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<th>Journal:</th>
<th>Arctic Science</th>
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<tr>
<td>Manuscript ID</td>
<td>AS-2017-0010.R1</td>
</tr>
<tr>
<td>Manuscript Type:</td>
<td>Article</td>
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<tr>
<td>Date Submitted by the Author:</td>
<td>19-May-2017</td>
</tr>
<tr>
<td>Complete List of Authors:</td>
<td>Anderson, Katherine; University of Alaska Museum, Earth Sciences; University of Alaska Fairbanks, Department of Geosciences Kaden, Ute; University of Alaska Fairbanks, School of Education, Secondary Education Druckenmiller, Patrick; University of Alaska Museum, Earth Sciences; University of Alaska Fairbanks, Department of Geosciences Fowell, Sarah; University of Alaska Fairbanks, Department of Geosciences Spangler, Mark; University of Alaska Fairbanks, Department of Biology and Wildlife; University of Alaska Fairbanks, Institute of Arctic Biology, EWHALE lab Huettmann, Falk; University of Alaska Fairbanks, Department of Biology and Wildlife; University of Alaska Fairbanks, Institute of Arctic Biology, EWHALE lab Ickert-Bond, Stefanie; University of Alaska Museum, Herbarium (ALA); University of Alaska Museum, Department of Biology and Wildlife</td>
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<tr>
<td>Keyword:</td>
<td>specimen-based science, STEM education, place-based education, citizen science, University of Alaska Museum</td>
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<tr>
<td>Is the invited manuscript for consideration in a Special Issue?:</td>
<td>N/A</td>
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https://mc06.manuscriptcentral.com/asopen-pubs
Arctic science education using public museum collections from the University of Alaska Museum: An evolving and expanding landscape

Part of the special volume of Arctic Science: Arctic Museum Collections – documenting and understanding changes in biological and cultural diversity through time and space


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Abstract

Alaska faces unique challenges in STEM (science, technology, engineering and mathematics) education, including limited accessibility to resources and learning opportunities, and a lack of place-based education resources. Museum education programs, traditionally focused on public outreach through docent-led tours, are playing an increasingly important role in both formal and informal aspects of STEM education to help address these challenges. The University of Alaska Museum (UAM) stands as a model in the Arctic region exemplifying how public natural history museum collections can be utilized to create active place-based learning experiences with the aim of increasing engagement in STEM literacy, and building connections between museums and communities. These efforts take many forms, including the development of teaching materials involving physical objects and/or online data from the open-access database ARCTOS, training pre-service teachers, and implementing citizen science projects. Because many UAM specimens and objects are from Alaska, they are easily incorporated into place-based education, thereby demonstrating how the Arctic environment is unique at local and regional scales. Here, we showcase several programs that are either unique to UAM, or part of larger national projects, and include exemplar teaching modules in order to provide learning opportunities in the Arctic region and other rural settings.

Keywords: specimen-based science; STEM education; place-based education; citizen science; University of Alaska Museum

Introduction

While issues such as global climate change and evolution increasingly dominate the public debate, and a countless number of personal and societal issues require citizens to make informed decisions based on their understanding of STEM (science, technology, engineering and mathematics) fields, museums are playing an increasingly important role as an educational platform (Rockström et al. 2009; Bhatt et al. 2010; Mace et al. 2010; Moerlein and Carothers 2012; Ogden et al. 2013; Huettmann 2007, 2015a). The need for increased understanding of global change requires an informal and formal educational approach to interdisciplinary science knowledge, reflection, debate, active learning, and broad participation inclusive of minorities in STEM careers. This is all the more important in Arctic environments given that this is where the impacts of human-caused climate change are most visible (e.g., Stone et al. 2002; Callaghan et al. 2004; Hinzman et al. 2005; Beck et al. 2011; Phoenix and Bjerke 2016). Herein, Arctic Alaska is inclusive of regions of the state south of the Arctic Circle, including the Interior, due to both cultural and biological continuity.

Public natural history collections such as the University of Alaska Museum (UAM) provide accessible baselines for understanding the consequences of ecological and evolutionary change, and extinction. Specifically, these archives provide benchmarks
that allow researchers to contrast past and present conditions, to understand the evolutionary and historical drivers for biodiversity, and to construct realistic predictions about the impacts of future environmental change. Natural history collections are now being used in a series of innovative and integrative research programs (see Moritz et al. 2008; Suarez and Tsutsui 2004). Further, they establish a high standard for replicable and verifiable research (e.g., museum vouchers) related to the development of online databases (e.g., VertNet, GenBank, MorphBank, iDigBio; Table 1).

While natural history collections represent primary sources and are used in high impact science research (Graham et al. 2004; Elith et al. 2006; Cook et al. 2014, 2016; Wen et al. 2015), they can also be used in object-based learning (Chatterjee 2010; Chatterjee and Duhs 2010) outside of a docent-guided museum tour. Bringing collections and associated research into the classroom provides the opportunity to engage students in real-world science investigations. Science literate students become citizens with the ability to make informed decisions based on their understanding of STEM fields. Interaction with museum objects can give students authentic and active learning experiences, and an enhanced use of university collections can provide powerful pedagogical tools in both formal education (K-16), and informal education outside of a traditional classroom environment (Chatterjee 2010; Chatterjee and Duhs 2010).

Research has shown that object handling has a long-lasting effect and relationship with memory, more so than text-based learning (Romanek and Lynch 2008).

