Revolutionizing the Use of Natural History Collections in Education

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Abstract

Natural history collections are an irreplaceable and extensive record of life, and form the basis of our understanding of biodiversity on our planet. Broad-scale educational accessibility to these vast specimen collections, specimen images, and their associated data is currently severely hampered. With emerging technologies and massive efforts towards digitizing specimens, there is enormous potential to revolutionize biology education at all levels. These specimens, images, and data provide an unparalleled opportunity to integrate both inquiry-based and place-based learning into education at all levels and in all venues. Natural history specimens and associated data have an inherent focus on spatial and temporal variation and are uniquely situated to integrate traditionally segregated disciplines, and to develop creativity, generative thinking, and rigorous inquiry; qualities that will be required of successful future generations. These collections are excellent tools for engaging students in biology and helping students draw connections among sub-disciplines within biology (e.g., ecology, evolution, and molecular genetics) and connect biology to other fields (e.g., art, computer science, and geography). Natural history specimens can nurture student interest in solving important societal issues such as sustainability, invasive species, declining biodiversity, food security, climate change, and emerging pathogens. To realize these educational opportunities we need to overcome the disconnect between educators and museum scientists by providing greater access to teaching collections and building student-friendly digital interfaces and educational modules that demonstrate how to explore the vast natural history collections. There are a growing number of excellent models for overcoming these hurdles that illustrate how these approaches could be expanded and more widely adopted in educational settings/environments.

University researchers working in natural history collections are continuing a long academic tradition of using specimens to teach undergraduates and graduate students about the diversity of the natural world. A university student's initial encounter with the fascinating patterns of organismal diversity in taxon-oriented courses (mammalogy, entomology, botany, etc.) often leads to a life-long interest in research and education in systematics, natural history, or evolutionary ecology. In addition, university faculty associated with museums mentor graduate and undergraduate students in inquiry-based projects and research theses that are based on natural history specimens as the primary source of evidence. This tradition remains strong on many campuses, but advances in molecular biology, and surging budgets for molecular research focused on few model organisms, tend to overshadow the fundamental importance of the study of organismal diversity (Wilcove & Eisner, 2000). In response, many academic programs have discontinued taxon-oriented courses and closed smaller university museums (Gropp, 2003). Once considered essential teaching tools in organismal biology, many biological collections have been orphaned or lost support (Schmidly, 2005). The result is progressively fewer opportunities for students to be exposed to the scope and complexity of the planet's biodiversity (Leather & Quicke, 2009), to questions in evolutionary biology, and to the resources and systematic expertise associated with specimen collections, and this is likely to be especially true for those from urban, low-income backgrounds.

Free-standing museums often partner with nearby universities to conduct distinguished training programs at the graduate and undergraduate level, using their unparalleled collections resources and personnel. Many museums have a long tradition and considerable institutional expertise in utilizing specimens as part of educational and interpretive programs directed at the general public, and at K-12 (ca. 5- to 18-year-olds) students, encouraging hands-on activities with the specimens.

While many K-12 educators are compelled to teach their students about organismal diversity, they often lack time, specimens, and the specialized expertise required to conduct specimen-based activities in the classroom. By combining educators' experience in engaging the interest of their students, and in finding stimulating, age-appropriate content, with easily accessible biodiversity data and specimens, there is great potential to further integrate educational programs into university and public museums. Current and ongoing efforts to centralize specimen data, develop educational modules related to museums and museum data, and the broadening use of specimens in all scientific disciplines makes this an ideal time to include specimen-based science in the K-12 classroom.

Three trends are creating exciting new opportunities for the use of natural history specimens in education. First, the rapidly-accelerating pace of specimen digitization programs and the development of collections-based bioinformatics resources make comprehensive specimen-level data, including high-quality specimen images and metadata associated with specimens, available to anyone worldwide with an internet connection and a web browser (e.g., Beaman & Cellinese, 2012; Hanken et al., 2013). That resources such as the Global Biodiversity Informatics Facility could be more effectively used in education seems obvious, but at present there are few examples (e.g., Monaghan, 2011). What are the reasons for the limited use of these resources in education?

Second, there is a growing emphasis on inquiry-based education (e.g., Feldman, Chapman, Vernaza-Hernandez, Ozalp, & Alshehri, 2012). Natural history specimens are ideal subjects for inquiry-based research at all educational levels. How can this opportunity be most effectively articulated to educators, and what tools or training will they need to be successful?

