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Citizen Science

From spectators to stewards: Transforming public involvement in natural history collections

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Abstract

A comprehensive overview of volunteer-driven public programs focused on activities to enhance natural history collections (NHCs) is provided. The initiative revolves around the WeDigBio events and the Collections Club at the Field Museum, aiming to deepen the public's connection with scientific collections, enhance participatory science, and improve data associated with natural history specimens. The implementation and journey of these programs are outlined, including surveys conducted from 2015 through 2021 to gauge participant motivation, satisfaction, and the impact of these events on public engagement with NHCs. Results show trends in on-site and virtual volunteer participation over the years, especially during the peak period of the COVID-19 pandemic. The majority of participants expressed high satisfaction, indicating a willingness to continue participating in similar activities. The surveys revealed a shift towards more altruistic motivations for participation over time, with increased emphasis on supporting the Field Museum and contributing to the scientific community. The success of participatory science events demonstrates the potential of volunteer-driven programs to contribute meaningfully to the preservation, digitisation, and understanding of biodiversity collections, ultimately transforming spectators into stewards of natural history. From 2015 to present participants celebrate a significant milestone, with over a thousand community scientists contributing to the inventorying, collection care, curation, databasing, or transcription of 286,071 specimens, objects or records. We also discuss accuracy and quality control as well as a checklist and recommendations for similar activities.

Key words: Citizen science, community science, natural history collections, WeDigBio, curation, volunteering

Introduction

Globally, thousands of institutions house nearly three billion scientific collections with associated metadata (Sweeney et al. 2018). Natural history collections (NHCs), with their broad taxonomic, geographic, and temporal scope, offer unparalleled resources that contribute to both science and society (e.g., Graham et al. 2004; Berendsohn and Seltmann 2010; Hedrick et al. 2020). The first two decades of the twenty-first century have seen a rapid rise in the mobilisation of digital biodiversity data (Nelson and Ellis 2018; Spiers et al. 2019). For example, the National Science Foundation (NSF) has facilitated the digitisation of over 140 million biodiversity specimens from NHCs in the United States (iDigBio 2024; Thiers 2024). Digitisation has greatly enhanced the use of herbarium data in scientific research, impacting diverse research areas, including biodiversity informatics, global change biology, analyses using next-generation sequencing technologies, and many others (Bebber et al. 2010; Heberling and Isaac 2017; James et al. 2018; Lang et al. 2018; Soltis et al. 2018). Natural history collections are uniquely poised to broaden access and opportunities for public engagement (Bakker et al. 2020). Natural history museums, with their extensive collections, create a foundation of components for participatory science (Sforzi et al. 2018). For example, over the past decade, public participation has advanced digitisation through the transcription of scientific labels from NHCs (Ellwood et al. 2015; Ellwood et al. 2018). This has led to global participatory-science events focused on the digitisation of biodiversity specimens such as Worldwide Engagement for Digitizing Biocollections (WeDigBio) that started in 2015 (Ellwood et al. 2018).

The Field Museum of Natural History, Chicago, U.S.A., has been participating in this event since its inauguration. Shortly after, the Collections Club was created after volunteers expressed a strong interest to contribute more often following their participation in the 2015 and 2016 WeDigBio events. The Collections Club includes members that are unable to regularly volunteer (defined at the Field Museum as investing a minimum of 4 hours per week) and typically meets quarterly.

The infrastructure provided the foundation to expand over time to include ad hoc events providing opportunities for collaboration with other partners, including high school groups, and internally, with Institutional Advancement and their Corporate Program. Significantly, NSF-funded Thematic Collections Networks (TCNs) were able to leverage WeDigBio and Collections Club in crowdsourcing efforts for transcription of scientific labels. For example, "Building a Global Consortium of Bryophytes and Lichens: Keystones of Cryptobiotic Communities," which is a collaboration of 25 universities, museums, and gardens located across the United States.

Participatory science, and the contributions to the field of science by "amateur" scientists, has been in use since the mid-1990's. Data produced via crowd-sourcing has been shown to have huge impacts on data digitization efforts (Sforzi et al. 2018). In this paper, we use the term participatory science as a way to refer to the field of public participitation programs. Other terms, such as 'citizen science' or 'community science' are used here to address terms utilized in other publications and do not represent our preferred term for participatory science programs and events. However, we strongly advocate that the term 'citizen' is a non-inclusive term and should not be used, instead, consider an alternative name for participatory science projects for the reasons outlined by Ellwood et al. (2023) and Christian et al. (in press).

Aims & goals

This paper outlines the journey of implementing public participation programs associated with WeDigBio and the development of a new initiative called the Collections Club. The major goals of these programs are to i) harness the enthusiasm generated by public events; ii) deepen the connection between scientific collections and the general public; iii) increase engagement through participatory science; and iv) improve and enhance physical specimens or data associated with scientific specimens and objects. The overarching aim is to provide a framework and insights to aid other similar participatory science events utilising natural history collections.

Methods

At the end of many WeDigBio and Collections Club events spanning from 2015 through until 2021, the volunteers were provided an anonymous link to a survey. Many of the event surveys were part of the broader WeDigBio campaigns and followed Ellwood et al. (2018) that outlined the inaugural 2015 WeDigBio event, including results from surveys of that year. Surveys were anonymous, including no information about names or email addresses. Surveys used a variety of platforms including Qualtrics Survey Software, Google Forms, and

Survey Monkey. The surveys generally assessed participants' motivations and enjoyment, sought feedback for improvement, investment of time, and value and awareness of NHCs. Some surveys were conducted during the COVID-19 pandemic and had some specific questions relating to that period. Institutional Review Board approval was sought for the surveys, but considered exempt as no identifying information was collected and all respondents were adults.

Raw data for the participant surveys and other information is available in the Supplementary Files. Suppl. materials 1, 2, 3, 4, 5, 6, 8.

Suppl. materials 1, 2, 3, 4 and Suppl. material 8 contain the raw survey data for WeDigBio events from 2015 through to 2018 as well as 2021.

Suppl. materials 5, 6, 8 contain the raw survey data for Collections Club events in 2017, 2020, and 2021.

Suppl. material 9 aggregates the data on attendance and activity for multiple events per year, between 2015 and at time of publication in 2024, including WeDigBio, Collections Club, and Corporate Volunteer events.

For the surveys, in some cases identical questions were asked over several years. In other cases, responses to similar questions were aggregated, e.g., questions about motivation for participating or willingness to participate in future activities. The exact questions that were asked as part of each survey are available in the raw data. Note also that many of the responses were on a Likert scale, e.g., Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree. For clarity, the responses have been aggregated as Negative, Neutral, and Positive.

All graphics were prepared using R (R Core Team 2023). The graphs were specifically designed with colour blindness in mind, as many reports and publications do not take this into account (da Mota 2022). Some colour palette options were suggested by Venngage (2023), and some graphs used palettes from ViridisLite, a colour blind-friendly set of colour palettes (Garnier 2023).

Transcription platforms included Notes from Nature (Hill et al. 2012) and Symbiota (Gries et al. 2014).

ChatGPT-4 was used to generate the Word Cloud from a PDF of responses to open ended questions and to provide an initial suggestion of categories for open ended questions, which was then modified and presented here.

Results

Metrics from the outset of our public programs have been captured from 2015 to present (April 2024) and are presented below, as well as various surveys conducted from 2015 through to 2021.