Unfortunately not all educators and students can readily visit a museum and see specimens first-hand. Digital explorations of museum objects are becoming more important (see Huettmann 2015b,c for real world examples and needs). The specimen-based, open-access database ARCTOS (http://arctos.database.museum) provides an example of how easily natural history museum collections can be accessed remotely. Multiple institutions in North America, including UAM, utilize ARCTOS. Online databases are the fundamental core for object-based learning using digital objects, and allow multiple entry points for the user to experience natural history collections and science, even in under-resourced areas. Many of Alaska’s rural school districts fall in this category. Furthermore, databases like ARCTOS provides 24 hour and equitable access to collection and object information. Object-based learning built around the vast specimen resources in ARCTOS often leads to greater engagement of students and may result in self-directed learning (Chatterjee 2010; Chatterjee and Duhs 2010).

**Alaska Access to Quality Education**

Alaska is a unique area in the Circumpolar North and within the United States, and is one of the states with the largest percentage of American Indians and Alaska Natives (AI/AN) (U.S. Census Bureau 2004; Haycox 2017). Alaska Native people have thrived in the regions of Alaska for millennia. With the arrival of a larger influx of Western cultures in the late 1800s, which continues to grow even today, Alaska is now a merging of ethnicities and backgrounds. Although most Alaskans now live in cities, the largely indigenous population lives in small rural communities. In Alaska and other circumpolar regions, public education was initially a tool to inculcate the knowledge and
values of Western society, and to forcibly govern through assimilation policies (Cochran et al. 2013; Huntington and Watson 2012). Many Alaska Natives still perceive Western schooling as a negative influence on communities, and a threat to social and landscape sustainability. Many see themselves as “climate victims” of a far away world (Krupnik and Jolly 1980).

Destroying cultures, breaking bonds of language and tradition resulted in a disconnection of the people from the land they knew well and disrupted their capacity to develop, practice and pass on traditional ecological knowledge (TEK). Those frequently targeted and systematic efforts to destroy and redirect Indigenous ways of knowing also meant a diminishment of environmental stewardship and attitudes by people adapted over millennia to live in the far North (Barnhardt 2005; Spring 2016). The generational disconnect and physical removals from traditional learning environments were detrimental to the resilience of rural Alaskan communities across many dimensions (Hirshberg et al. 2005).

One critical challenge facing Alaska is access to quality education that incorporates its cultures, communities and land. For residents of Arctic Alaska, quality education includes the promotion of indigenous skills, values, history and languages. Over the millennia, indigenous people have developed a traditional knowledge that allowed survival through sustainable means in the landscapes and seascapes of the North (Huntington and Watson 2012). Teaching students in Alaska in ways that allow them to keep their cultural identity is important for student motivation, curriculum relevance, and ultimately community and cultural stability (Andersen-Spear & Hopson 2010). Educational goals, learning outcomes, and corresponding assessments should be place-based and directly informed by community-participatory needs. This makes Alaska unique and demanding for federal programs focused on STEM.

Access to quality education requires a consistent, well-prepared, and culturally responsive teacher workforce that is integrated into the community life, and one that understands local culture and environment. At present, approximately 60 percent of Alaska’s teachers leave the Arctic region after less than two years, informally citing a number of reasons, many of which are tied to school and community relations (Kaden et al. 2016). High teacher turnover impacts student achievement, and it contributes to an educational climate of instability and mistrust. Students and their teachers need to be able to respond to local concerns such as clean drinking water, climate change, erosion of land, and sustainable sources of food and energy. They need to have access to the latest data, current research and resources to engage in learning projects that support community health.

**Formal and informal learning, and place-based education**

In recent years, the education system has shifted toward more equity in access to education, local governance, and the acknowledgement that non-traditional socio-cultural, community-based teaching and learning experiences effectively promote student engagement and resilience. Yet, all of this is ongoing in a digital world providing global
access to information (Huettmann 2007, 2015b,c). The search is on for new and
innovative ways toward collaborative, respectful, place-informed, experiential, and
sustainable education models that engage students in formal and informal learning while
utilizing digital connectivity (Fig. 1).

We argue that reconciling the divergent analytical approaches of Western Science
and place-based education might allow culture, knowledge and place to become more
interconnected, and as a result find common ground between these seemingly disparate
approaches in order to promote STEM engagement among AI/AN students (Delparte et
al. 2016). Place-based education, as a culturally responsive, collaborative, holistic, and
engaged approach to understanding relationships and processes promotes local ecological
and cultural sustainability (Sobel 2004). Because many UAM specimens are from
Alaska, they are easily incorporated into place-based education. Combining STEM
advances, and traditional knowledge and values can provide skill sets necessary to protect
the land, mitigate environmental and socio-economic problems, and shape the future
using research innovations.

Research on formal science education indicates that educational activities
structured around local geography, and built on history and local culture are particularly
effective in engaging K-16 and higher education students in sciences (Castagno and
teachers and students with natural history museum collections, we can provide
opportunities for participatory research and learning that addresses local community and
environmental issues. This, in turn, can build knowledge and trust toward an education
model of the future that is inclusive of indigenous knowledge, and may increase both the
number and diversity of qualified STEM professionals. Students in rural communities
already have knowledge of their surrounding environment, providing a solid foundation
upon which they can build STEM concepts and skills. Those collaborations can further
develop students’ and educators’ capacities to envision and imagine their future in a
complex and changing world.

The breadth of human learning includes a substantial portion over one’s life, in
informal settings, outside of the traditional classroom (NRCNA 2009, Fig. 2-1; Stauth
2011). Museums provide unparalleled opportunities for K-12 students, undergraduate
students, pre-service teachers, educators and the general public to walk into a science lab
and experience science in action. A step further for museum scientists is to involve
members in their communities with science on a closer level by conducting research. This
can be achieved with citizen science projects. The interplay between informal science
education in the museum and real-world science conducted by members of the
community are part of the ever evolving and expanding landscape of science education at
museums across the globe.