Third, there is renewed interest in educational and outreach activities by university and museum-based researchers (Alpert, 2009; Roberts, 2009). In part, this has been stimulated and driven by the emphasis on broader impacts of research activities that are now an integral part of research proposals to the U.S. National Science Foundation (NSF) and other federal agencies. As scientists increasingly engage in outreach, they discover that these stimulating activities can contribute to their own research efforts in unexpected ways (e.g., Feldman et al., 2012). What opportunities already exist for partnerships between collections-based researchers and educators? What are the priorities for investment in new programs to foster these activities?

The Utility of Specimens and Specimen-Based Electronic Resources in Education

Scientists are asked to address major challenges facing our society, such as sustainability, invasive species, food security, climate change, and emerging pathogens. By establishing baseline environmental conditions, collections provide our best perspective on the Earth's changing biota and, by extension, how we might expect the earth to change in the future (Pyke & Ehrlich, 2010; Schmidly, 2005). In 250 years, taxonomists have named only a small fraction of the organisms on Earth. Because climate change, habitat fragmentation, pollution, and invasive species now threaten millions of species globally, organisms are disappearing faster than they can be catalogued and understood (Barnosky et al., 2011; Loarie et al., 2008; Pimm et al., 2014; Pimm & Raven, 2000). However, there is a real and growing gap between scientists and institutions that study organic diversity and the instructors and students that need to understand biodiversity sciences. This gap results in poor levels of understanding of biodiversity and confusion interpreting the body of specimen-based evidence available to inform discussions on evolutionary hypotheses or climate change impacts.

Museum collections are especially tuned to teaching the concepts of scale across time and space, and from genomes through organisms to ecosystems. Specimens can be used to effectively demonstrate the process of scientific discovery and also how scientists integrate across numerous aspects of biotic and abiotic systems. Specimens also help students understand the fundamentals of complexity, diversity, and sustainability (Lane, 1996). Natural history museums now provide an unparalleled platform for inquiry-based learning about our planet's diversity and virtually limitless opportunities to introduce the use and integration of multiple databases in the discovery process (Cook et al., 2014).

Traditionally, natural history museums engaged students in biodiversity studies through specimen-based laboratories, field projects, or training opportunities related to the curatorial process, mainly reaching graduate students. A new educational direction is possible with web- based dissemination of teaching modules that take advantage of the growing cyberinfrastructure related to museum digitization, reaching a much more diverse audience from educators to elementary students. These modules are being developed around national and state teaching standards (e.g., evolution and conservation) and provide a ready resource for K-16 teachers in the United States. and abroad for inquiry-based exercises and lesson plan development in the sciences (e.g., AIM-UP!, n.d.).

Natural history museums create interest and enthusiasm for the natural world. Specimen-based experiences are often transformative, as witnessed by the large number of influential environmental and evolutionary biologists who count their early exposure to natural history collections as pivotal to their career path. Museums provide an immediate connection to discovery of the natural world by bringing historical and on-going field studies in natural history (that have produced well-documented specimens) to the cutting-edge of innovative science in molecular evolution, stable-isotope ecology, and developmental biology.

Specimen-based inquiry (physical or virtual) fosters the development of creativity, generative thinking, and rigorous inquiry that will be required of future leaders in research and practice. Because natural history collections emphasize physical, spatial, and temporal variation, they also are uniquely situated to bridge the gap between traditionally segregated disciplines. By using specimens to incorporate art and history into biology, we take the first step in efforts to develop and strengthen future ties between the sciences and the humanities within our educational curricula and ultimately research activities.

A common interest in place-based research and experiential, inquiry-driven learning underpins approaches to pedagogy in both the sciences and the arts. While scientific education and research offer rigorous methods for creating new knowledge, arts education and practice provide the tools to foster exploration. All disciplines stand to benefit through stronger associations. Natural history museums are expanding on their long and productive tradition of educating the next generation of scientists, artists, and historians necessary to interpret our changing natural environments and develop novel solutions to emerging problems.

Universities and colleges have seen unprecedented interest in online learning (Allen & Seaman, 2010; International Association for K-12 Online Learning [iNACOL], 2009; Searson, Jones, & Wold, 2011). Students have embraced virtual courses that are affordable and provide personalized and adaptive learning experiences. As academia embraces this trend, science educators are scrambling to deliver virtual labs that are interactive and utilize scientific inquiry and modern methodology. Advances in computer technologies and software have provided innovative tools to engage students and foster a dynamic and interactive online classroom; smart phone applications and social networking keep students connected to virtual resources and an online community. Scientists managing natural history collections are at the cutting edge in adapting these same tools to facilitate communication, engage citizen scientists (e.g., Hill et al., 2012), and create global online databases. Natural history collections are uniquely poised to offer digitized data for incorporation into online labs, allowing students to make open inquiry, examine virtual specimens, explore research questions, collaborate globally on projects, query scientists, and interact with a growing database representing diversity over time and space.

