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Research Article

Open Citizen Science: fostering open knowledge with participation

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Abstract

Citizen Science or community science has been around for a long time. The scope of community involvement in Citizen Science initiatives ranges from short-term data collection to intensive engagement to delve into a research topic together with scientists and/or other volunteers. Although many volunteer researchers have academic training, it is not a prerequisite for participation in research projects. It is important to adhere to scientific standards, which include, above all, transparency with regard to the methodology of data collection and public discussion of the results, and open educational resources (OER). Hereby, Citizen Science is closely linked to Open Science. In our contribution, we will introduce two projects, both developed within the Wikimedia Fellowship Freies Wissen.

The top-down approach: ERGo! An Entomology Research Tool to raise awareness of biodiversity protection.

Inclusion in academia and pressing social problems such as climate change are fundamentally social justice issues. To facilitate early participation in the scientific process on the part of people holding underrepresented identities in science, we develop a Citizen

Science initiative based on a low-cost open-source platform (ERGo!) to perform a technique for electrical recordings from insect eyes known as electroretinograms (ERGs) while presenting visual stimuli. Pasadena Unified School District High School students pilot ERG experiments to test the feasibility of this technique as a large-scale Citizen Science initiative. With ERGo!, future Citizen Scientists contribute data to cutting-edge research that monitors insect biodiversity, adaptation, and health in rapidly changing environments caused by monocultures, pesticides, and climate change.

The bottom-up approach: Open cultural data collection. A Citizen Science initiative for regional knowledge curation.

We catalogued the 18th century German magazine ‘Die Gartenlaube’ (in Wikisource) with bibliographic metadata in Wikidata in a project called ‘Die Datenlaube’. We develop collaborative approaches for linked open data methods to produce data sets about historical knowledge. The concept of ‘Open Citizen Science’ offers a methodological baseline for Open Science practises in fields of digital humanities. Scanned documents and structured open metadata revealed open access to historic collections. Through the Wikimedia platforms 'Die Datenlaube' creates possibilities to edit entries, to design own investigations, and to contribute to OER.

Based on the elaboration of the two rather different projects (natural and social sciences, involvement of pupils vs citizens, top-down vs bottom-up), we will discuss similarities and hence the challenges and lessons learned for using and developing Open Science elements in Citizen Science and mutual learning. Furthermore, we will conclude by focusing on the opportunities resulting from the integration of societal expectations in science and vice versa.

Keywords

Citizen science, Open Science, Open Citizen Science, Open Hardware, Open data, Citizen Data

Introduction and motivation

Citizen Science is an expression of a modern understanding of science that enables social engagement through participatory methods (Bonn et al. 2016). In this context, scientists and non-scientists jointly develop solutions for scientific and social challenges within the framework of participatory research and co-design. Citizen Science - including Citizen Social Science and Citizen Humanities - also makes use of the concept of social innovation (Butkevičienė et al. 2021). Social innovation is understood as an approach that aims to provide new means for answering social questions, addressing societal challenges and bringing about social change. Thus, Citizen Science and Social Innovation are closely related. On the one hand, Citizen Science projects create tools for social innovation, for example digital platforms and instruments for participation in scientific processes, mobile

applications for networking or supporting actors, or programs or instruments for participation in political processes and evidence-based decision making (Mayer et al. 2018). On the other hand, Citizen Science is also described as social innovation in science, as it enables new methods of data collection and interpretation, and is considered a central tool for the democratisation of science (Irwin 1995). Citizen Science contributes to the development of scientific foundations and the systematic production of knowledge on social innovations. Furthermore, Citizen Science offers many opportunities for citizens to engage in the systematic production of knowledge. In this context, science takes a bit more of a backstage role and provides the methods for bringing together different types of expertise by diverse stakeholders to support social change.

Participatory action research (PAR) is the a process by which members of a community, and optionally professional scientists engage in the scientific process to solve a local, place-based problem (Caraballo et al. 2017). This approach centers and celebrates the expertise and lived experience of people who are not necessarily formally trained scientists, which allows formally trained scientist collaborators to operate with community leaders in a way that emphasizes intervention and change above all.

