asynchronously with no specified meeting times. However, the class

Fig. 1. Map of Alaska showing the 25 communities where student observers have completed Weather and Climate of Alaska since spring 2012. Yellow stars indicate the communities, with the community name labeled in yellow italics (e.g., Anchorage, Nome). Climate divisions are identified in yellow print (e.g., Southeast Interior, West Coast). Geographic features including the coastal seas and major mountain ranges are identified in white print (e.g., Alaska Range, Bering Sea). For clarity, communities close to Fairbanks (i.e., North Pole, Eielson, and Salcha) and Anchorage (i.e., Eagle River, Chugiak, Wasilla, and Houston) are not labeled.
is structured around weekly units that include an online lecture, reading assignment, investigation, quiz, and discussion. There are three traditional pen-and-paper exams that are taken by the students at local testing centers. Each student purchases an equipment kit that includes 16 items: digital maximum/minimum thermometer, barometer, sling psychrometer, compass, four plastic mailing tubes (for snow sampling), graduated beaker, ruler, tape measure, safety goggles, two foam cups (as calorimeters), pack of batteries, and headset with microphone (Fig. 2). In the spring semester of 2015, the kit cost each student $200. The course requires two textbooks: the AMS’s *Weather Studies* (Moran 2012) and *The Climate of Alaska* (Shulski and Wendler 2007).

The students conduct 12 investigations: four based on outdoor observations of the sky with meteorological measurement, one based on sampling of a snow bank, three based on benchtop experiments, one based on review of a climate change video, and three based on analyses of meteorological data. The outdoor investigations progress from making a single sky observation as a sky watcher, to making a single set of observations and measurements, to making a week of measurements. The students make a week of weather observations early (late January) and late in the semester (late March). These two investigations are used to understand weather directly, but they also provide a basis for three units that study weather systems, forecasting, and climate. In the final investigation of the class, the students study climate as the prevailing pattern of weather, and they reflect on whether the observed weather patterns over the two weeks reflect the climatological pattern or a significant departure from that pattern. Thus, students base eight of their investigations on weather they have observed and measured. In studying snow, the students dig out a snow bank to expose a vertical section of the snow bank. The students measure the snow depth; document the layering in the snow; record the snow hardness, crystalline structure, and temperature; and take samples of the snow at different depths in a snow bank. The students sample the snow by inserting a plastic mailing tube horizontally into the snow bank. They determine the snow water equivalent (SWE) by melting the snow. The students analyze the layering in the snow bank based on the NWS records of snowfall and compare their SWE measurements with measurements from NWS sites. The students reflect on how the characteristics of snow vary in the snow bank, locally between snow banks, and regionally. In the benchtop investigations, students explore the physical behavior of gases, humidity, and latent heat of fusion.

The course promotes learning by doing. The fact that the students purchase their own equipment kit and use it to make their own measurements outdoors is important. While some students report being intimidated at having to go outside and make their own measurements, the majority of students report that making their own measurements with their own equipment gives them a sense of ownership and discovery that they do not experience in a traditional benchtop laboratory. They claim that investigations based on weather they have experienced are more authentic than a predefined laboratory exercise. Students have also reported that they conduct their weather observations with their children as a family activity. The students submit their measurements and observations using electronic fillable worksheets. For six of the investigations the students provide a video report (or screencast) where they present their measurements, analysis, and interpretation. The students create their screencasts using publicly available web-based software, Screen-O-Matic. The screencast
is a slide presentation with an audio narration by the student, not a video of the student as a weather reporter. The students post these screencast videos to YouTube. The use of YouTube represents a balance between student privacy and convenient access to the presentations by other students with variable Internet connectivity. The students are instructed to post these videos with the unlisted privacy setting and then post the video URL to the Blackboard discussion board. Thus, the students can limit the access to the YouTube video to their classmates. All students report being initially intimidated in making screencasts and talking to their peers about their work when they do not feel they are expert meteorologists. Students are required to watch and comment on videos by other students. Each week the instructors alert the students in the class as student screencasts are posted, and students are encouraged to review the posted work as they prepare their own screencast. In the five other investigations, the students complete problem sets that explore the concepts of the investigation. The students complete each unit by posting a reflection on the investigation.