Obstacles to Use of Specimen-Based Resources in Education

There is great potential to use museum specimens and specimen-based electronic resources in an educational setting for the extension of thoughts/concepts taught in the classroom, and for use of the scientific method process. However, missed opportunities abound. Although not insurmountable, we identify challenges to fully incorporating specimen-based resources in an educational context.

First, we acknowledge a clear disconnect between museum scientists and educators at all levels (K-12, 2- and 4-year colleges, and universities). Generally, few educators enroll in taxon-oriented courses en route to obtaining their licenses or degrees, and therefore miss a fundamental step in realizing the inherent educational value of museum specimens in teaching. Lacking that essential step in their own educational pathway, they neither seek to use specimens in learning (if resources are available), nor do they seek out collaborations (if resources are limiting). Furthermore, state-mandated standards of learning (SOL) or equivalent requirements in K-12 environments do not emphasize the connection between learning outcomes and specimen-based materials. This combination of teacher inexperience in specimen-based learning and the perceived deviation from required SOLs creates a lack of incentive to move in the direction of specimen-based teaching exercises.

Second, unless the museum is an institution explicitly designed with space for interactive educational outreach, student/teacher access to the facilities is limited. Field trips to large free-standing museums, like the Smithsonian Museum of Natural History, American Museum of Natural History, and Field Museum are likely limited to schools within a small radius of the institution. Furthermore, time is always a limiting factor in a K-12 environment. Teachers often are limited to covering the topics directly related to the SOLs (unique to each grade level). Thinking “outside the box” is simply not a temporal or financial option.

If large museums are not immediately available or accessible to K-12 institutions, teachers might consider collaborating with their local colleges and universities. Although colleges and universities may house a substantial number of museum specimens, they often are inaccessible to the public. Display of more than a few charismatic specimens is rarely an option. Without existing incentive-based collaboration, local K-12 teachers simply would not know that these resources are available for educational purposes. Although there is a disconnect between K-12 teachers and college-level professors, the increasing emphasis from the NSF on broader impacts has incentivized some researchers to work with K-12 educators. However, the scales of these interactions usually are limited. The big push to digitize specimens and make images and metadata available in an on-line format might help alleviate this chasm. The creation of manageable, user-friendly, searchable databases provides access to specimens by teachers of all levels. If there is flexibility in the search engines, teachers can ask questions at the appropriate level of scientific understanding for their students.

However, this one-stop searchable database is not yet a reality. Multiple taxa are grouped across multiple databases with multiple structural components. Many of these databases are bulky and data-intense, and the learning curve is substantial. Data overload is a frequent issue when first introduced to a taxon-specific database. Unless database managers work directly with educators to create teaching resources and interfaces appropriate for multiple age groups (e.g., Animal Diversity Web employs BioKids [2014] projects for K-8 students and uses its Quaardvark data-mining tool [University of Michigan, 2013] for college-level students), the meaningful use of specimen-based electronic resources in teaching too often is overwhelming. As teachers are already hard-pressed to meet the demands for preparing standard classroom exercises, additional time to develop materials to engage and extend the learning process for their students may simply not be available. Therefore, the production of such collections exercises for teachers would alleviate such time constraints. Finally, limited opportunities exist for hands-on collaborations between students and museum curators and scientists. A few of the large museums, such as Field Museum, offer summer internships to local high school students. One creative collaboration taught science majors to be knowledgeable docents (e.g., Pyatt, Rosser, & Powell, 2009). However, the number of students that can be reached per year is miniscule due to time, money, and logistical support.

Potential Model Programs for Specimen-Based Education

There are a number of highly successful programs that are focused on education using natural history specimens and specimen-based electronic resources. These innovative programs illustrate the diversity of opportunities for cross-fertilization between museums and educators in a number of forums and with a diversity of audiences.

Research Coordination Networks

Research Coordination Networks (RCNs, funded by NSF) have proven to be highly effective at creating new directions in research in a number of different disciplines. A few, like CollectionsWeb: Building a National Community of Natural History Collections, are focused on, or deal in part with, natural history collections. Additionally, a number of RCNs were funded recently to improve undergraduate biology education. One of these, AIM-UP! (n.d.), is focused on the role of natural history collections in undergraduate education. AIM-UP! seeks to modernize and broaden the role of natural history collections in education by focusing on opportunities for inquiry-based education using specimens and specimen-based electronic resources as educational resources. New educational modules are needed to make museum data accessible and user-friendly to instructors in multiple biological disciplines and build upon informatics tools and other databases now accessible online, such as VertNet, GenBank, Education LifeDesk, Encyclopedia of Life, and MorphBank.