The scope of individual, group or community involvement in participatory science initiatives ranges from short-term data collection or contribution of expertise to intensive engagement. The intensity of this involvement can range from participating in study design to collecting and processing data, but always delving deep into a research topic together with scientists and/or other volunteers. Bonney et al. 2009 grouped participation into the following types: contributive, collaborative, or co-creative participation. Whereas contributive projects are driven by professional science for the purpose of data collection, collaborative projects involve citizens in multiple research activities in line with the scientific research design. In co-creative projects the citizen engagement already starts with the research question and the design of the research project, and citizens may “exert significant control” in the co-creative research process as well as in the use of the research results.

In the literature on Citizen Science, we find different perspectives on participation in research and the opportunities and challenges associated with it. Wynne 2007 reminds us that power dynamics frame the normative shaping of public engagement. Who can participate and under what conditions depends on how formalised participation procedures are set up. Participation ranges from being “invited” - being “part of institutionalised procedures that are dominated by scientific expertise and linked to policy-making” (Göbel et al. 2022) - to “uninvited” - as civic mobilisation or even resistance (Kullenberg 2015). The work of drawing boundaries between what should be inside and what should be outside of science is all too familiar to practitioners and requires a great deal of institutional innovation and individual perseverance (Kasperowski and Hillman 2018). The epistemic cultures (Knorr Cetina 1999) of the scientific fields provide very different framework conditions and recognition processes for citizen participation in research. Whereas the Social Science and the Humanities have several established traditions of participation in research, such as participatory action research PAR dating back to the mid 20th century (Tauginienė et al. 2020, Albert et al. 2021), the Natural Sciences are just at the beginning

of exploring the potential of participation with the beginning of the 21st century (Frigerio et al. 2021) .

The term citizen is somewhat misleading and has been debated for a while (Eitzel et al. 2017). Practitioners engaging in this type of participatory science neither have to be legally recognised subjects or nationals of states nor inhabitants of particular places. The term citizen refers more to the responsibility of science to democratic society, citizens being members of such societies (Irwin 1995), as well as points to the opportunity of empowerment of societies by inclusive knowledge production.

Although many volunteer researchers have academic training, it is not a prerequisite for participation in research projects. It is important to adhere to scientific standards, which include transparency with regard to the methodology of data collection, public discussion of the results, and open educational resources. Hereby, Citizen Science is closely linked to Open Science. “Open Science is frequently defined as an umbrella term that involves various movements aiming to remove the barriers for sharing any kind of output, resources, methods or tools, at any stage of the research process. As such, open access to publications, open research data, open source software, open collaboration, open peer review, open notebooks, open educational resources, open monographs, Citizen Science, or research crowdfunding, fall into the boundaries of Open Science”*[1]. In our contribution we will introduce two Citizen Science projects, developed within the Wikimedia Fellowship program Freies Wissen and focus on their experiences with Open Science (Behrens et al. 2022). These projects approach Citizen Science from the opposite directions: one is what we call "top-down", a scientist-led effort to map insect biodiversity, the other one is "bottom-up", a citizen-led linked open storytelling initiative on the basis of historical knowledge of cycling and open cultural data. Both projects are offering new ways of enriching knowledge production, be it in education and training or in culture. By elaborating the approaches of these two very different projects towards participation and openness, we will discuss similarities and from there the challenges and lessons learned for using and developing Open Science elements in Citizen Science and hence in mutual learning - be it top-down or bottom-up Citizen Science. Table 1 describes, compares, and summarises the Citizen Involvement to categorise the two projects as co-creational Citizen Science initiatives (Bonney et al. 2009). Furthermore, we will conclude by focusing on the opportunities resulting from the integration of citizen generated knowledge in science and vice versa, with a particular emphasis on citizen generated data and collaborative open platforms.

Table 1.

Comparison table of Citizen Involvement in ERGo! and Digital 'Heimatforschung' / Die Datenlaube

Citizen Involvement in	ERGo!	Digital ‘Heimatforschung’ / Die Datenlaube
Research Design	Researchers and students discussed the selection of insect species and environmental significance.	Citizen scientists explored digital sources and methods for their regional studies and science communication.