**SUPPORTING A STUDENT COHORT AND OBSERVATION NETWORK.** Student support is particularly important in a distance class where students can be working alone and struggling with the course content and materials. Experience in distance education has shown that students are more likely to succeed when they receive both academic and nonacademic support (Simpson 2002).

For academic support, both instructional videos and text manuals have been developed for all the equipment used by the students. Example screencasts are provided for all of the screencast investigations, so that the students can see what is expected by example as well as by instruction. A teaching assistant who is assigned to this laboratory course is available to meet with students by appointment and also schedules open office hours by teleconference several times a week. At the start of each week the instructor makes a series of Blackboard announcements to the students giving tips and advice for completing the unit, commenting on any interesting weather occurring in the state, and responding to students (e.g., how to make your measurements at −50°F, discussing a storm at a student’s site, posting a photograph of a Fata Morgana sent in by a student). These announcements serve to both reinforce instructions on the Blackboard site as well as to prompt students to plan their work over the course of the week. This combination of support with the textbook, online resources, NWS information, and dedicated teaching assistant provides a high level of learner–content interaction.

The course is designed so that the students spin up in a very structured way that promotes learner–learner
interaction and establishes the students as a cohort and an observer network. In the initial sky-watching investigation, the students have a rubric that asks them to describe what they see rather than categorize their observations. They describe the wind in terms of movement of plants, plumes, flags, and clouds (rather than wind speed, which some students look up on their phones) and describe the clouds in terms of their height, color, texture, and form (rather than cloud type, which some students look up in the textbook). In the second week, they make their first measurement and sky observation and report it by screencast. In this screencast the students also introduce their location using Google Maps. In their third week, the students make their first week of five weather measurements and report by screencast. In their fourth week, they compare their week of measurements with NWS measurements and report by screencast. By the end of the fourth week, using this scaffolding approach, the students have developed the reporting and observing skills they will employ through the rest of the semester. In these initial weeks students watch each other’s screencasts and students from the same communities discuss their measurements and experience working in the same local conditions, while students from different communities discuss differences in the weather and their working conditions.

Early in the semester the faculty member responds to each of the students’ work with detailed feedback on the Blackboard discussion board and has a 20-min teleconference with each student that provides both academic and nonacademic support and promotes learner–instructor interaction. The faculty member and the student confirm that the student has all their materials and equipment (postal service to rural Alaska can take longer than expected), assess the student’s academic and technical skills, review the student’s experience with the initial assignments, share tips on succeeding in the course, discuss how the course fits in their larger program of study, and identify the student’s goals for the course. The faculty member conducts two more teleconferences with each of the students later in the semester. This allows the faculty member and student address challenges and problems as they arise and to develop the student’s observational and analytical skill. This level of learner–instructor interaction provides both academic and nonacademic support to the students and contributes to a student course completion rate of over 85%.
EXAMPLES OF STUDENT WEATHER OBSERVATIONS. We present two cases of measurements made by five students in fall 2012 and spring 2015. In each case the students were asked to make five weather observations and measurements over the course of the week. Each daily measurement included current temperature, maximum temperature, minimum temperature, and current pressure (Fig. 3). Each observation included recording the cloud cover and type, precipitation, visibility, wind speed (using the Beaufort scale), and wind direction. The instructors gathered the NWS measurements and daily weather maps during the week and provided them to the students. The weather maps are a composite map with cloud cover indicated by the infrared satellite image (Fig. 4).