NSF GK-12 Graduate STEM Fellows in K-12 Education

Graduate student researchers in science, technology, engineering, and math (STEM) disciplines have tremendous, but underutilized potential, in K-12 education. The GK-12 program provides the opportunity for graduate fellows to interact with K-12 educators and even to be placed in the classroom. The benefits are obvious; graduate students are afforded an opportunity to enhance their teaching skills and to develop their ability to communicate science while enhancing the scientific instruction and content for the K-12 students. Interactions with young scientists is certain to be inspiring to the K-12 students involved, enhancing their interest and literacy in science and encouraging them to pursue careers in STEM disciplines.

Perhaps more importantly, the young scientists and classroom educators that are involved will become comfortable in these types of interactions and will hopefully continue to develop such interactions throughout their careers, affecting many more students than those directly involved in the GK-12 program. Building these bridges between scientists and K-12 educators is potentially a tremendous boon to STEM education in the United States. Natural history collections are widespread across the United States and the potential for using specimens, images, or data to teach K-12 students in the classroom is nearly unlimited, but a solid framework for developing the types of collaborations needed to do this effectively on a large scale is missing.

Smithsonian Institution's Naturalist Center

The education potential of natural history museums is enormous and their educational programs are extremely popular around the United States and the globe. These museums draw a tremendous number of visitors every year and have reached tens of millions of visitors. Over the last few decades, museums have become much more interactive and technologically advanced, which has heightened visitor experiences. However, educators agree that education can be most effective when it is inquiry-based.

A former partnership between Loudon County, Virginia and the Smithsonian Institution, the Naturalist Center pioneered a learning ecosystem using natural history specimens and other Smithsonian resources. Their approach consisted of three elements: resources, access, and cognitive skill. Resources included specimens, images, databases, and literature. Beyond physical or electronic access to these resources, staff sought to instill motivation to use these resources. Finally, through effective presentation of materials and thought-provoking initial questions, they encouraged visitors to seek not only answers, but also to develop their own questions and then use the available resources to answer them (Efthim, 2006). This approach was very resource-intensive, but was highly successful and was one excellent model for inquiry-based education in a museum setting.

K-12 Teacher Education

Three mechanisms for "teaching the teachers" are currently available: teacher sabbaticals, summer workshops for teachers, and research experiences for teachers.

Teacher sabbaticals. The U.S. Department of Education and other funding agencies or foundations provide funds for K-12 teacher sabbaticals and many schools allow leave (unpaid or at a reduced level of compensation) for professional development. The purpose of these sabbaticals is usually to allow the teacher to acquire new skills and expertise that will enhance their teaching, such as training in a new subject area or learning new teaching methodologies or classroom skills.

Research experiences for teachers. A number of government, industry, and nonprofit agencies currently offer, or have offered, funds to provide K-12 teachers with research experiences, such as the Department of Energy, the National Institutes for Health, National Aeronautics and Space Administration, and the Howard Hughes Medical Institute. The NSF is probably the largest source of such funding and provides support for Research Experiences for Teachers (RET) (National Science Foundation, n.d.) in two ways: supplemental funds to existing grants (RET Supplements) or larger programs where many teachers are trained as part of a common program (RET Site). The availability of RET funds varies among directorates or programs and other agencies offer similar programs. The overall goal of these programs is to provide teachers with laboratory experiences in the sciences that can translate back to classroom education and be used to develop new classroom activities.

Summer workshops for teachers. Multiple funding agencies have programs for summer workshops and training for teachers to broaden their expertise and help keep their training current. Most of these provide Continuing Education Credits that teachers are typically required to accumulate. The programs cover all areas, including STEM disciplines, and can take a variety of forms.

These mechanisms for interactions between researchers and teachers, instead of directly between researchers and students, have greater capacity building, are very cost-effective, and can take advantage of the strengths of the educators in developing lesson plans and curricula. While all three of these mechanisms can be highly effective, their scale is typically very small. To broaden the role of specimens in education, large-scale, focused programs are needed.

Grand Challenges

Bringing scientists and educators together will create tremendous opportunities for using specimens and specimen-based electronic resources in education at all levels, far exceeding what has been done in the past. These opportunities will be realized by the integration of three resources: specimens and collections, specimen-based electronic resources, and people and human resources.