Method Design	Open source DIY hardware and free access to method videos to invite citizens for comments. Stimulation protocols and experimental set-ups change co-creationally over time.	Use of digital tools and communities of the wikiverse. Open documentation and publication.
Data Collection and Curation	Collaboratively with scientists in a workshop or at home with online support. Students uploaded the data via Google Forms or Google Drive.	Independent research, collaborative editing and discussion. Open publication of data and resulting reflections.
Data Analysis	Google Colaboratory analysis scripts were created by researchers and executed online by the students.	Query design, data visualisation and *Linked Open Storytelling* using Wikidata Query Service and Scholia
Communication of Results	Results were presented in school workshops by the students to the researchers and each other.	Results were presented in social media, presentations and open access venues.
Project Governance	Commenting on open access materials and communication with the ERGo! team	Independent research and editing in Wikimedia based environments.

Fellowship Projects

In the following, we will elaborate a detailed description of the fellowship projects, elucidate their impact on Citizen Science, and highlight how opponent approaches can complement their efforts in the future.

ERGO! Entomology Research Go!

One of the most pressing issues of our time is anthropogenic climate change. Climate change will continue to affect worldwide systems during this century at all levels, from small practicalities in day-to-day life to global food security (Carayannis et al. 2012). European biotopes are already feeling shockwaves as whole insect species disappear in droves (Thomas et al. 2004, Seibold et al. 2019, Hallmann et al. 2017, Outhwaite et al. 2020). This disappearance will destabilize ecosystems and drive potentially catastrophic downstream effects on food supply (Katumo et al. 2022). These environmental disasters are fundamentally a social justice issues: the first communities to feel the consequences of social, political, and environmental catastrophe have always been historically oppressed groups (Bullard 2007). Perhaps unsurprisingly, these same communities have been systemically underrepresented in academic science (Morgan et al. 2021). We view this disproportionate burden on oppressed groups, and their exclusion from academic science, as concomitant and unacceptable. Therefore, we designed a Citizen Science initiative to recruit and work with minoritized people in science with the intention of addressing, but not solving, both issues.

Academic science is playing an irreplaceable role in measuring, understanding, and ultimately countering this emergency, regardless of who counts as "academic scientists". Our ability to react and design the right measures depends critically on our ability to track changes. However, the number of professional scientists and their capacity to generate up-to-date maps of biodiversity are naturally limited. As a consequence, we are still in the dark about the full extent of this ongoing extinction event; we simply do not know enough about

the current health status of our insects (Simmons et al. 2019). Moreover, a lack of awareness in the general population could hinder the implementation of policies that counteract these changes. To make true progress on this issue, we urgently need more systematic mapping efforts. Moreover, we need more citizens to participate in academic science. Specifically, citizens who are interested in conservation should be trained in scientific methods to monitor early indicators of insect population changes.

While PAR is is often described as the gold standard for research (i.a. Baum et al. 2006), it and its youth-focused variant, YPAR, do not easily apply to biological questions because PAR and YPAR were formulated for sociological questions. Youth Participatory Science (YPS) is a Citizen Science/PAR framework that attempts to extend PAR into the realm of biology and natural science, but it again prescribes a strongly place-based formulation of problems and questions, and a community-centered approach to solve them, e.g. lead poisoning in water pipes (Morales-Doyle and Frausto 2019, Anselma et al. 2020). How might one implement a YPS-based approach for tackling large-scale, decentralised problems like biodiversity mapping? Indeed, when we tried to create a social justice-informed large-scale Citizen Science program we were unable to find any examples, especially when the problems were on the scale of global climate change rather than local plumbing infrastructure. We find that because large, decentralised problems like climate change and biodiversity decline comprise myriad localised problems, Citizen Scientists can affect change by adopting a localised, place-based approach: collecting evidence, presenting it to authorities, and advocating for change.