Metrics: Participation and project types

Fig. 1 shows the total number of on-site and off-site participants in all community science activities at the Field Museum, including WeDigBio and Collections Club. 3,846 volunteers participated on-site and off-site spanning almost ten years since 2015. We know anecdotally that there are a significant number of returning participants, with many that have been involved from the outset represented by some of those individuals as authors on this paper. This represents

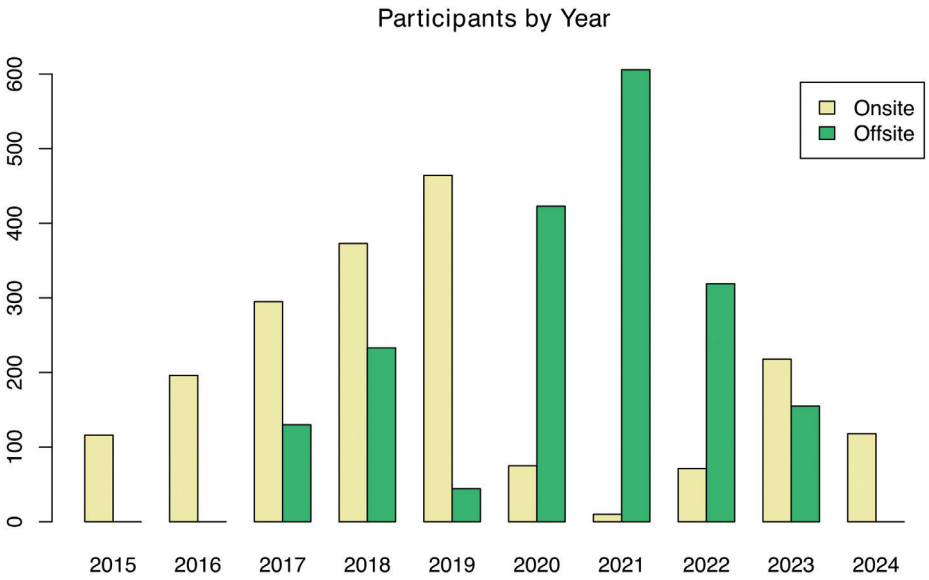

Figure 1. Participants in WeDigBio, Collections Club, and Corporate Volunteer events at the Field Museum, onsite and offsite, by year. (through April 2024).

13,549 hours, including 7,472 hours on-site and 6,077 offsite. Assuming a 35 hour work week and 48 weeks annually, this is the equivalent to one full time position for 4.45 years on-site and one full time equivalent for 3.62 years off-site. Figs 2, 3 show volunteers actively participating during Collections Club/ WeDigBio events. There is a marked increase in off-site participation in 2020 and 2021, during the height of the COVID-19 pandemic restrictions. As on-site participation has recovered post-pandemic, the off-site participation is remaining strong. This noticable reduction in virtual participation and revitalization of in-person events potentially could be due to participants experiencing Zoom fatigue; the burnout and exhaustion due to overexposure to Zooming (Al Ma'mari et al. 2020; Amponsah et al. 2021). Fig. 4 shows that since 2015, volunteers have processed, curated or handled almost 260,000 specimens, objects or records; activities were broadly categorised into ten groups, e.g., barcoding, curation, inventorying, and transcription. Details can be found in Suppl. material 9. Table 1 lists five National Science Foundation projects that provided the

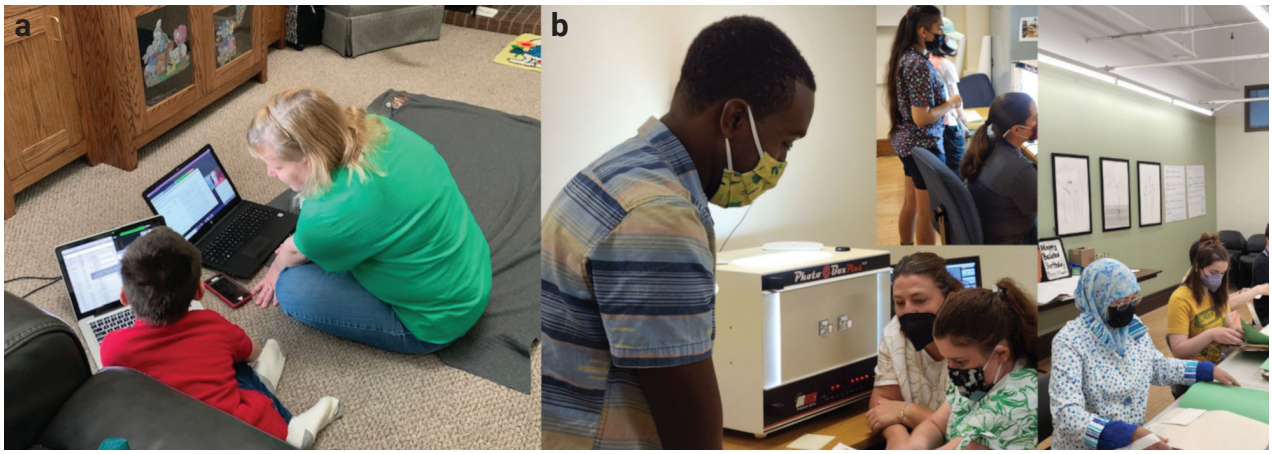

Figure 2. Collections Club/WeDigBio participants participating virtually in 2020 and then onsite in 2022. **a**: Virtual Collections Club/WeDigBio with mother and son transcribing remotely during the peak of the pandemic in 2020. **b**: Return to first onsite event in 2022 with volunteers masked following protocol at the time doing hands-on activities.

Figure 3. Classroom with over 35 volunteers during a WeDigBio event doing a variety of activities including transcription and curation.

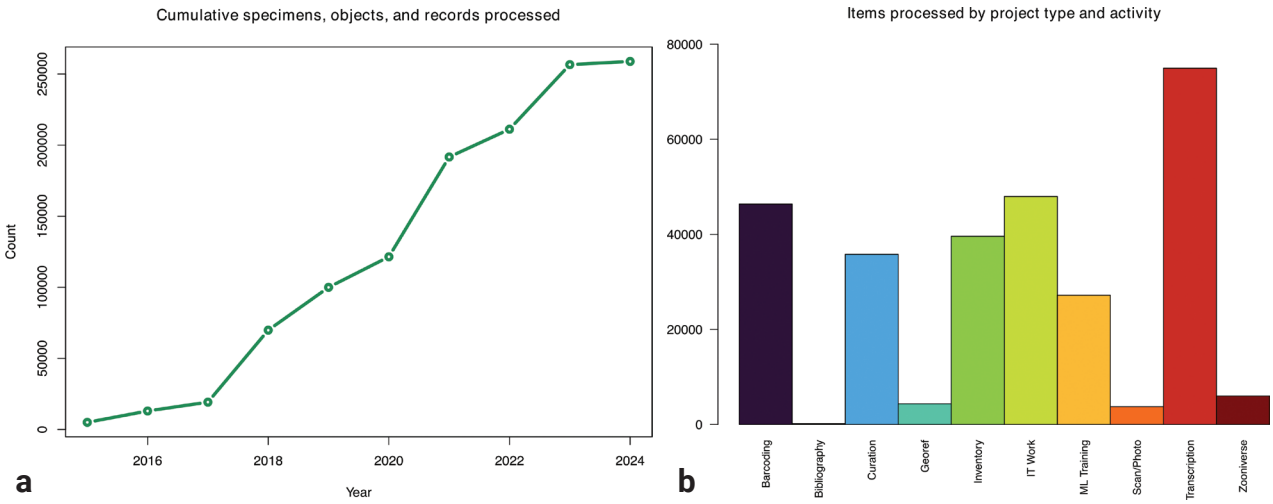

Figure 4. Items processed by participants in WeDigBio and Collections Club activities. **a**: Cumulative items (specimens, objects or records) processed by year. (through April 2024). **b**: Items/objects/records processed by broad project type: barcoding, bibliography, curation, georeferencing, inventory, database cleaning (IT work), human transcription for machine learning (ML training), scan/photo, transcription, Zooniverse.