Specimens and Collections

The billions of specimens in natural history collections across the United States are located in hundreds if not thousands of institutions, both large and small, including academic institutions and independent local, state, and national museums. These specimens and the data they represent constitute a tremendous national resource for engaging young students in the study of natural history, modeling the process of scientific inquiry, stimulating curiosity about the natural world, and potentially solving major societal issues.

Scientific specimens possess a power and authenticity that engage people of all ages. Naturally, public engagement with specimens needs to be conducted in an appropriate manner, and with specimens that are either expendable or robust to being handled. One way to provide specimens to school children would be to develop teaching collections with good quality specimens and conduct teacher workshops on specimen-based instruction. Natural history collections could provide specimens and training with programming options extending from future collection personnel in developing countries, to local teacher training, to home-schooled children, to elder-hostels (training local species experts), to special training for persons with disabilities.

Further, we acknowledge that many young people are isolated from the natural world and their experience with natural systems is increasingly limited. Natural history expeditions, specimens, and specimen-based electronic resources all provide opportunities for young people to overcome the barriers between people and nature that are increasingly common in contemporary society.

Specimen-Based Electronic Resources

Exponential growth of specimen-based databases and electronic resources has profoundly changed how scientists conduct research activities and report their results. With the Advancing Digitization of Biodiversity Collections program at NSF, and related initiatives such as the Encyclopedia of Life, MorphBank, and Map of Life, digitization and educational use of substantial portions of our nation's legacy of natural history collections is now a realistic goal.

We emphasize that there exist diverse ways that specimen-based electronic resources are, or could be, used in education, including mining electronic data as raw material for student research projects and developing programs in which students themselves are creating electronic content. However, the potential of these electronic resources is unappreciated outside of a rather narrowly-defined scientific community. The ability to adapt information from these resources to meet local programmatic needs, such as on-the-fly local biodiversity resources (e.g., species lists), and then combine those data with local and current specimen observations to monitor the status of migrating birds, spider webs in the fall, or invasive weeds, would be a powerful mechanism for engaging students.

The lack of user-friendly portals to these resources now presents formidable obstacles to their use by the public. At the present time, the interfaces to most electronic resources appear complicated and off-putting to anyone other than dedicated and experienced research scientists. However, we recognize that elegant and powerful interfaces such as Google Earth are now almost universally utilized by educators at all levels as an organizational template for teaching content such as geology and earth history. Development of visually-engaging, intuitive, and easy-to-use public interfaces to collection-based informatics resources is an urgent priority.

People and Human Resources

Collection-based scientists and educators have many common interests, and at some levels they can easily relate to one another's goals and activities. However, it is apparent that scientists and educators often speak two very different languages and that even a common vocabulary may express different meanings in different disciplines.

Universities have specialists (e.g., science educators) that are experienced in communicating and building bridges between scientists and educators, and including them in the development of educational initiatives would help ensure success. Directly involving teachers in collection-based research activities is another, proven method to promote communication between, and appreciation for, the goals and challenges of educators and scientists.

Perhaps most importantly, placing K-12 students and teachers in environments in which scientists, graduate students, and post-docs are working together to solve scientific problems will build professional relationships that can have far-reaching effects. Students and teachers quickly relate to the excitement of scientific discovery. With the right tools and programs, they can become valuable participants in the scientific enterprise. Furthermore, many scientists are gifted teachers; they are passionate about their interests and often have the ability to clearly articulate the importance of scientific research through the use of compelling communication. There is probably no better way to recruit future scientists, and to produce a general citizenry that has a basic level of scientific literacy, than to actually engage students in research activities at a very young age (e.g., Sadler, Burgin, McKinney, & Ponjuan, 2010).

Conclusion

Numerous programs exist that successfully incorporate specimens into education, and other initiatives are now being developed. These programs remain limited in their reach so we need to develop new initiatives that allow us to implement what we have learned on a much broader scale and effectively take advantage of the tremendous opportunities offered by natural history collections. First, investment of time and funds to develop a national distributed resource that puts specimens in the hands of teachers and students is sorely needed. Second, investment in developing easy-to-use tools to access, analyze, and visualize specimen data in a meaningful way will be required before the overwhelming array of data can be effectively integrated into educational efforts. To do this, we need to incorporate teachers, other educational experts, museum scientists, graphic designers, computer scientists, statisticians, geographers, and experts from many other communities. Finally, to be effective, this resource must engage teachers and museum scientists across the country and reward them to encourage participation. Effort must be spent developing a sustainable model for this interaction.

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