We set out to develop a model for science outreach based on the YPS framework for Citizen Science (Morales-Doyle and Frausto 2019) in Pasadena, California. Because we were newcomers to this community, to create a socially just outreach program, we first spent several months (~6) learning about the community. We spoke with administrators and professors affiliated with the California Institute of Technology (Caltech) and the local community college (Pasadena City College, PCC) about needs of the community that could be filled by a science outreach program. After a long networking process, we met with representatives at PCC's Upward Bound Math-Science, a program of the US Department of Education's TRIO initiative. We agreed to implement our Citizen Science initiative as part of a larger program that Upward Bound already had running. Since this is the first social justice-focused initiative of its kind that we could find, and because Daniel J Pollak (DJP) and Étienne Serbe-Kamp (ESK) are both white, we do not intend to present this as a finished methodology, but rather as a description of a first attempt, and our plans to improve moving forward. Jahel Guardado, a PhD student who grew up near Pasadena, graduated from PCC, and finished her bachelor's degree at UCLA, met DJP during this networking period. Jahel holds two underrepresented identities in science, being Hispanic/Latinx and a woman, and she agreed to design and teach a summer-school style Citizen Science initiative with PCC's Upward Bound program alongside DJP. Jahel's previous experience doing science and science outreach provided crucial guidance and perspective that shaped the experience of our students for the better.

We believe that it is crucial to highlight this community-building as the first and the most important step in our methodology for doing Citizen Science. Only after this intensive

networking could we have a vision and a venue to set up our pilot program. Underrepresented minorities in science are systemically excluded from science (Stevens et al. 2021), so we decided at the beginning to work only with students holding underrepresented identities in science, particularly Hispanic/Latinx students, as Pasadena is 33% Hispanic/Latinx*[2], but Caltech's student body is only 13.4% Hispanic/Latinx*[3]. We piggybacked on the work that Upward Bound had already done to recruit mostly Hispanic/Latinx students, and simply selected the students they recruited who were interested in participating in a neuroscience "class" once a week for two to three hours.

ERGo! aims to create new scientific knowledge using inexpensive and easy to use methodologies. However, the advantage of an in-person workshop like the kind provided by Upward Bound is that we have the opportunity to benefit the participants; to have learning objectives. Our learning objectives for our six students was simple: create 6 full-fledged scientists at the end of six weeks who were competent, experienced, and recognised as scientists (Carlone and Johnson 2007). Our ten-minute lectures at the start of class covered the scientific process, streetsmarts in academia, the importance of networking and creating resumes, and finally scientific communication. The rest of the class was devoted to the actual practice of science. We took one entire class period to practice writing resumes, making sure to include the word "Caltech" in the experience section of each student's resume, and practiced science communication skills using the results of students' project outcomes.

Simple experiments can create the possibility of large-scale impacts to the public. The Citizen Science organisation “Insektenverein Krefeld" (Hallmann et al. 2017) found insects’ populations declining by up to 75% over the last few decades, which then produced a flurry of multiple mainstream media articles about “Insectageddon”, resulting in awareness-raising about the urgency of the climate crisis, pesticide overuse, and leading to public discussions about possible interventions. This is the gold standard for how Citizen Science can produce an impact on the world: by including the people who are directly affected by the scientific question at hand in the scientific process, the urgency of the findings is embedded into the hearts of everyone who participated, professional scientists and laypersons alike. In order to make progress on such gargantuan problems as climate change and biodiversity loss, this urgency must not remain locked in the ivory tower. ERGO! (Fig. 1) invites a broad range of Citizen Scientists to explore the field of Entomology Research as well*[4].

Whereas biology often requires prohibitively expensive equipment, we established ERGo! as a low-cost and open-source experimental platform. Specifically, ERGo! wants to provide Citizen Scientists with DIY electrophysiological tools (Pollak et al. 2019) to record insect eye light responses. ERGo! comprises a growing cohort of high school students, undergraduates, and professional scientists collectively working to establish an affordable hardware tool that empowers Citizen Scientists to assemble in-depth analyses of insect biodiversity through performing insightful, affordable, and easy physiological experiments. This approach paves the way for in-depth investigations of insect biodiversity and serves as a powerful and innovative model for Citizen Science in modern biology.

