Citizen Science Can Improve Visitor Experiences and Research Outcomes in Museums and Cultural Institutions

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Applying citizen science protocols to imaged museum specimens can help lessen the digitization burden on research staff members and address research gaps in existing citizen science datasets while providing meaningful visitor engagement opportunities. Citizen science is still a relatively young field, but because museum collections are often substantially older, pairing the two can allow us to ask questions on a much broader time scale. Applying consistent protocols to citizen science observations and museum specimens enables high-quality derived data that can be quickly combined without uncertainty in definitions or differences in approaches. Citizen science protocols can be well suited to use with image data because they are often developed for visual-only information (e.g., presence of flowers on a plant, the number of seeds on a page, the number of clouds in the sky). Because many collection objects are imaged as part of the digitization process, the visual information is often already available and searchable as an input.

Utilizing pre-existing citizen science protocols also allows museums to tap into a broader community of existing participants who are already familiar with the protocol. For example, the National Phenology Network has more than 15,000 citizen science

observers who are already trained in applying their protocols to living specimens. Citizen scientists from active collection projects can easily transition to the digital interface and vice versa, allowing for mutually beneficial collaborations. Also, during times when citizen scientists cannot make traditional onsite or in-person observations (e.g., global pandemic, short-term disability, long-term disability), digitization and digital engagement opportunities allow for continued engagement with the observer community through citizen science opportunities. It also enables museums to continually digitally interact with users who may not view collection items in person or engage traditionally with museum infrastructure. Finally, citizen science projects and protocols often emphasize education and engagement, which means there are often pre-existing tools that can be modified for use in formal educational settings such as schools and universities and informal educational settings such as museums, libraries, and botanical gardens.[1]

CHALLENGES AND OPPORTUNITIES OF COLLECTIONS-BASED RESEARCH

Museums and other cultural institutions are rich storehouses of historical information, mainly through objects, documents, and physical specimens.[2] Access to museum collections enables research in diverse fields, including anthropology,[3] paleontology,[4] art history,[5] and women's studies. Collections-based research is of high and increasing importance to researchers.[6] In particular, natural history specimens, which include preserved insects and pressed plants, are of growing research interest within ecology and environmental sciences because they provide a historical snapshot of biodiversity, species interactions, and even genetics.[7] Yet, researchers often need physical access to specimens or objects, which is a barrier to making collections-research more inclusive to international researchers, disabled researchers, and researchers at smaller institutions.[8] Natural disasters, including the coronavirus pandemic, have also limited and complicated research access to museum collections and have left many collection items vulnerable to threats, including pests and environmentally driven degradation.[9] One way collections are working to make collections more accessible is through digitization, but digitization can be time-consuming and expensive and does not directly equate to accessibility, particularly if digitized collections are not findable, accessible, interoperable, and reusable.[10]

Presently, the best practices for digitization include the database of information about specimens and the imaging and georeferencing of collection items.[11] Databasing involves the standardization of text-based metadata about an item like what it is (e.g., the taxonomic identification or categorization of the item), the date of item collection or creation, the identities of the collector or creator, where it was created, and other details like the preservation methods.[12] There are multiple standardized metadata profiles in the museum setting, including Dublin Core,[13] Darwin Core,[14] Ecological Metadata Language,[15] and the Federal Agencies Digital Guidelines Initiative.[16] Often, the databasing step of digitization includes the assignment of a unique identifier,

which may be a collection-specific barcode or a standardized persistent identifier for the object controlled by a domain-specific authority.[17] While databases may provide information about the specimen's location, georeferencing provides a specific mapped GPS point.[18] Georeferencing is the process of converting a text-based description of a locality to a geospatial coordinate, which allows for rapid, computer-based analyses of geospatial patterns.[19] Finally, imaging typically includes capturing, processing, and archiving a high-quality 2-D image of the specimen, often with a color scale or ruler.[20] As the technological tools available to museums continue to grow, best practices in digitization across fields are expanding to include 3-D scans, microscope images, x-rays, genetic information, or other experimentally derived quantities.[21]

As the scope of digitization expands, fully digitizing museum collections becomes an increasingly challenging process, both in terms of the physical costs of the technological tools and in the hours required to preserve details of their collections for future research use. Digitization can be a significant challenge, particularly at smaller institutions,[22] and can lead to the absence of critical collections in research datasets.[23]