In the first case, students in Fairbanks and Anchorage reported the weather from two distinct climate divisions in fall 2012. Anchorage lies 260 miles south of Fairbanks. Anchorage is in the Cook Inlet climate division and has a marine climate. Fairbanks is in the Southeast Interior climate division and has a subpolar continental climate. The Alaska Range lies between the two cities. The Anchorage student reported temperatures that did not change significantly during the week and reported pressure that decreased through the week with an increase over a 2-day period in the middle of the week (Fig. 3). The student noted that the weather was dominated by cyclones throughout the week with clouds present throughout the week (Fig. 4). The Anchorage student reported thicker clouds present at the beginning of the week on 30 October and at the end of the week on 3 November, and thinner clouds present in the middle of the week. The student described the thicker clouds as gray and
flat and identified them as stratus and the thinner clouds as white and wispy and identified them as cirrus. The student reported winds of Beaufort scale 3 and 4 through the week with branches and twigs moving. In reflecting on their measurements, the Anchorage student noted that the colder temperatures were associated with the higher pressure and clearer skies in the middle of the week, that changes in the weather were preceded by the arrival of cirrus cloud, and that the higher winds correlated with a narrower spacing of the isobars on the weather maps. The Fairbanks student reported temperatures that varied considerably from day to day and pressure that decreased through the week (Fig. 3). The Fairbanks student reported changes in cloud cover through the week, highlighting the fact that the colder days on 30 October and 1 November had clear skies. The student reported a mix of calm conditions and light air with a Beaufort scale of 0 and 1 through the week, with the exception of gusts that swayed the treetops with a Beaufort scale of 4 on 31 October. The Fairbanks student reported the arrival of cirrus clouds from the south on 2 November and made an extra set of measurements later that day because they recognized from their studies that the arrival of cirrus clouds signaled the passage of a front and a change in weather. The student also provided photographs of the clouds in their screencast. In reviewing the weather maps during the week, the Fairbanks student correlated the change in temperatures and cloud cover with the movement of high- and low-pressure systems and cold fronts over Fairbanks. On 2 November the student associated the change in weather with a strong cyclone in the Gulf of Alaska and noted that the movement of the clouds from the southeast was consistent with the wind direction indicated by the isobars on the weather map (Fig. 4). In the discussion board, students compared the warmer weather in Anchorage with colder weather in Fairbanks and reflected on the difference between maritime and continental climate and the how the Alaska Range influenced weather systems as they traveled from the Cook Inlet region to the Interior region.

In the second case, students in Eagle, Fairbanks, and Tok reported the weather from a single climate division in spring 2015. These three communities are in the Southeast Interior climate division. Fairbanks lies 190 miles west of Eagle and 200 miles northwest of Tok. The students in Eagle and Fairbanks used NWS measurements in Eagle and Fairbanks, respectively. The student in Tok used NWS measurements from the nearest NWS site in Northway, 40 miles southeast of Tok. All three students noted the pronounced daily cycle in temperature through the week and the general decrease in pressure through the week (Fig. 5). The students reported that the weather during the week was “very nice,” with sunny days, unseasonably high temperatures, and
ATMI01X: WEATHER AND CLIMATE OF ALASKA POSTTEST

Please answer questions 1–5 using the following scale:

- **Basic**: I have a basic understanding of common weather terms and information.
- **Informal**: I can evaluate patterns of weather as data that changes over time and can convert simple units, such as Celsius to Fahrenheit and Z time (Zulu) to Alaska time.
- **Knowledgeable**: I am knowledgeable about weather and climate as systems and understand the physical principles that drive their behavior.
- **Practiced**: I can confidently assess scientifically credible data about weather and climate and communicate it to others in meaningful ways.
- **Advanced**: I am able to make well-informed, evidence-based, and responsible decisions about activities that may (or may not) affect weather and climate.

All answers will receive full credit.

1) How would you rate your current ability to use weather-related content (meteorology) to meet your needs in daily life?
   a) Basic  
   b) Informal  
   c) Knowledgeable  
   d) Practiced  
   e) Advanced

2) How would you rate your current ability to understand how science is conducted by using examples from meteorology?
   a) Basic  
   b) Informal  
   c) Knowledgeable  
   d) Practiced  
   e) Advanced

3) How would you rate your current ability to access current weather data and information from the Internet to learn science?
   a) Basic  
   b) Informal  
   c) Knowledgeable  
   d) Practiced  
   e) Advanced

4) How would you rate your current ability to assist family and friends in using meteorological data and information from the Internet?
   a) Basic  
   b) Informal  
   c) Knowledgeable  
   d) Practiced  
   e) Advanced

5) How would you rate your current ability to manipulate and present quantitative information, such as measurement or laboratory data, in a spreadsheet?
   a) Basic  
   b) Informal  
   c) Knowledgeable  
   d) Practiced  
   e) Advanced