Figure 1. doi
ERGo! Logo.

To this end, the ERGo! team developed low-cost hardware (Pollak et al. 2019) that plugs into smartphones, tablets, and computers and allows users to perform multi-colour electroretinograms (ERGs, Fig. 2; Vilinsky and Johnson 2012) on wild-caught insects to measure the spectral sensitivity of insect photoreceptors in a broad variety of species. In his famous 1914 experiment, Karl von Frisch demonstrated that colour vision is essential for detecting and discriminating between similar objects in a visual environment for bees (von Frisch 1914), as it is for humans. Von Frisch showed that bees remembered the colours and shades of paper pieces inoculated with pollen and visited those colours more frequently even in the absence of food. This experiment proved that bees can sense and differentiate colours and shades. Although we cannot track individual bees and reconstruct their exact visual imagery throughout flight, Citizen Scientists can further interrogate Von Frisch's initial finding by using ERGo! to measure their sensitivity toward different colours - even to those that are invisible to the human eye.

The ERG is an elegant way to catalog spectral and temporal properties of vision across insect species and to show, for example, that honeybee trichromatic vision differs from human visual sensitivity (Fig. 2d, e, f). ERGs function on the principle that photoreceptors chemically turn light into an electrical potential (Fig. 2a, b, c). The ERG waveform comprises the collective response of hundreds or thousands of photoreceptors. The overall waveform components of ERGs are fairly consistent across individuals of the same species, but can vary wildly between species.

ERGs present an unusually fruitful source of insights into several fields of biology, from basic scientific questions to essential readouts of environment health, impacts of global climate change, and local pollution. Visual systems can evolve specializations by developing the ability to detect spectral wavelengths that are relevant to their ecological niche. These physiological responses provide a window into visual adaptations, biochemically and anatomically. When these physiological responses are compared across species, we can formulate hypotheses about ecological specialisation and evolutionary relationships (Stowasser et al. 2015).

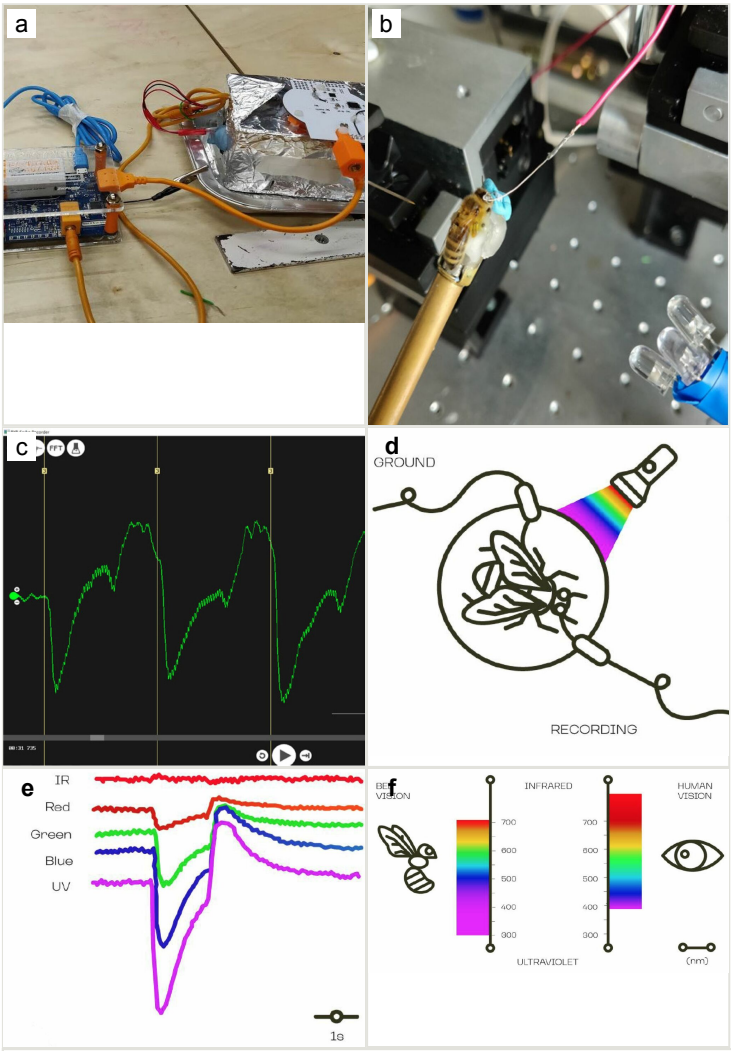

Figure 2.