Table 1. Table listing National Science Foundation digitization projects under the Advancing Digitization of Biodiversity Collections (ADBC) program, which is a series of thematic collection networks (TCNs) based on an important research themes.

TCN Title	Year Volunteers Contribution	NSF Award No.	Lead Instiution
North American Lichens and Bryophytes: Sensitive Indicators of Environmental Quality and Change	2011 Pre-curation; transcription	1115116	University of Wisconsin - Madison
The Macroalgal Herbarium Consortium: Accessing 150 Years of Specimen Data to Understand Changes in the Marine/Aquatic Environment	2013 Transcription	1304924	University of New Hampshire
The Pteridological Collections Consortium: An Integrative Approach to Pteridophyte Diversity Over the Last 420 Million Years	2018 Barcoding; transcription	1802504	University of California - Berkeley
Building a Global Consortium of Bryophytes and Lichens: Keystones of Cryptobiotic Communities	2020 Pre-curation; transcription	2001500	University of Tennessee - Knoxville
Digitization and Enrichment of U.S. Herbarium Data from Tropical Africa to Enable Urgent Quantitative Conservation Assessments	2022 Barcoding	2223875	University of Kansas

basis for many WeDigBio and Collection Club events; volunteers participated in transcription, pre-curation, and the application of physical barcodes on to specimens. For example, recently in 2022 and 2023 volunteers applied barcodes to physical specimens for over 15,000 flowering plant specimens from Africa.

Survey responses

Motivation

Figs 5, 6 indicate motivation reported by volunteers for participating both in on-site WeDigBio events in 2016–2018 (Fig. 5), and in a virtual Collections Club event in 2021 (Fig. 6). The survey design for motivation was slightly different between the WeDigBio survey and the virtual Collections Club survey, but they captured similar themes. There are some interesting trends in the responses with a motivational shift. For example, the percentage of respondents who chose "Thought it would be fun" or "Seems fun" reduced from 24% to 13% over time, while the percentage who chose "Help Field Museum" or "Supporting the Field Museum" increased significantly from 12% to 41%. The percentage who chose "Help the scientific

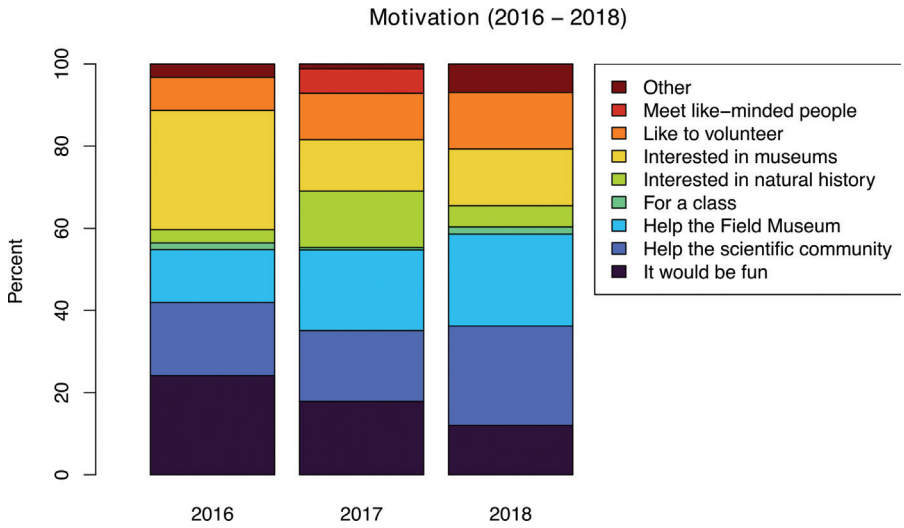

Figure 5. Motivation for participating in WeDigBio events between 2016–2018, as reported in survey responses; 2016 n = 62, 2017 n = 34, 2018 n = 58. Classifications in responses included: 'Thought it would be fun', 'help the scientific community', 'help the Field Museum', 'for a class, interest in natural history', 'interest in museums', 'like to volunteer', 'meet like-minded people' and 'other'.

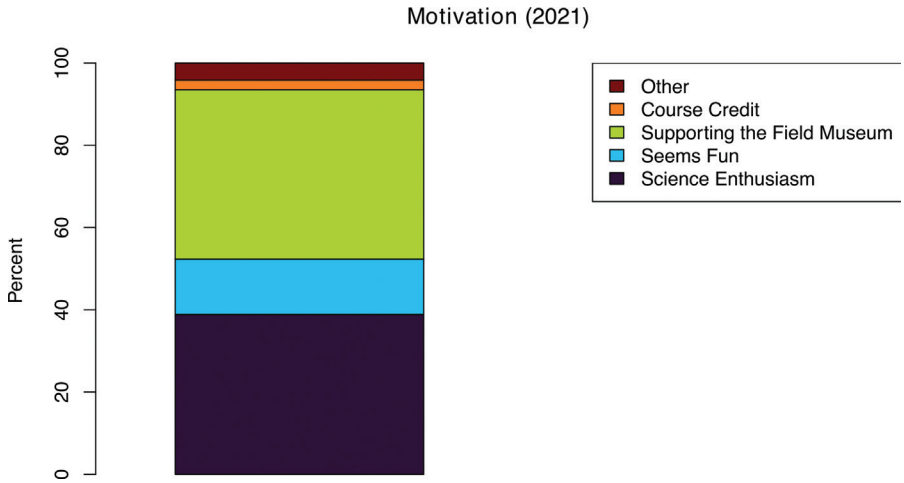

Figure 6. Motivation for participating in Collections Club events in 2021, as reported in survey responses. Fixed choices included: 'science enthusiasm', 'seems fun', 'supporting the Field Museum', 'course credit' and 'other'. n = 42.

community" or "Science Enthusiasm" increased from 18% to 39%. The common trend seems to be that over time, participants report more altruistic motivations for participating in the events. During the height of the pandemic, overwhelming motivating factors included supporting the museum (over 40%) and enthusiasm for science (almost 40%) for the 2021 virtual Collections Club event.