The University of Alaska Museum

UAM is part of the University of Alaska system, and located on the University of
Alaska Fairbanks (UAF) campus. It was founded to aid teaching and research within
UAF, and has major representative natural history and cultural collections from all corners of Alaska, the Circumpolar North, and beyond. It was designated the official state repository of natural and cultural collections by the State of Alaska in 2015. The museum's collections include more than 1.5 million specimens and artifacts representing millions of years of biological diversity and thousands of years of cultural traditions in the North (http://www.uaf.edu/museum/collections/). The curators are faculty members with a dual appointment in the museum and in their respective discipline of expertise at UAF, allowing them to access educational funding via the National Science Foundation, United States (NSF), and integrate specimen-based science into their curriculum. UAM provides content for public exhibits and programs, and it is also deeply involved in training tomorrow's professional scientists at all levels of education.

In this article we highlight selected formal and informal STEM education programs and citizen science activities using UAM collections guided by UAM curators and collaborators. These activities address the unique issues of STEM education in Alaska. Students of all ages, and at all education levels can participate. Activities include identifying objects, considering contextual factors, discussing and reflecting on details, answering questions or forming hypotheses, and inquiry based on previous theoretical learning.

Science education programs using museum resources at UAM

Traditionally, there has been a recognized dichotomy between formal and informal education. However, newer studies suggest that this strict categorization of educational experiences is artificial and may not reflect the complexity of learning and gaining knowledge that takes place in our society today (Diamond et al. 2016; Matthews et al. 2017). Digital connectivity and accessibility of global resources and knowledge are particularly relevant for connecting formal and informal learning (Dabbagh and Kitsantas 2012). In this article we adhere to the distinction between the two forms of education, which is largely driven by funding agencies’ definitions; however, our examples demonstrate blended learning.

A. Formal Education

Formal education is based on structured curriculum, may lead to a formally recognized degree or credential, and is often guided by government regulations. Teacher-led or teacher-directed learning is typically closed ended, and has empirically measured outcomes (Hofstein und Rosenfeld 1996). In this section, we feature a number of NSF-funded UAM collaborative projects that are directly linked to STEM education in classroom environments across all levels of education. Modules are designed to support pre-service teacher education, K-12 teacher professional development, and project-based learning for undergraduate and graduate students. UAM models constructivist education strategies by placing educators in active learning situations to support metacognitive insights that help them create similar experiences for their students.
1. GeoSTEM (NSF ICER-1540674)

Curricula for science education in K-12 schools are guided by the Next Generation Science Standards (NGSS). Implementation of the NGSS leads to an increasing demand for geoscience educators who are able to combine relevant science and engineering practice with a disciplinary core idea and a crosscutting concept, referred to as the three dimensions of learning (NGSS 2013).

However, only a small percentage of teachers have completed undergraduate coursework in geoscience (geological and earth sciences) or related STEM fields. Furthermore, research on teacher qualifications and retention across Alaska indicates that more than 85 percent of all teachers hired between 2009-2013 to teach in Native communities were from outside of Alaska, had never visited the community prior to their hire, and had no previous experiences teaching indigenous students (Hill and Hirshberg 2013). High teacher turnover, single subject teacher qualifications, and irrelevant geoscience curricula are variables that prevent students from participating in place-based STEM activities in K-12 classrooms. This results in a disengagement of Alaska Natives in sciences, and low graduation rates (Castagno and Brayboy 2008; Lyon 2013; Kaden et al. 2014).

The NSF-sponsored GeoSTEM- Teachers for the Arctic Region (https://sites.google.com/a/alaska.edu/teachgeostem/) program is designed to increase access to quality science education in rural Alaskan communities by providing pre-service teachers (undergraduate and graduate students studying education, and student teachers) with training in place-based geoscience education followed by a three week mentored teaching internship in a rural Alaskan community school. The goals of this multi-year program are to prepare pre-service teachers for place-informed teaching, introduce future teachers to the opportunities and challenges of rural Alaskan classrooms, and develop hands-on geoscience modules relevant to rural communities throughout Alaska.

Sample GeoSTEM Module: Comparative Dinosaur and Human Anatomy

Despite its high-latitude location, dinosaurs roamed Alaska during the Mesozoic Era, and fossil bones and teeth are common in Cretaceous rocks that crop out in northern Alaska. Hadrosaurs (duck-billed dinosaurs) were particularly abundant, and more than 6,500 hadrosaur specimens from Alaska are present in the UAM Earth Sciences Collection. Replicas of the bones form the centerpiece of a GeoSTEM module adapted from a CASE (see below) activity originally designed for delivery in the North Slope Borough School District. Students begin by re-articulating the skeleton of a familiar vertebrate. GeoSTEM teachers have commonly used a disarticulated human skeleton for this purpose (Fig. 2A), but the activity is equally well suited to use the skeleton of common game animals, such as caribou or moose. Once the students have assembled the skeleton, and learned relative positions and identities of each bone, they are given casts (plastic replicas) of actual dinosaur bones from Alaska and asked to identify which element (type of bone) is represented. This activity is designed to reveal the fundamental
similarities due to common ancestry (homology) in the skeletons of mammals and other vertebrates, such as reptiles and birds. Students are frequently impressed how well they can recognize and identify bones of unfamiliar species (even if they don’t know it is called a femur or a scapula) no matter how distantly related to a human it may be. It can also be used for exercises about scale (for example, dinosaur phalanges can be deceptively large) and inferences about Cretaceous paleoclimatic conditions in the Arctic.