CITIZEN SCIENCE AS A TOOL FOR RESEARCH AND EDUCATION

Citizen science is a research method that fosters collaboration between professional and informal scientists.[24] Citizen scientists can include students, museum visitors, civic educators, retired scientists or educators, volunteers, or any individuals interested in scientific work. As research becomes increasingly high-dimensional and data-driven, citizen science provides research datasets that can reach previously unachievable sample sizes, geographic extent, and temporal coverage.[25] Simultaneously, citizen science enables meaningful engagement in the scientific process to individuals often excluded from academic research. Citizen science is quickly proliferating in the physical and natural sciences, and a growing number of projects address research questions in the social and cultural sciences. In the natural sciences, citizen science datasets have enabled broad research investigations into wide-ranging topics such as the spatial differences in dragonfly colors,[26] water quality in local watersheds,[27] bird population trends, and plant responses to climate change.[28]

Beyond the research benefits, citizen science in natural science fields can encourage political actions such as environmental and conservation activities, while improving scientific literacy, public understanding of science, and scientific engagement amongst citizen scientists.[29] Most citizen scientists are motivated to participate by a desire to contribute to scientific discovery.[30] Participation in citizen science projects enables individuals to join a community of other citizen scientists involved in their project, learn more about the science they are involved with, and meaningfully contribute to scientific inquiry.[31]

Many citizen science projects within ecology and environmental sciences are observation-based, with participants observing natural features (e.g., cloud cover, species presence, water conditions) in a specific area. For example, iNaturalist crowdsources photos of organisms and identifications as documentation of species presence and ecology;[32] the OPAL air quality survey used counts and identifications of lichen on tree bark and counts of fungal infections on sycamore to better understand air quality in Great Britain;[33] and Nature's Notebook, a project of the USA National Phenology Network, leverages more than 15,000 volunteers to document the seasonal phenology (the timing of life stages) in plant and animal species.[34] These projects continue to develop and proliferate across a variety of fields and research topics and provide new opportunities for research and educational partnerships.

Although citizen science projects can provide high-quality data at a regional, continental, or even global scale,[35] many projects are limited in their temporal scope. While biological and environmental studies, particularly those of birds, have greater longevity relative to other disciplines,[36] most citizen science projects are fewer than 15 years old. New projects are frequently under development as the availability of technology and platforms continues to advance.[37] One way to improve this temporal coverage is to encourage participation in citizen science projects into the future, but another opportunity is to supplement citizen science data with historically collected data, including data stored in museums and libraries.[38]

CASE STUDY ONE: COLLECTIONS-BASED CITIZEN SCIENCE IN UNDERGRADUATE RESEARCH

Digitized herbarium specimens are increasingly used as a source of information on the timing of plant and animal life stages such as flowering, reproduction, and the fall color change—a collection of phenomena known as plant phenology.[39] However, classifying herbarium specimens for phenology is hugely time-consuming, leading to low sample sizes across most studies, especially compared to the enormous volume of available data.[40] Citizen science is well suited to process large volumes of visual data that would otherwise be time-consuming to classify. There are many current phenology citizen science projects, but Nature's Notebook is the largest, and its protocols provide species-specific, standardized definitions of the life stages of more than 1,000 species.[41] Data contributed to Nature's Notebook is freely available and can be visualized, aggregated, and queried from their data portal.

Over the past few years, we applied the Nature's Notebook protocols to more than 3,000 specimens of red and sugar maples housed in more than 50 museums and herbaria across the Eastern United States.[42] This project involved a small number of individuals, with three undergraduate interns and a graduate student leading the process. In the initial project, we did not use a public platform to conduct the classification, though we envision expanding the project to include broad digital

participation in the future. Because the specimens used in this project were all digitized and imaged, we could easily integrate data from museum collections we could not have visited during the project, allowing for virtual student engagement with collections across the country.

Our work generated an integrated phenology dataset spanning more than 120 years, with details on various phenological states, including flowering times, fall coloration, and new leaf growth. This dataset allowed us to investigate the impacts of anthropogenic environmental changes such as climate change and land-use change on these important tree species. Comparatively, just using Nature's Notebook data provided fewer than 10 years of robust data. While significant, these data became much more impactful when paired with the herbarium data. Because of these paired data, we can investigate previously impossible questions about the changes in maple tree phenology, particularly the fall color change, over the past 120 years and into the present.[43]

We discovered changes in maple leaf production, maple reproduction, and maple interactions with other species, including insects and pathogens. Pairing these historical data with ongoing citizen science observations by Nature's Notebook allows us to continue building our understanding of how climate change impacts the natural world and better understand our ecological and environmental past. Because these data involve protocols developed for citizen scientists and already digitized herbarium resources, this project could be operationalized on a larger scale, across the billions of herbarium specimens worldwide and those that have yet to be collected.