Time well spent: Feedback - response to closed ended questions

Fig. 7 shows the responses to questions about the event. a) "Was the event well organised?" with at least 92% agreeing positively for all four years, and b) "Was the event worth my time?", with at least 92% of respondents agreeing that the event was worth their time. Fig. 8 provides response rates to questions a) "How likely is it that you would volunteer to transcribe specimen labels on a regular basis?" with an increasing percentage over the four years indicating they would want to continue participating, and b) "How likely would you be to participate in other collections-related activities?", with at least 88% likely to volunteer to perform other tasks in biodiversity collections. Fig. 9 reflects whether the inclusion of a lecture from a collections expert (Fig. 9a) and the inclusion of a

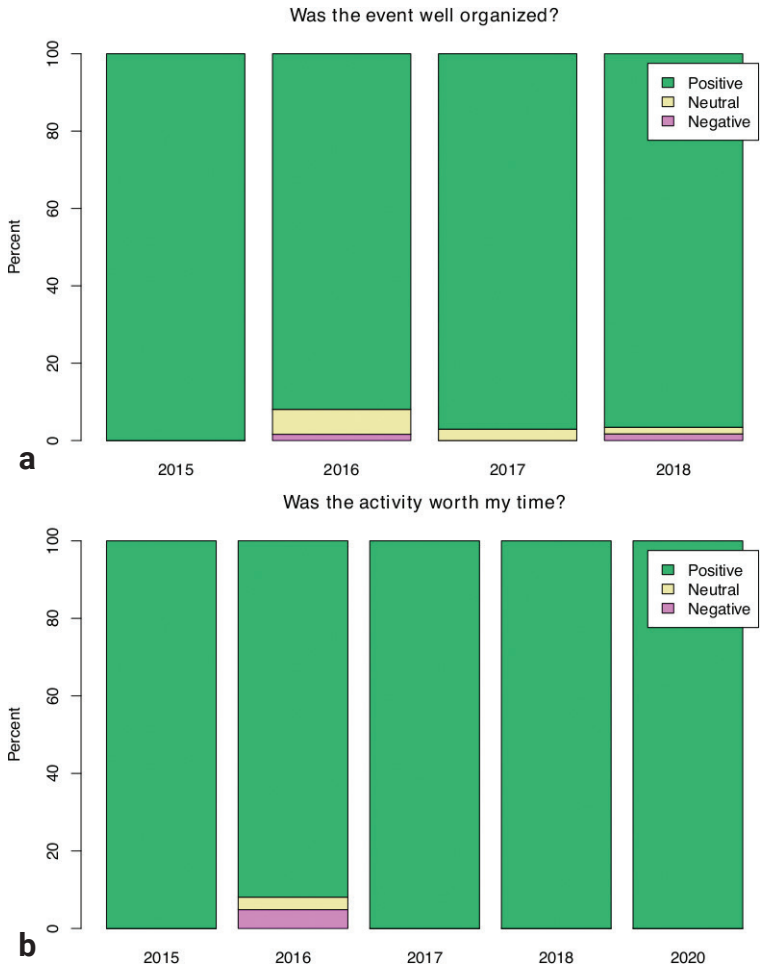

Figure 7. Responses to survey questions about the events. **a**: Response to question: Was the event well organised? for 2015–2018. **b**: Response to question: Was the event worth my time? for 2015–2020.

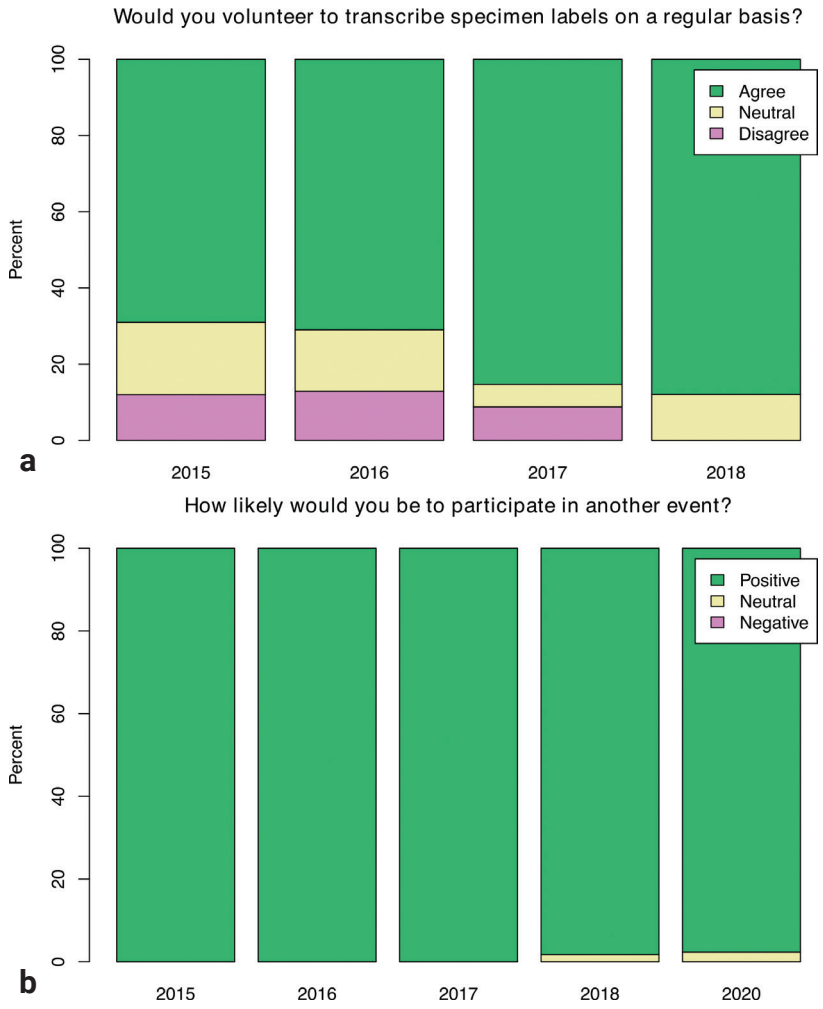

Figure 8. Responses to questions about possible future participation. **a**: Response to question: How likely is it that you would volunteer to transcribe specimen labels on a regular basis? for 2015–2018. **b**: Response to question: How likely is it that you would participate in another event? for 2015–2020.

behind-the-scenes tour (Fig. 9b) was meaningful for participants. 82% and 88%, respectively responding positively across all years surveyed.

Constructive feedback - Response to open-ended questions

Complete responses from all years to the open-ended questions are available in Suppl. materials 1, 2, 3, 4, 5 spanning 2015 through to 2018. Suppl. material 7 highlights 42 selected comments that illustrate the breadth of over 200 comments.

Value & awareness of natural history collections

Participants were surveyed between 2015 and 2018 asking about their awareness of the number (Fig. 10b), kinds (Fig. 10c), and value of biodiversity specimens (Fig. 10d). In each year, at least 70% of respondents responded “higher”