Preliminary Setup for inexpensive DIY ERG recordings

a: ERG recording configuration: Modified Heart&Brain SpikerBox (left, blue), improvised light isolation chamber (right, silver), and 3 LED visual stimulation device (right, white and 27 orange). doi

b: Honeybee (*Apis mellifera*) mounted for ERG recording on an early prototype. Recording electrode touching the eye (from top). doi

c: Sample raw electrical signal in Spike Recorder software, recorded from a honeybee eye during visual stimulation (vertical lines indicate offset). doi

d: Schematic overview of experimental setup. doi

e: ERG responses recorded with DIY setup from A. *Apis mellifera* eye was stimulated with light of five different wavelengths doi

f: Overview of the visual sensitivities of bees & humans doi

For more advanced or motivated Citizen Scientists who want to delve deeper into entomology and help to establish ERGo! as a flexible platform for various biology-related experiments, we propose a project to investigate co-evolutionary relationships between insects and plants (Darwin and Kebler 1859, van der Kooi et al. 2020) by comparing insect visual sensitivities to the colours of pollinated flowers. Most importantly, given the stereotypy of ERG responses within species, ERGs could be used as a health indicator of direct (ecological niche changes) and indirect (pesticide use) effects of climate change (Memmott et al. 2007, Martelli et al. 2020).

The use cases for ERGo! do not just include a Citizen Science initiative as a readout to monitor and characterise insect populations, but also as a YPS initiative. Indeed, ERGs promise to be a useful tool in the toolbox of conservation biology when used in the context of tracking population changes. Some of the most important kinds of population changes to track are physiological indications of health, particularly among pollinator species. Neonicitinoid (neonic) pesticides are widely considered to be extremely dangerous to humans and the environment (Cimino et al. 2017, Martelli et al. 2020), and fruit flies (*Drosophila melanogaster*) inoculated with these pesticides show weakened ERG responses (Martelli et al. 2020). Because ERGs reflect the influence of pollutants in the environment on local insects, the authors propose that communities could use a YPS framework to combat environmental racism by collecting ERG recordings as a proxy for toxicity data.

The first years of ERGo! consisted of research and developement and piloting workshops. The initial ERG measurement prototype, the ERG Spikerbox, was developed in collaboration with Backyard Brains, and was built on a completely-open source technology stack*[4], [5]. However, this process only represents the first iteration in the research cycle of this “top-down Citizen Science” approach, where scientists of all educational stages trained students and pupils to collaboratively perform electrophysiological experiments. We grappled with the uncertainties of building a Citizen Science initiative centered on social justice, and we hope our perhaps error-prone first attempt will provide some measure of instruction for others interested in connecting science with social justice.

The second iteration of this "top-down Citizen Science" initiative will incorporate the insights gained from pilot cohorts into a publically available program, while trying to center the voices of community leaders we met in Pasadena and in other communities into which we will expand. There are so many ways to “center the voices of community leaders” that it is not exactly clear how a Citizen Science initiative must do that. It is crucial to remain in conversation with the Pasadena community so that we can improve, without asking people to perform an egregious amount of uncompensated work. Thus, the second iteration of this top-down Citizen Science will include surveys for teachers, parents, and administrators within PUSD and PCC. These surveys will be short, requiring only a few minutes of time, but will have open ended questions for people to share miscellaneous feedback, as well as contact information for DJP to reach out with any questions/concerns.