GeoSTEM teaching interns have tailored the module for rural middle and high school classrooms in order to address the following Next Generation Science Standards (http://www.nextgenscience.org/get-to-know):

**Middle School Life Science Standard MS-LS4-2**: Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms and between modern and fossil organisms to infer evolutionary relationships.

**High School Earth and Space Science Standard HS-ESS2-7**: Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.

A version of this module has also been successfully delivered to primary school students by asking students to color in the portions of a hadrosaur skeleton represented by selected fossil bones.

### 2. Advancing Integration of Museums in Undergraduate Programs (AIM-UP!, NSF DEB-0956129)

The NSF-sponsored Research Coordination Network Advancing Integration of Museums into Undergraduate Education (AIM-UP!, Table 1, http://aimup.unm.edu/) was a Research Coordination Network (RCN) in Undergraduate Biology Education (UBE) that developed innovative training opportunities for undergraduate students based on the experiences of a diverse cadre of museum scientists whose research and teaching programs are integrally connected to the temporally and spatially deep resources available in natural history museums. The project engaged curators from four university museums (UAM-Fairbanks, MCZ-Harvard, MVZ-Berkeley, and MSB-New Mexico), as well as curators from federal collections (USDA, US National Parasite Collection) and staff from a federal science agency (USGS-Alaska Science Center), a natural resource agency (National Park Service) and an international genomic consortium (Barcode of Life Initiative based in Ontario, Canada). It created a network across more than 50 institutions in 32 states over 6 years (2011-2016).

The network facilitated discussion among a diverse set of undergraduate educators, curators, collection managers, database managers, scientists, and others (artists, federal resource managers) that was centered on emerging opportunities in specimen-based education (Cook et al. 2014, 2016; Lacey et al. 2017). The RCN explored and produced new ways of incorporating the extensive archives and cyber infrastructure of natural history museums into undergraduate education. AIM-UP!
stimulated ongoing efforts and developed new approaches (e.g., modules, videos) to collections-based training through regional thematic meetings, webinars, symposia, publications, workshops (Fig. 2B), presentations at scientific meetings, and an annual fall semester seminar course (held in Fairbanks once and distance delivered the rest of the years; http://aimup.unm.edu).

The network shared information and ideas, and coordinated novel educational activities. Through workshops it fostered synthesis and new collaborations, and developed community standards that will help integrate and allow educators to exploit existing collections and the vast digitized collections on museum databases that are now available online in the form of videos (http://aimup.unm.edu/about/videos.html). In addition, we developed educational teaching modules, including detailed lesson plans, step-by-step instructions for completing an activity, access points to the museum database ARCTOS, specific instructions for implementing the module, and suggested background reading. The modules are intended to introduce students to the vast resources (specimens) available in natural history museums worldwide. In the past, these specimens were unavailable to educators but now, with digitized information available over the web, teachers and students can begin to explore this previously hidden library of biodiversity. Outreach efforts were targeted especially to underrepresented students with an emphasis on issues relevant to their communities (e.g., indigenous communities in New Mexico and Alaska).

**Sample AIM-UP! Module: Plant Range and Distribution in Alaska**

In this activity, students explore the effects of geography and other abiotic factors on plant range and distribution using digitized plant specimens from the Herbarium at UAM. Students access the online database ARCTOS to retrieve distributional data on plants as well as view specimen images of plants to review different leaf morphologies, use climate and elevation data from the Worldclim database (http://www.worldclim.org/current), complete a data table, and map plant distributions and environmental layers to explore ranges of selected plants in Alaska. This activity is scalable to the K-12 classroom and can also be used in the undergraduate curriculum. The activity teaches the integration of different disciplines such as geography, evolutionary biology and earth science, and emphasizes the intellectual and practicable abilities to work collaboratively across disciplines. The instructions, worksheets, and introduction to using a museum specimen database such as ARCTOS can be downloaded from http://aimup.unm.edu/for-educators/plant-range.html.

**3. The CASE (Changing Alaska Science Education) for enhancing understanding of climate change by involving STEM graduate students in K-12 education (GK-12; NSF DGE-094802)**

The NSF Graduate STEM Fellows in K-12 Education (GK-12) program began in 1999 with the goal of training graduate students in STEM fields and K-12 teachers to effectively communicate science through a partnership that lasted one school year (http://www.gk12.org/). Graduate students became resident scientists in the classroom, developing and teaching lesson plans with the guidance of their partner-teacher, and
establishing transferable skills in both pedagogy and communication to non-scientific audiences. Teachers, in addition to offering mentorship, gained community connections and valuable insight into real-world science that could in turn inform more authentic STEM learning experiences for their students both present and future. K-12 students perhaps benefited the most, if not only because of the enriched experiences in the classroom, but also the enthusiasm and excitement of becoming scientists in their own right.

At UAF, the NSF GK-12 Changing Alaska Science Education (CASE) program placed graduate students studying arctic science in both local and rural Alaskan classrooms. Among these graduate students were those who work extensively with UAM collections, offering a portal for students to explore not only how inspiring museum collections can be, but also how they inform scientific research. These teachers and students received a glimpse beyond the relatively few objects on public exhibit and delved into the true significance of what research museum collections can offer in a formal education setting. In addition to developing lesson plans, GK-12 fellows at UAM have also contributed to the easy access of museum objects by educators, including the development of education kits that can be checked out at the museum, as well as the creation of casts of dinosaur bones and tracks that can be shared at the school or district level.