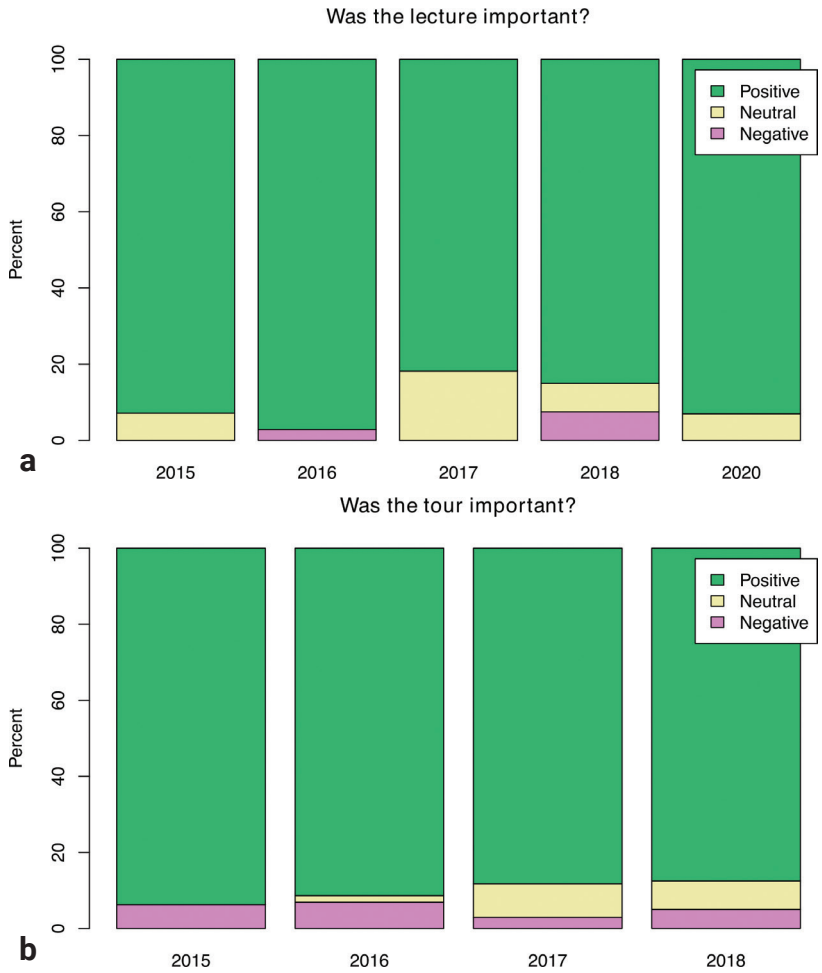

Figure 9. Responses to survey questions about the value of the available activities: **a**: How important was the lecture or discussion by the scientist? **b**: How important was the collections tour?

or "much higher" in rating their increased awareness of these three categories, now compared to prior to participating in the event. Fig. 10a pools the responses from 2015 to 2018 to each of the three categories.

A similar survey was conducted in 2020 and 2021 about awareness of the type of research conducted on NHCs, but phrased slightly differently. In 2021 there was an increase of those who remained neutral to the question, which might be attributed to those who had participated the year before. In 2020, the question was asked if respondents had learned new information about the significance of NHCs at the museum - 88% agreed.

Over the four years, greater than 90% of respondents agreed that biodiversity research collections merit public funding (Fig. 11).

Enjoyment and satisfaction of participation

Complete responses from all years to the open-ended questions are available in Suppl. materials 1, 2, 3, 4, 5 spanning 2015, 2016, 2017, 2018 and 2020. For example, one standout highlight was the following from an anonymous

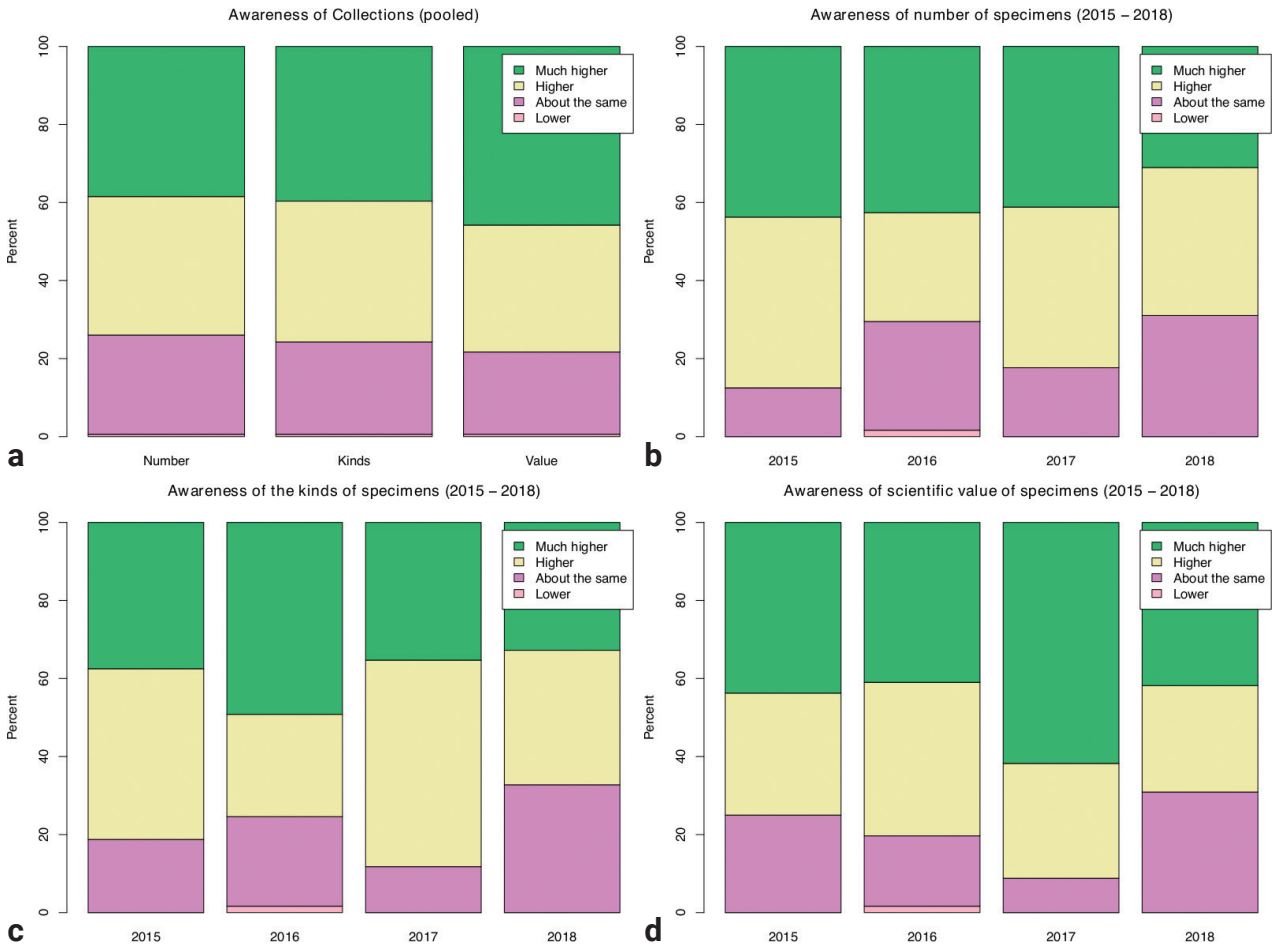

Figure 10. The results of a participant survey for the years 2015 to 2018 showing ratings in response to the question: Rate your awareness now compared to prior to participating in the event: **a**: Pooled responses to the three questions below. **b**: Of the number of biodiversity specimens held in collections, by year. **c**: Of the kinds of biodiversity specimens held in collections, by year. **d**: Of the value of biodiversity specimens held in collections, by year.

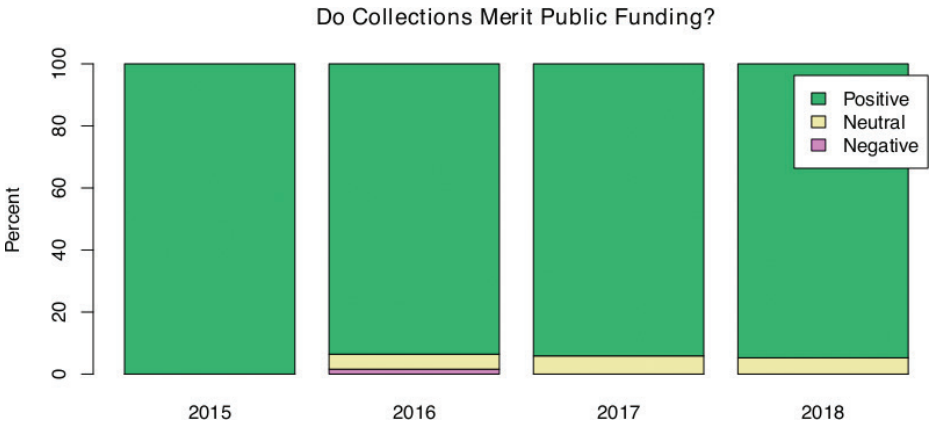

Figure 11. Responses to survey question "Biodiversity collections merit public funding" for 2015–2018.

individual: "The fact it wasn't actually local - I drove 4 hours for this event and it was totally worth it. To see behind the scenes and help transcribe data for such a great institution was worth it for me!" [2016]

For the open-ended question 'What did you find most enjoyable or satisfying about participating in your local WeDigBio Event?' we categorised into eight broad buckets (Fig. 12) which provides a year by year account. The eight broad buckets and their average percentage over the five years are the following: 1) Exclusive access (16%); 2) Contributing to science (19%); 3) Learning (13%); 4) Engagement with specimens (15%); 5) Interaction with scientists (14%); 6) Personal fulfillment (4%); 7) Social interaction (15%); 8) Other (4%).