6) Your weather is currently under the influence of a low-pressure system (Low) whose center is located due west of you. The wind at your location is most likely from the ______ and your air pressure is ______.
   a) northwest, rising  
   b) southeast, falling  
   c) southeast, rising  
   d) do not know

7) The relative humidity of sinking, clear air ______.
   a) increases  
   b) remains constant  
   c) decreases  
   d) do not know

8) In Alaska, assuming clear skies, the daily amounts of incoming solar radiation in late September are ______ the amounts at the same location in late March.
   a) less than  
   b) about equal to  
   c) greater than  
   d) do not know

9) Wind speeds shown on upper atmospheric weather charts are generally ______ where the height-contour lines are closer together.
   a) slower  
   b) unchanged  
   c) faster  
   d) do not know

10) Weather radar reflectivity displays show precipitation ______.
    a) location and intensity  
    b) motions  
    c) sizes and types  
    d) do not know

11) Consider a balloon filled with air, as the temperature increases the volume ______.
    a) stays the same  
    b) decreases  
    c) increases  
    d) do not know

12) Immediately after a warm front has passed your location, you usually can expect precipitation to ______ and temperatures to ______.
    a) begin, drop  
    b) end, drop  
    c) end, rise  
    d) do not know

light winds with a Beaufort scale of 0 and 1. A record high temperature of 52°F was reported in Fairbanks on 26 March. The Eagle student noted that the cloud conditions had varied during the week, with clear skies at the beginning and end of the week and cloudier skies in the middle of the week that corresponded to the warmer nighttime temperatures. The three students compared their observations with the weather maps and discussed the variations of pressure and cloud cover (Fig. 6). The students also discussed how the southerly flow over the Alaska Range due to the cyclones in the Gulf of Alaska contributed to the warm weather.

The students also used the NWS data to reflect on the quality of their measurements. Students noted...
13) As the temperature of a gas decreases the average kinetic energy of the molecules in the gas _______.
   a) decreases  
   b) increases  
   c) stays the same  
   d) do not know

14) “Black-and-white” infrared satellite views of Earth display clouds in shades of gray. Generally, the darker the shade of gray, the _______ the cloud-top temperatures and the _______ the cloud tops.
   a) warmer, higher  
   b) warmer, lower  
   c) colder, higher  
   d) do not know

15) Two adjacent columns of air, one warm and one cold, exert the same barometric pressure at the Earth’s surface. At a height of 2 km above the surface, the pressure in the cold air would be _______ in the warm air at the same elevation.
   a) the same as  
   b) lower than  
   c) higher than  
   d) do not know

17) As altitude increases in the lowest few kilometers of the atmosphere, the atmospheric temperature generally _______.
   a) increases  
   b) decreases  
   c) remains the same  
   d) do not know

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Differences between the data and (sometimes) suggested a reason for their differences. It is not uncommon for students to report a constant offset between the pressure they measure and that measured by the NWS because of their calibration of their barometer. In fall 2012, the Fairbanks student noted that their minimum temperature measurements were lower than the NWS measurements and attributed this to the fact that their site was at one of the lowest elevations in Fairbanks and experienced pooling of colder air. In March 2015, the Fairbanks student reported that the maximum temperatures were sometimes higher than the NWS temperatures and attributed it to direct solar heating of the thermometer. The Tok student discussed the good agreement between their March measurements and the NWS measurements. In January 2015, the Tok student had reported temperature measurements that had been higher than the NWS and pressure measurements that had shown an offset relative to the NWS measurements. In reviewing the January measurements, the instructor and student discussed possible reasons for the difference that included the fact that the NWS measurements were made at Northway 40 miles from Tok. However, the student found that exhaust from a building was influencing their instruments. Each semester students improve their measurements in their second week of weather based on their review of their first week of measurements.

The students also employ NWS measurements of humidity and satellite images in the visible, thermal infrared, and water vapor channels to study water in the atmosphere. During the week in March 2015, they saw how the dewpoint temperature remained relatively constant while the relative humidity varied over through the day, and they used this behavior to explore the difference in absolute and relative humidity. Students also study periods with changes in temperature, dewpoint temperature, and pressure to study the motion of air masses across Alaska.