The use of museum objects in the classroom inspired and excited students, increasing their motivation and enthusiasm for science. It also allowed the application of scientific concepts to physical objects. Students developed a scientific skill set, including the ability to observe, ask questions, formulate hypotheses, and devise experiments to explore testable questions; over time, these skill sets strengthened and their application became natural. Of particular importance, the museum objects are relatable to the students’ “backyard” and local natural history as opposed to existing materials that are geared toward classrooms across the country, and could allow them to understand how places like Alaska are unique and change over time.

The GK-12 CASE program ended in 2015 following the end of the national program in 2011. New programs with similar goals have risen in its place at the university-level. The Scientific Teaching and Outreach certificate program at UAF continues to benefit STEM graduate students, teachers, and K-12 students by placing scientists in classrooms.

**Sample CASE Module: Inquiry with Dinosaur Tracks**

Objects from museum collections can be a launching point for inquiry and exploration, even in primary education classrooms. Using plastic Carnegie (1:40 scale) model dinosaurs, elementary students create tracks and track ways in Play-doh to find similarities and differences between tracks of different taxa. Through observations of their toy tracks and replica dinosaur tracks from the UAM Earth Sciences collection, they match what kind of dinosaurs made which track. At this step, students discover multiple dinosaurs can make very similar tracks, and why scientists use different ways of categorizing trace fossils and body fossils. The use of plastic dinosaurs also facilitates an experiment; students explore what substrate (dry sand, wet sand, mud, gravel) is “best”
for preserving dinosaur tracks and where that type of environment would be found locally. (In this case, “best” is defined as held the most similar shape to the track seen in the Play-doh). While this lesson has the added benefit of focusing on Alaskan dinosaurs, it also teaches young students to apply the steps of the scientific method to come to conclusions.

B. Informal Education - Citizen Science

In contrast to the structured programs described above, which are designed to advance specific aspects of formal science education, citizen science is a broad category of science programs that focus on lifelong learners in informal settings (Bell et al. 2016). They encompass a limitless array of topics and frameworks, but the key to citizen science programs is that participants are involved in collecting data for scientific use (Table 2). Citizen science projects increasingly serve education and outreach goals in addition to scientific inquiry (Ballard et al. 2017a; Domroese et al. 2017; McKinley et al. 2017). Though most often applied to research projects, citizen science can be employed by museums to teach the public about the importance of museum collections, while simultaneously giving them the ability to make direct contributions to those collections (Ballard et al. 2017b). Citizen science programs can also be incorporated into formal education curricula. The Reaching Interests Beyond Boundaries Inquiry Trips (RIBBIT, https://wwusdribbit.wordpress.com/about/) provides a great example; it follows the FrogWatch USA (Table 2) framework and protocol. It is modified to provide elementary school teachers and students with field experience, supplemented by lesson plans with learning objectives centered on independent project completion.

Citizen science, regardless of topic, requires a holistic, interdisciplinary approach that addresses aspects of scientific integrity and educational goals for participants of all ages. A detailed plan must also address data quality (“vetting”), submission, management, and distribution, as the dataset can quickly grow out of control. Program activities should be interactive and engaging, as well as interspersed throughout the participation season to ensure volunteer recruitment, enthusiasm and retention. Understanding what the audience needs, how the project will benefit them, and being aware of their specific challenges greatly increases the success of the project while building a relationship with the end user. The old model of “build it and they will come” is no longer valid in a crowded digital education landscape that increasingly demands demonstrated success. Truly effective projects view citizens as more than just data collectors; participants are included in developing the question and analyzing the data. Rather than diminishing data quality, including the citizenry in these aspects of the project actually improves data accuracy and completeness (Lukyanenko et al. 2016). The Informal Science website offers ten prompt questions to further evaluate how effective a budding citizen science program is (http://www.informalscience.org/news-views/learning-through-citizen-science-aspirational-vision-and-ten-questions-prompt-reflection-practice).

Successful implementation of citizen science programs into museum education and outreach will enable collections to grow at an unprecedented rate. Alternatively, they
may allow museum researchers to collect data over a much larger temporal and spatial scale than would otherwise be possible, greatly expanding the impact of the research project. In return, participants will gain an increased understanding and appreciation of the scientific process, and shed negative stereotypes and distrust of scientists. To incorporate citizen science projects and data, however, museums will need to create innovative solutions for integrating observational records into their collections. Non-intrusive data collection has been the rule of thumb for citizen science, while museums have historically been focused on the collection of physical specimens. Further development of database features that support direct ingestion of observational data from citizen science platforms such as iNaturalist is needed; ARCTOS already accommodates observational data.

**Sample Informal Module: Plants and Fungi of Alaska**

Two proven techniques for recruiting citizen science participants and maintaining enthusiasm are to incorporate a social media element and to “gamify” natural history, as exemplified by iNaturalist (Table 2). The UAM Herbarium adopted the iNaturalist platform in 2016 to develop a project called *Plants and Fungi of Alaska* (Fig. 2C), loosely based on the San Diego Natural History Museum’s *San Diego Plant Atlas* (Table 2). Rather than submitting physical specimens, volunteers (20 to date, accessed 2nd March 2017) contribute geo-referenced photographs to the museum’s iNaturalist project. The goal for this project is to recruit trained plant observers to help fill collection gaps that have been identified in ARCTOS for plants and fungi in Alaska. UAM Herbarium staff use the photos to identify the specimens. A total of 410 species have been identified to date (accessed 2nd March 2017). The successful integration of these observations and other non-traditional (i.e. not a physical specimen) data into ARCTOS will greatly expand its utility and data holding by enabling the use of all data pertinent to understanding biodiversity in Alaska. UAM is also working with K-12 educators to incorporate iNaturalist into classroom curricula.