Fig. 13 represents a Word Cloud (from over 140 responses, highlighting key words from the open-ended questions focusing on what participants enjoyed most).

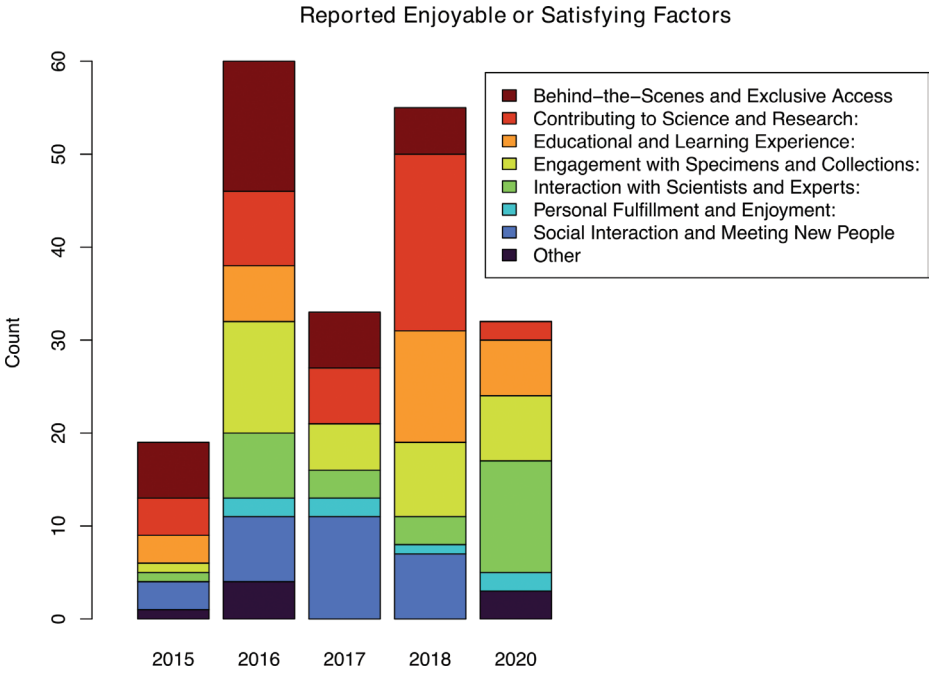

Figure 12. Grouped responses to the question "What did you find most enjoyable or satisfying about participating in your activity".

Figure 13. This visualisation emphasises key terms and themes associated with community science, volunteering, and the nature of the public event. This is generated from 140 responses to open ended questions.

Virtual participation

Fig. 14 surveys attitudes about virtual participation, asking respondents about previous experience with virtual events, interest in attending future virtual events, and interest in future in-person events. This survey was taken during the height of the COVID-19 pandemic when we conducted only virtual events. In October and November, 2021, 60% of participants responded they had not participated in a virtual event like WeDigBio before, while the remaining 40% had. An overwhelming majority (95%) agreed that they would be interested in attending another virtual event in the future. At the time, 50% of respondents expressed interest in participating in an in-person event during the pandemic, while 33% responded "maybe". Although we have seen a resurgence in in- person participation since 2022 (Fig. 1), these virtual participation events are still popular and well attended.

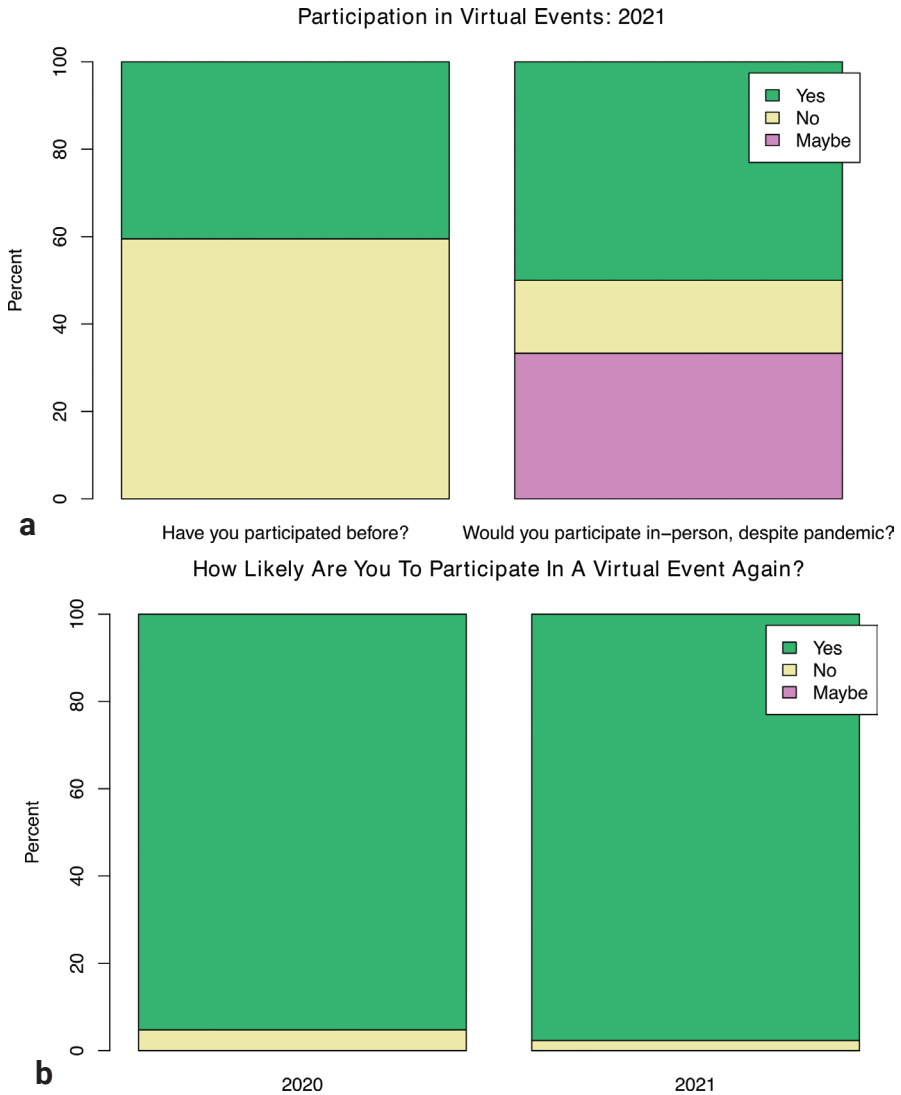

Figure 14. Responses to survey questions from virtual WeDigBio/Collections Club events in 2020 and 2021. **a**: Responses to survey questions for a virtual event in 2021: "Have you participated before?" and "Would you participate in-person despite the pandemic?". **b**: Responses to survey question for 2020 and 2021 events: "How likely are you to participate in a virtual event again?".