Digital collections offer an unparalleled opportunity for educational and classroom engagement. By supporting students in developing digital collections research projects, students build digital literacy skills while allowing them to engage in integrative and active topical exploration.[44] Freely available lesson plans for integrating natural history collections data into classroom and independent research activities are becoming increasingly common, lowering the barrier to including these modules in digital and in-person educational experiences.[45] Projects such as AIM-UP! (Advancing Integration of Museums into Undergraduate Programs) continue to support the development and implementation of these types of materials,[46] but museums can directly partner with organizations to improve these resources. Developing classroom curriculum and independent research experiences for collections-driven investigations can harness existing museum and citizen science educational materials to enhance student exposure to citizen science and museum research opportunities.

CASE STUDY TWO: DIGITAL CITIZEN SCIENCE AND DIGITIZATION AT THE MOHONK PRESERVE

The Mohonk Preserve is a nature preserve and land trust located in the Hudson Valley region of New York. In addition to their land protection activities, the Mohonk Preserve maintains an archive, library, and physical object collection that includes more than 60,000 physical items, 14,000 notecards with natural history observations, and 9,000 photographs.[47] These data have been used to document plant and animal phenology changes, assess impacts of acid rain on fish communities,[48] and predict potential climate change effects in the region.[49] While the data are valuable and expansive, the preserve has a relatively small number of conservation staff members, and few are devoted exclusively to the digital preservation of the preserve's collections.

In addition to the archives, the Mohonk Preserve supports a robust suite of citizen science programs, including tracking the phenology of local species using iNaturalist, ongoing weather monitoring and tracking, volunteer-driven testing of stream water quality, and a variety of other projects.[50] These data are collected by local individuals, requiring onsite and in-person activities, but provide significantly more data than staff members alone could provide. Volunteers in these programs receive dedicated instruction in using specialized tools, expanded access to preserve lands and archives, and are credited collectively and (as applicable, individually) for their contributions to the resulting datasets.[51]

Beyond the ongoing environmental data collection, citizen scientists and volunteers have played a critical role in the digitization process of the preserve's many physical objects and card files.[52] For example, at the Mohonk Preserve, volunteers have been instrumental in scanning notecards with wildlife observations, notebooks of weather observations, and written ecological and geological reports.[53] In this case, the scanned cards are the source material for an ongoing Notes from Nature project on Zooniverse.org, where volunteers transcribe the data from the notecards.[54] As of December 2020, more than 1,700 volunteers have provided more than 30,000 classifications of the data preserved on the notecards, allowing staff to provide the associated data more quickly to interested researchers.

Digitization is ongoing in museums, but research staff members are often involved in many other aspects of collection management, in addition to the expectation to rapidly transcribe, describe, and categorize objects resulting from the digitization process. Citizen scientists can often perform these tasks, even without subject matter expertise, while learning and engaging with the collection.[55] Citizen science is not passing work off to the public; it is a collaborative process that allows the public to do genuine work within the museum while giving users unprecedented access to collections and a whole new form of engagement.

A growing number of platforms provide institutions to host and build these types of projects. The largest is Zooniverse.org, the platform we used for Notes from Nature, a collection of online citizen science projects that have enabled over two million online volunteers to contribute to over 250 research projects spanning disciplines from astronomy to zoology. Using these tools for digital engagement in tandem with

volunteer- or staff-driven digitization can allow for significant opportunities for continued research, education, and visitor engagement.

DISCUSSION AND CONCLUSIONS

Mohonk Preserve Citizen Science activities primarily use citizen science as a tool to engage with visitors and improve overall institutional research outcomes (e.g., digitize collections and collect data on preserve property). In contrast, in the herbaria, citizen science protocols were applied to collections in an educational setting to address a particular research question. In both cases, the citizen science monitoring and observing protocols improved the research use of museum collections and holdings, enhanced user engagement with museum collections, and supported crucial environmental research.

Cultural institutions focusing on natural history often have much more extensive and diverse collections than universities and government institutions.[56] These trends may also be present in other types of research collections such as ethnographic and art collections. Using emerging tools like citizen science, particularly on platforms like Zooniverse.org, can improve digital public access to museum collections and their associated data. Particularly in the unprecedented times of the coronavirus pandemic of 2020, cultural institutions are increasingly dependent on robust digital engagement and education opportunities. These types of opportunities can enable meaningful visitor engagement with cultural institutions and their collections while supporting research goals, even when in-person work is not possible.

Citizen science is a very flexible research tool. While I have focused on applications of citizen science in the museum setting to environmental research, there are growing opportunities to apply citizen science, particularly digital citizen science, to other natural, physical, and social science fields. Digital tools are becoming increasingly available to citizen scientists, and more field-specific tools are allowing for more variety in citizen science projects. As these tools continue to evolve and proliferate, the opportunities for engagement, research, and education are rapidly growing. As museums continue to expand their digital presence, citizen science is a tool that can improve and expand both institutional research and visitor educational opportunities.

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