**Discussion**

Museums have the task of educating and inspiring visitors and the general public, and have traditionally met this goal through public exhibits. But increasingly, museums are sharing knowledge through workshops, educational programs for children and families, and partnerships and programs to train undergraduate and graduate students through universities and research funding agencies like NSF. Those efforts translate very well to formal classroom education, where students and educators can benefit from exposure to museum collections. UAM stands as a model exemplifying how natural history museum collections can be incorporated into STEM education in the Arctic. In addition to the American public education problems (Van Heertum and Torres 2011; Kastberg et al. 2016), Alaska faces unique challenges in STEM education, including accessibility to opportunities and resources, incorporation of place-based knowledge, and a need for quality educators that are connected to and understand their communities.
(Lipka et al. 2014; Kaden et al. 2016). Connecting educators and students to UAM collections meet these challenges in a variety of ways, both in a formal classroom setting, as well as outside of the classroom.

Advancing place-based education in Alaska using museum collections

Bringing museum specimens into the classroom does more than just inspire and spark interest. Museum collections are especially well suited to meet specific local needs because they are connected to the region; specimens are collected in the area and are part of a rich history, illustrating the environment both past and present. At UAM, the majority of specimens come from Alaska and the Arctic, and the specimens are a natural fit for place-based education, which has been shown to increase engagement in STEM among K-16 students (Kisker et al., 2012; Barnhardt 2014). Curators, collection managers and graduate students offer a broad base of knowledge, along with very specific knowledge of the Arctic and how it fits into a broader worldview. Development of place-based education materials by the scientific community in collaboration with community members forms connections and builds mutual trust. For example, through a partnership of the NSF GK-12 CASE program and the North Slope Borough School District, place-based lessons centered on earth science specimens collected on the North Slope successfully incorporated the Iñupiaq Learning Framework, a set of guiding principles upon which the borough builds its curriculum.

Despite the proven benefits and applicability of place-based education in Alaska, there are not enough educators knowledgeable in place-based science methodology and native culture. This, along with the lack of resources and issues such as high teacher turnover, contributes to overall disengagement in STEM education among Alaska’s students (Cajete 2008; Hill and Hirshberg 2013). GeoSTEM remedies the lack of culturally and place-informed instruction by training pre-service teachers in place-informed geosciences, including guidance in the inclusion of museum objects and native knowledge. Pre-service teachers are being mentored by native educators to increase awareness of native knowledge, and geoscientists and museum curators to increase access to the scientific community. GeoSTEM serves as a model for other disciplines to use museum collections, expert local knowledge, and curator expertise in teacher education.

Access to collections-based education and research

Many Alaskan educators and students, especially those living in distant rural areas, cannot readily access a museum or its resources. Thus, UAM has developed several strategies to increase accessibility to collection-based education materials that cover a range of STEM topics and can be incorporated into existing curricula. Physical objects in the form of replicas of specimens, and hands-on museum kits with accompanying lesson plans, have been developed and utilized through GK-12 CASE, AIM-UP! and GeoSTEM. These materials, supported by digital UAM lesson materials, can be mailed out to rural schools or picked up at the museum by local educators. Digital specimen data on the open-access database ARCTOS requires only a computer and Internet connection to access. Educators and students can explore a variety of questions
using ARCTOS by focusing on one specific specimen, and/or addressing broader questions such as species distributions across a region. AIM-UP! has developed specific lesson plans and teaching modules for using ARCTOS. All curriculum materials are readily available online to educators, students and the general public.

Citizen science projects involve large numbers of the public directly in the research process, with the capability of answering big questions such as how species distributions and populations are changing. The public most often gathers data in the form of observations, though they can also become a part of data processing and analysis. The UAM Herbarium has its own citizen project through the iNaturalist framework, and national citizen science projects are also applicable in Alaska (Table 2). Further developments in the vetting of data and its incorporation into databases like ARCTOS are strengthening the connection of museums to citizen science projects (Powers et al. 2014). Because these projects are based online, they can be accessed anywhere with an Internet connection, and they grant flexibility in involvement both inside and outside of a traditional classroom environment. Citizen science projects provide an innovative way to implement place-based science education in Alaska. Further partnerships between rural school districts and citizen science projects would be mutually beneficial; educators and student learn about scientific research first-hand and become invested in Alaska’s natural history, and data would be collected in rural areas not otherwise included in these projects.

Teaching STEM skills to students is not a new idea; the current challenge is finding ways to integrate the four discrete disciplines of STEM. UAM has embraced this challenge by immersing students and teachers in real-world, problem-based learning at the boundaries of these four disciplines where they naturally overlap. Connecting educators, students and scientists gives scientists valuable experience communicating complex research to the public, a skill commonly overlooked in academia. The focus on inquiry-based and object-based learning allows students to connect more easily with the world around them; they are able to learn about their environment or further enrich existing knowledge through active learning and application, rather than just by reading a textbook.

Broadening participation

Alaska has among the highest percentages of indigenous students in the nation (U.S. Census Bureau 2004). Linking home, family, and learning has been shown to be a strong factor in the recruitment and retention of American Indian students (Heavy-Runner and DeCelles 2002). It is of particular relevance in Alaska, where subsistence hunting and gathering are still important means of survival. However, research in science education shows that minorities and indigenous people have the lowest participation rates in STEM careers and face one of the greatest challenges of all – the sustainability of their cultures, villages, and ways of life for future generations (McNeeley 2012; Barnhardt 2014). The number of AI/AN earning bachelor degrees in each of the broad science and engineering fields has totaled about 1% in the last two decades (NSF 2017). The failure of schools and school personnel to link family and culture for AI/AN students may be
one reason resulting in the highest dropout rates among marginalized groups in the US; this is corroborated by the National Indian Education Study 2011 (National Center for Education Statistics 2012).