Discussion

This paper provides insights from volunteers participating in community science events involving NHCs. The fundamental objectives of these initiatives are to 1) Increase engagement through participatory science; 2) Evaluate the motivation and driving forces behind participatory scientists and their engagement with NHCs; 3) Improve and/or enhance physical specimens or data associated with scientific specimens and objects through focused volunteer programs, including quality of contribution; 4) Augment the quality and value of physical samples or data related to scientific specimens and artefacts. Outlined below is also a brief discussion on accuracy, quality control, a checklist for events, and recommendations.

Motivation & attitude towards science

Natural history collections are uniquely poised to broaden access and opportunities for public engagement (Bakker et al. 2020). Natural history museums are constantly exploring mechanisms to engage diverse audiences in order to raise awareness of the importance of biodiversity collections and their value to science (Sforzi et al. 2018). A core tenet of participatory science is that both the professional researcher and the participant mutually benefit. However, although it's often assumed that participants benefit positively, this is rarely studied directly (Leonard et al. 2023). Our research adds to the expanding knowledge in this area. Studies from participatory science involving the natural world through monitoring, observations, and conservation have shown that the events often have a strong impact on the participants, leading to a long-term positive perception of the natural world (e.g., Peters et al. 2015; Lynch et al. 2018). Jones et al. (2018) investigated the motivations and perceived benefits in citizen science projects to better inform efforts to encourage participation. As digital participatory science projects become more common, our survey results contribute towards gaining a better understanding of why people participate and what motivates them (e.g., Jennett and Cox 2017; Skorupska et al. 2022).

Our surveys broadly indicate that participatory scientists, after participating in the WeDigBio and Collections Club events, were motivated to contribute to research, help the scientific community, and the Field Museum more generally (Figs 5, 6). This is also reflected by more than 90% of respondents indicating the event was worth their time (Fig. 7b). In the 2020 survey alone 88% of respondents learnt new information about NHCs. Interestingly, perhaps participatory science events may help contribute towards the perception of increasing public funding in science (Fig. 11). Motta (2018) noted that only a minority of Americans see a need for increased federal support. Our survey over the four years indicated greater than 90% of respondents supported public funding for biodiversity collections.

Accuracy and quality control

The level of accuracy and quality control depends on the type of project, the length of an event, and volunteers' backgrounds, ages, and skill levels with technology. Thus, projects can be tailored accordingly. Informative instruction and

immediate feedback help increase levels of accuracy. Minor elements can be also implemented to increase engagement, for example, we noted when we began public programming, some students would not pay attention to detail. However, if they were informed that a points system was set in place by their instructor, a notable change in attention and engagement was observed.

Transcription

Transcription platforms have different mechanisms for evaluating accuracy and quality control. Procedures can be put in place at the front end, e.g., drop- down menu for country, state etc., reducing errors. Symbiota employs an approach in which one volunteer transcribes and then a second validates the transcription (Ellwood et al. 2018). In contrast, Notes from Nature asks three different volunteers to transcribe a specimen, and then the transcriptions are reconciled using Notes from Nature tools to derive a final output (Matsunaga et al. 2016). Generally, we have found high levels of accuracy in label transcription, but we have learnt that it is critical to tailor transcription activities depending on the audience, project goals and time allotment. For example, full label transcription in a short period, e.g., two to three hour event, with first time exposure for volunteers, often leads to a low number of transcribed labels and significant staffing time. On the other hand, transcription activities have led to the development of an ongoing community of transcribers who have become proficient. Soteropoulos and Marsico (2022) provide a series of excellent recommendations to promote success in transcription-based endeavours.

Hands-on activities

Similarly, when designing a hands-on activity, the choice of activity depends on factors such as time allotment, audience background, and mobility access. For on-site activities, project leaders were constantly on hand, giving immediate feedback and evaluating the quality of work being accomplished. Project leaders were largely pleased with levels of accuracy, and some projects evolved over time. For many large scale ongoing hands-on projects, some volunteers became so confident, engaged, and skillful, that they became co-managers in follow-up events. An excellent example is the conversion of over 20,000 specimens of liverworts transferred from newspaper to packets for accessibility, achieved by Collection Club members spanning several years (von Konrat et al. 2021).

A checklist for event planning

A detailed event checklist is provided in Suppl. material 10. This includes a simple checklist for pre-event planning, the event itself, and post event; everything from creating registration forms, promoting events, participation surveys and tracking metrics. Soteropoulos and Marsico (2022) provide useful implementation strategies to achieve specific goals, tailored for transcription events specifically, but can be broadly applied to public programming involving participatory science.

Opportunities and recommendations

1. **Harness Enthusiasm and Deepen Connections (**Figs 8, 12, 14**):**
   - **Utilise Past Successes**: Build on the enthusiasm generated by successful events such as WeDigBio to foster a deeper connection between the public, communities and scientific collections.
   - **Expand Education and Community Outreach**: Provide opportunities to engage a diverse audience by partnering with high schools, colleges, universities, local communities, and other organisations to reach a broader demographic. Biological collections offer unique resources that enhance STEM education (Cook et al. 2014) and boost learning and engagement, particularly for school-age and undergraduate students (Pivarski et al. 2022).
2. **Enhance Engagement Through Participatory Science** (Figs 5, 6, 12): Public participation has the potential to advance digitisation and has the additional benefits of improving science literacy amongst contributors, community support for bio-collections, and the sustainability of digitisation activities (Ellwood et al. 2015). Our surveys also support a greater awareness of the kinds, the diversity, and the significance of NHCs compared to their prior awareness.
   - **Innovative Engagement**: Incorporate a variety of participatory science activities that cater to different interests and abilities, such as specimen transcription, digitisation projects, and behind-the-scenes tours.
   - **Virtual Participation**: Maintain and improve virtual participation options, as they have shown to significantly increase engagement, especially during the COVID-19 pandemic. Virtual participation may also help reduce barriers into participatory science such as transport, distance, etc.
   - **Media outreach opportunities**: Participatory science programs focusing on natural history collections and specimens also attract beneficial media coverage. Media coverage of events has the potential to significantly boost broad interest and can even drive increased registration (as evident from survey responses). This was evident by annual media coverage from various media including television, newspapers and online forums through our own experience (Suppl. material 11). In 2018 alone, three major TV networks, including WTTW, NBC Chicago, and ABC7 covered the events extensively, and we know from survey responses that this coverage helped encourage curiosity and spark registration.
3. **Continuous Improvement and Refinement** (Figs 7, 8, 9):
   - **Solicit Feedback**: Regularly gather and analyse feedback from participants through surveys to identify areas for improvement and refine programs accordingly.
   - **Data Accessibility**: Make raw data from participant surveys and activities available for further analysis and research, fostering transparency and community involvement in scientific research.
4. **Foster Long-term Sustainability** (Figs 10, 11, 14):
   - **Volunteer Management**: Develop and foster a strong volunteer community with a focus on building a long-term sustainable program that is eventually co-managed and coordinated with their help. Utilisation of online project management tools such as Slack also helps maintain a community and provides a forum for troubleshooting and discussion for ongoing online community science such as transcription.