The students use weather and climate data for the two weeks during the semester for their final investigation of weather and climate. In spring 2015, the students reinvestigated the January and March weeks of weather in Eagle. In January the temperatures had been −5°F at the start of the week and fell to very low values, staying below −20°F all week and fell below −40°F on four of the days, with daily average temperatures 20°F lower than the climate average. The students reflect on the pattern of weather where a cyclone that had moved north from the Gulf of Alaska early in the week was displaced by strong anticyclones over the Southeast Interior. This allowed the students to reflect on the meaning of a climate average as either representing a single prevailing pattern of weather or the average of distinct and different patterns of weather. In March, the daily average temperatures were 20°F higher than the climate average (Fig. 5). For the March period the students reflected on the diurnal cycle and the pattern of weather where southerly flow maintained higher temperatures and the thin cloud cover prevented nighttime cooling, yielding higher-than-normal temperatures (Fig. 6).
**ASSESSMENT.** The course includes a voluntary pre- and posttest of the students in ATM101X. The tests are composed of 17 questions: five self-assessment questions that ask the students to rate their own expertise and 12 technical multiple-choice questions based on the AMS Weather Studies concept survey (see sidebar). The tests are provided online and the students receive credit for completing them, but they are not absolutely required to attempt them. In the pretest we award full credit for all answers to encourage students to report what they do not know rather than guess a correct answer.

A total of 110 students completed both the pre- and posttest technical questions. The results of the 12-question survey in terms of pretest score ($S_i$) versus posttest gain (the difference between the posttest and pretest score, $S_f - S_i$; Fig. 7). The three lines show the gain for three values of the normalized gain $g$ of 0.3, 0.7, and 1. The normalized gain is defined as the ratio of the actual gain to the maximum possible gain [$g = (S_f - S_i)/(100 - S_i)$]. The normalized gain is used to identify gain in terms of the average value of $g$ for the course $\langle g \rangle$, as high $g$ ($\langle g \rangle \geq 0.7$), medium $g$ ($0.7 > \langle g \rangle \geq 0.3$), and low $g$ ($0.3 > \langle g \rangle$; Hake 1998). The individual student results fall into the low-, medium-, and high-$g$ regions. However, the five class averages and the overall average fall in the medium-$g$ region, with values varying between 0.41 and 0.57, with an overall normalized gain of 0.50 ± 0.03. A study of student performance in 62 introductory physics courses found normalized gains of 0.23 (low $g$) for courses using traditional methods, a normalized gain of 0.48 (medium $g$) for courses using interactive engagement methods, and no courses showing high normalized gain (Hake 1998, 2007). Thus, the student performance in ATM101X is typical of introductory courses that employ interactive engagement methods.

A total of 107 students completed both the pre- and posttest self-assessment questions. The five survey questions were chosen to see how students might use the skills they had developed in the course. The responses were a five-point Likert scale that rated their comfort and ability as 1) basic, 2) informal, 3) knowledgeable, 4) practiced, or 5) advanced. The student responses show significant increases in their comfort, with meteorology characterizing their abilities in these five areas as “basic/informal” on starting the course and as “knowledgeable/practiced” on finishing the course (Fig. 8). The survey did not formally address the students’ interest in science or their likelihood of pursuing further science education, as has been explored in other studies of introductory science courses (Reed and Lyford 2014).

**CONCLUSIONS.** Weather and Climate of Alaska (course ATM101X) draws on the geography of Alaska as a natural laboratory and online NWS resources to allow students study weather, climate, and climate change. The course incorporates a hands-on approach that grounds their understanding in meteorology they have experienced, documented, and analyzed for themselves. The use of video allows students to both report their investigations and review the other students’ investigations and thus form a cohort of peer observers across the state. The use of NWS data allows students to both validate their measurements and extend the scope and understanding of their observations. The instructor support and feedback contributes to high levels of student participation and course completion. The students gain experience as local experts, their scientific performance significantly improves, and their comfort with science increases. The course provides a model for teaching investigation-based meteorology and meeting core science curriculum requirements by distance.

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Fig. 8. Likert scale (1–5) of student survey responses pretest (red) and posttest (blue). The error bars represent the standard error in the average values.

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