Several of the UAM programs aim to increase student retention for AI/AN students by improving communication with rural communities and families, building a relationship based on equality and respect. In addition, “retention programs must affirm and strengthen [all] families’ cultural, racial, and linguistic identities and enhance their ability to function in a multicultural society” as well as develop components that “are embedded in their communities and contribute to community-building processes” (HeavyRunner and DeCelles 2002, p. 32). A goal of the educational programs discussed here is to increase access to and engagement in STEM fields among Alaska Native students, many of which live in rural communities. UAM is collaborating with members of Alaska’s rural communities to develop education materials and programs in order to create sustainable, meaningful learning experiences that match the community’s needs and values.

**Future directions of museum collaboration in object-based learning**

Arctic communities face disadvantages beyond climate change. Many rural villages are located off of the road system, but are becoming increasingly connected via the Internet. This digital connectedness provides new and expanding opportunities for collaborations that benefit both remote communities and scientists alike. Existing projects, such as iNaturalist and UAF eLearning, already extensively utilize the Internet and computers (including smartphones). Advances in technology and the Internet, as well as increased accessibility, continually open new avenues for their innovative use in education. This has the potential to more readily extend the museum into the classroom.

One example of how new digital technologies have great potential to connect museums and rural communities via the Internet is through the use of rapid prototyping methods, particularly three-dimensional (3D) scanning and printing. 3D printers convert (“print”) digital shape files acquired through photogrammetry, laser scanning or other methods into physical models (usually made of plastic) of an object. Objects can also be shared virtually without printing. 3D models of museum objects (artifacts, mammal skulls, etc.) can be created at a museum and then shared digitally to schools and communities where those objects have particular relevance. For example, dinosaur bones or tracks found near a rural village could be scanned and then sent digitally to that village school for 3D printing in order to share the results made by museum researchers with local communities. 3D printers are becoming increasingly affordable and are gaining popularity in classrooms and other educational venues. These printers are ideal because multiple copies can be readily produced for teaching and outreach without risk to the original object; this can allow multiple copies of one-of-a-kind museum specimens to be produced rapidly compared to traditional methods of molding and casting. They can even print at different scales in order to render objects at different sizes more useful for communicating (for example, a small rodent tooth printed at 10 times its actual size).
The use of 3D scanning and printing is a two way street: while museums can share both digital files and printed copies of collection objects, educators and students can also send 3D models to researchers at museums for study, including identification. With a little training in basic photogrammetry, and the use of a small affordable point and shoot camera (including phone cameras), students can create 3D object files. These files, coupled with photos, allow data to be sent locally, regionally or even globally for scientific study, while still allowing original objects to remain local. This is useful for both cultural objects as well as natural history specimens. In addition, it has the potential to enhance data collection for citizen science projects where a photo is not sufficient.

Conclusions

Museums have a responsibility to offer solutions to challenges facing STEM education while the need for increased science awareness and literacy is at an all time high. Alaska has unique challenges that are now, in part, being met through continued efforts by UAM to contribute to place-based education, to increase the number and quality of educators with the ability to teach place-based STEM education, and to increase accessibility to resources including physical collections and online data. While these challenges are unique to Alaska and the Arctic, their solutions have broader applicability; UAM is just one piece of a growing national movement to increase museum collections involvement in education (Cook et al. 2014, 2016; https://www.idigbio.org/education). The overall objective is to increase engagement in STEM fields across all levels of education, as well as to raise students who understand the scientific process and can make informed decisions regardless of whether they pursue STEM in their futures. Arctic STEM education using public museum collections can serve as a catalyst to open doors and expand learning opportunities among a diversity of citizens who are interested in Arctic science. This collaborative approach will lead to better understanding of STEM education, career pathways, recruitment, and sustainable partnerships between scientists and communities. And it will build expertise in research and innovation of STEM learning for engaging diverse students, educators, and the broader public.

Acknowledgements

Thanks to all participants of the ASSW special session, Dr. Jeff Saarela and an anonymous reviewer for their constructive comments, as well as to all enthusiastic researchers and citizen scientists in Alaska and Arctic regions. This work was supported, in part, by AIM-UP!, a Research Coordination Network in Undergraduate Biology Education by NSF DEB-0956129 (PIs Cook, J.A., Lacey, E.A., Ickert-Bond, S.M., Edwards, S.V.); Collaborative Research: Arctic Dinosaur Paleobiology - Hypothesis Testing Through Cross-Latitudinal Comparison by NSF EAR-1226730 (PIs Druckenmiller, P.S., Erickson, G.M.); Collaborative Research: GP-EXTRA: Preparing GeoSTEM Teachers for the Arctic Region (GeoSTEM) by NSF ICER-1540674 (PIs...
Kaden, U., Fowell, S.J., Patterson, P., Druckenmiller, P.S.); New GK-12 Program: The CASE (Changing Alaska Science Education) for enhancing understanding of climate change by NSF DGE-0948029 (PIs Boone, R., Conner, L., Winker, K.); and by the University of Alaska Fairbanks and the EWHALE lab at UAF (to F. Huettmann and M. Spangler).
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U.S. Census Bureau 2004. 2000 Census of Population and Housing, Population and Housing Unit Counts PHC-3-1, United States Summary. U.S. Census Bureau, Washington, DC.


Figures

Fig. 1. Innovating education with museum collections: integration of formal and informal learning.