- **Dedicated resources:** Allocated resources are essential for growth and scaling of participatory programs. While volunteers can gradually take on more roles and responsibilities, committed financial support for at least a part-time position is necessary to ensure sustainability. Alternatively, allowing a percentage of time for "innovation time off" for employees to pursue projects they are passionate about can also provide the resources necessary for projects of this scale. Opportunities afforded by the National Science Foundation can also provide some financial support. However, institutions need to support these endeavours as well. Clearly, extra efforts such as collection tours or scientist interviews help to drive the success and satisfaction of participation, yet do take up dedicated staff time.
- **Sponsorship:** Refreshments, such as coffee and treats, can be expensive, but, as seen by the surveys, are an important part of the events. Local cafes and restaurants were glad to offer their support with in-kind contributions, and the exchange was mutually beneficial. In our case, Aurelio's Pizza (South Loop) and Egg Harbor Cafe donated and received recognition in return.

5. **Embrace Technology and Crowd-sourced Science**
   - **Digital Tools and Platforms**: There is great potential in implementing community science activities within a natural history museum environment by using digital technology and crowd-sourced science to foster curiosity and engagement, while unlocking data and information from digital images of the specimens themselves.
6. **Focus on the Margins**
   - **Prioritise Diversity and Inclusion.** Significant gaps remain in both the educational attainment of historically under-represented groups and female students, especially in STEM fields (Carpi et al. 2016; Nimmesgern 2016). Digitised collections may help eliminate the boundaries created by geographic, economic, and social barriers, allowing people access to these collections on a much larger scale (e.g., Spiers et al. 2019; Hedrick et al. 2020). It is therefore logical for Natural History Museums to develop platforms for digital learning environments using NHCs for public engagement.
   - **Creating Digital Equity.** There is a significant lack of youth involved in participatory science programs (Sforzi et al. 2018). Many school districts are no longer restricted by accessibility issues regarding Internet access, paving the way for meaningful collaborations with scientists and scientific projects around the world (Eden et al. 2024).

Inspiring the next generation of scientists

The Mobile Museum, initiated by two fifth graders (Fig. 15) and inspired by WeDigBio and Collections Club, evolved from a local side-walk display to an educational platform with digital outreach and school programs. It leverages creative teaching tools, including a website and customised Radio Flyer wagon, to spark curiosity and discovery amongst learners of all ages, demonstrating the impact of innovative, community-driven science education. This is a great example of how such outreach events can inspire passion and dedication leading towards unexpected outcomes (Fig. 16).

Figure 15. Founders of Mobile Museum, both fifth graders, participating in a virtual WeDigBio/Collections Club event.

Figure 16. Mobile Museum developed by fifth graders inspired by their participation as part of Collections Club.

Conclusion

Participatory science programs emphasise the transformative impact of public participation in NHCs in accelerating scientific discovery and fostering a deeper engagement connection. Details about the implementation of these programs are provided, including surveys conducted to gauge participant motivation, satisfaction, and the impact of these events on public understanding with NHCs. The engagement in these volunteer activities not only increased awareness of the value of biodiversity specimens but also underscored the importance of public funding for biodiversity research collections. Successful

programs address challenges by continuously evaluating and adapting public programming strategies (Phillips et al. 2018). Enhancing virtual engagement platforms, diversifying participation, and tailoring programs to meet varied motivations are key areas for development (Pandya 2012). Furthermore, expanding outreach and inclusivity initiatives can help overcome demographic limitations, ensuring a broader representation of society in citizen science projects.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

Institutional Review Board approval was sought for the surveys, but considered exempt as no identifying information was collected and all respondents were adults.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

2015 WeDigBio Field Museum Survey Results

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Survey results for first WeDigBio event at the Field Museum, 2015.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl1

Supplementary material 2

2016 WeDigBio Field Museum survey results

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Survey results from 2016 Field Museum WeDigBio event.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl2

Supplementary material 3

2017 WeDigBio/Collections Club Field Museum Survey results

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Results from survey of the 2017 Field Museum joint WeDigBio and Collections Club event taken place in October 2017.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl3

Supplementary material 4

2018 WeDigBio/Collections Club Field Museum Survey Results

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Responses from the 2018 Field Museum WeDigBio/Collections Club event survey.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl4

Supplementary material 5

April 2017 Collections Club Survey Responses

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Survey responses from the April 2017 Collections Club event.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl5

Supplementary material 6

Responses to survey for Earth Day, Community Science Month, WeDigBio Lite and Collections Club (April 2020)

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Responses to survey for Earth Day, Community Science Month, WeDigBio Lite and Collections Club (April 2020).

Link: https://doi.org/10.3897/nhcm.1.138247.suppl6

Supplementary material 7

Highlights of a selection of responses to open-ended questions from surveys undertaken between 2015 onwards

Authors: Matt von Konrat, Colleen Bailey

Data type: pdf

Explanation note: Highlights of a selection of responses to open-ended questions. All responses can be accessed in Suppl. materials 1–7. From 2015 onwards for both WeDigBio and Collections Club events. Highlights of a selection of responses to TWO open-ended questions. All responses can be accessed in Suppl. materials 1–7. Please describe any other Blitz activities offered at your site that you felt were important or unimportant to your overall experience. Please share any ideas you may have to improve future WeDigBio events.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl7

Supplementary material 8

2021 Collections Club/WeDigBio Survey Responses - for event held on Oct. 2021

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Spreadsheet of raw responses to November distributed 2021 survey, for Collections Club/WeDigBio event held on Oct. 2021. Includes some collation of data.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl8

Supplementary material 9

Volunteer Events Tracking and Metrics - these include WeDigBio, Collections Club, Corporate volunteer events etc.

Authors: Matt von Konrat, Yarency Rodriguez, Colleen Bailey, Gilbert F. Gwilliam III, Christine Christian, Blanka Aguero, June Ahn, Zoe Albion, James R. Allen, Colin Bailey, Erryn Blake, Winnie Blake, Gwen Blake, Laura Briscoe, Jessica M. Budke, Thomas Campbell, Matt Chansler, Dina Clark, Robin Delapena, Michael Denslow, Daniel Dodinval, Elana Dux, Shari Ellis, Elizabeth Ellwood, Mendkhuu Enkhbayer, Belle Ens, Nkosi Michael Evans, Alejandra Fabian, Adam Ferguson, Wyatt Gaswick, Kate Golembiewski, Sharon Grant, Lauren Hancock, Kimberly Hansen, Brittany Janney, Janeen Jones, Zachary Kachian, Maria Lucia Kawasaki, Kacee Kellum, Olivia Leek, Alan Lichamer, Crystal Maier, Austin Mast, Joann Lacey Martinec, Paul Mayer, Melissa Mladek, Ainun Nadhifah, Christopher Neefus, Mary Nodulman, Margaret Oliver, Kelsey Overberg, A. Townsend Peterson, Ayesha Qazi-Lampert, Carl Rothfels, Zoe Anne Ryan, Robert Salm, Dawn Schreiner, Matthew Schreiner, Eric J. Tepe, Maureen Turcatel, Amelia Vega, Heaven Wade, Kate Webbink, Dianne Weinand, Todd Widhelm, Miranda Zwingelberg

Data type: pdf

Explanation note: Data on attendance and activities for volunteer events at the Field Museum 2015–2024.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl9

Supplementary material 10

Checklist for Citizen Science Events

Authors: Colleen Bailey

Data type: pdf

Link: https://doi.org/10.3897/nhcm.1.138247.suppl10

Supplementary material 11

Summary of media coverage highlights of WeDigBio and Collections Club hosted by Field Museum

Authors: Matt von Konrat, Kate Golembiewski

Data type: pdf

Explanation note: This is a list of print, tv, online media highlights that covered from 2016 through to 2022.

Link: https://doi.org/10.3897/nhcm.1.138247.suppl11