Fig. 2. Examples of formal and informal science education programs using museum resources at UAM. (A) Students examine an articulated human skeleton to identify hadrosaur dinosaur elements in a lesson on comparative anatomy. (B) Pre-service teacher examining nail polish cuticle peels made from herbarium specimens deposited at UAM to count stomata on a leaf. (C) Citizen Science iNaturalist workshop on *Fungi of the Interior* held at the UAF campus and adjacent trails.

Tables

Table 1. Selection of online natural history specimen databases

Table 2. A selection of successful citizen science programs
1. Improve
2. Reinvent
3. Supplement
4. Transform
Fig. 2. Examples of formal and informal science education programs using museum resources at UAM. (A) Students examine an articulated human skeleton to identify hadrosaur dinosaur elements in a lesson on comparative anatomy. (B) Pre-service teacher examining nail polish cuticle peels made from herbarium specimens deposited at UAM to count stomata on a leaf. (C) Citizen Science iNaturalist workshop on Fungi of the Interior held at the UAF campus and adjacent trails.

152x178mm (300 x 300 DPI)
<table>
<thead>
<tr>
<th>Name</th>
<th>Scope</th>
<th>URL</th>
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<tbody>
<tr>
<td>ARCTOS</td>
<td>ARCTOS is an open-access, specimen-based database utilized by multiple institutions in North America for data storage and management associated with natural history collections.</td>
<td><a href="http://arctos.database.museum/">http://arctos.database.museum/</a></td>
</tr>
<tr>
<td>VertNet: Distributed databases with backbone</td>
<td>VertNet is a tool designed to help people discover, capture, and publish biodiversity data of all vertebrates. It also integrate with several targeted biodiversity and collection management applications (GEOLocate, AmphibiaWeb, Map of Life, Specify, Arctos, DataONE, Encyclopedia of Life, and Animal Diversity Web.</td>
<td><a href="http://vertnet.org">http://vertnet.org</a></td>
</tr>
<tr>
<td>MorphBank</td>
<td>Morphbank :: Biological Imaging is a continuously growing database of images that scientists use for international collaboration, research and education.</td>
<td><a href="http://www.morphbank.net">http://www.morphbank.net</a></td>
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<tr>
<td>iDigBio</td>
<td>Integrated Digitized Biocollections (iDigBio), the National Resource for Advancing Digitization of Biodiversity Collections (ADBC) funded by the National Science Foundation USA. Through ADBC, data and images for millions of biological specimens are being made available in electronic format for the research community, government agencies, students, educators, and the general public.</td>
<td><a href="https://www.idigbio.org">https://www.idigbio.org</a></td>
</tr>
<tr>
<td>GBIF</td>
<td>The Global Biodiversity Information Facility (GBIF) is an international open data infrastructure, funded by governments. It allows anyone, anywhere to access data about all types of life on Earth, shared across national boundaries via the Internet.</td>
<td><a href="http://www.gbif.org">http://www.gbif.org</a></td>
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Table 2. A selection of successful citizen science programs.

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Project Description</th>
<th>Project Scope</th>
<th>Project Website</th>
<th>Selected Publication</th>
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</thead>
<tbody>
<tr>
<td>iNaturalist</td>
<td>Users upload photos of the living natural world to a social media website, online</td>
<td>Worldwide</td>
<td><a href="http://www.inaturalist.org/">http://www.inaturalist.org/</a></td>
<td>He and Wiggins 2015</td>
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<td></td>
<td>community can view and help to identify the observation.</td>
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<td>Audubon Christmas Bird Count</td>
<td>Seasonal census of birds organized to cover a 15-mile diameter circle.</td>
<td>Western Hemisphere</td>
<td><a href="http://www.audubon.org/conservation/science/christmas-bird-count">http://www.audubon.org/conservation/science/christmas-bird-count</a></td>
<td>Niven et al. 2004</td>
</tr>
<tr>
<td>U.S. National Parks Service Centennial BioBlitz</td>
<td>Volunteers work with experts to census all living things in a predetermined area</td>
<td>United States</td>
<td><a href="http://nationalgeographic.org/projects/bioblitz/">http://nationalgeographic.org/projects/bioblitz/</a></td>
<td>Machlis and McNutt 2015</td>
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<td></td>
<td>over a designated time period (usually 24 hrs).</td>
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<tr>
<td>FrogWatch USA</td>
<td>Volunteers acoustically monitor amphibian breeding ponds for diversity and abundance.</td>
<td>United States</td>
<td><a href="https://www.aza.org/frogwatch">https://www.aza.org/frogwatch</a></td>
<td>Steelman and Dorcas 2010</td>
</tr>
<tr>
<td>Local Environmental Observation Network</td>
<td>Local observers share knowledge about unusual animal, environment, or weather events.</td>
<td>Alaska</td>
<td><a href="https://www.leonetwork.org/en/">https://www.leonetwork.org/en/</a></td>
<td>Brubaker et al. 2013</td>
</tr>
<tr>
<td>San Diego County Plant Atlas</td>
<td>Volunteers collect and contribute plant specimens to the San Diego Natural History Museum.</td>
<td>San Diego County</td>
<td><a href="http://www.sdplantatlas.org/">http://www.sdplantatlas.org/</a></td>
<td></td>
</tr>
<tr>
<td>The Melibee Project</td>
<td>Volunteers monitor the impact of invasive plants on native subsistence foods and</td>
<td>Interior Alaska</td>
<td><a href="https://sites.google.com/a/alaska.edu/melibee-project/">https://sites.google.com/a/alaska.edu/melibee-project/</a></td>
<td>Spellman and Mulder 2016</td>
</tr>
<tr>
<td></td>
<td>compare plant phenology to Herbarium, UAM.</td>
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