In the next iteration, Citizen Scientists will also submit ERG data and assorted metadata (date, location, insect photo) via Google forms, and data will be stored on Google Drive. To

scale up engagement with the platform towards that of a global Citizen Science initiative, we will release a detailed tutorial series (similar to *[4], [5]) for performing electroretinogram experiments and host workshops and train-the-trainer events. ERG kits will be made available for purchase, and Citizen Scientists can decide the level at which they engage with the initiative, from doing experiments to participating in supervised analysis and interpretation of data.

Taken together, the authors will teach citizens how to use low-cost equipment to perform experiments that were previously exclusive to highly trained scientists with expensive equipment. As a Citizen Science entomology research tool, ERGo! promises to unravel complex environmental phenomena and raise awareness for the immediate necessity of floral and faunal biodiversity protection. ERGo! aims to function as a platform where amateurs and professional scientists can exchange ideas, communicate findings, and develop projects. To make this platform and these findings accessible to Citizen Scientists of all socioeconomic statuses, the team is currently working to incorporate these elements in an free educational application (*[6], *[7], *[8], and Fig. 3).

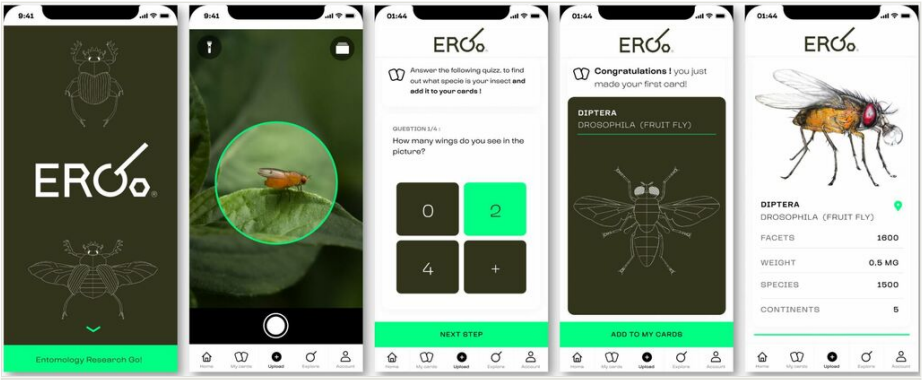

Figure 3. doi

ERGo! Citizen Science application layout. Automated photo upload, quizzes, and collection cards for an interactive open source application.

Heimatforschung (local studies) with open cultural data

The second Citizen Science initiative to be described here is more of a bundle of projects working with open cultural data for “local studies” - “Heimatkunde” or “Heimatforschung” in German. A local interested in the surrounding environment or trained in historical sciences usually works on a voluntary basis in the field of researching local histories. The practices involved hereby are - amongst others - the observation, measurement and documentation of nature and culture for example to construct genealogies or preserve oral histories.

In the project ‘More than cycling: European Heimatforschung – an approach for open data and narratives, including wanderlust research and cycling knowledge’ Jens Bemme’s main objective was to experiment and test the opening of historical accounts of cycling to

historical sciences and Citizen Science alike*[9]. In his exploration of historical cycling knowledge and in collaboration with other European cycling history enthusiasts, Jens focused on historical cycling literature and its representation around 1900*[10]. These sources consist of road books, maps for cyclists, newspapers, magazines, graphic illustrations and other art works and are commonly archived in local, regional and state libraries, ten years ago not openly accessible to a wider online audience, especially not to those with a wanderlust from other regions and across borders*[11].

The objective of the project was thus to demonstrate how local studies can benefit from Open Science. The concept of “Europäische Heimatforschung” (European local studies) also emphasises the need for international networking and the strengthening of international cooperation for research on European regional mobility history, which is an important basis for transforming the contemporary way we look at mobility and the environment.

Starting in 2019 from systematically collecting regionally available information about “cycling knowledge” and historical accounts of wanderlust in the area of the German Empire during their journeys and visits to archives, libraries and cooperation partners, such as German and other european public libraries, the team dramatically increased the stock of digitised sources, which made it possible to further refine the concept of European local studies. Since this project grew out of an interest, and became more and more systematic over time, we understand it as “bottom-up” Citizen Science, following in particular the “Open Citizen Science”*[12] route (Göbel 2019), by extensively making use of open Wikimedia tools and experimenting with tools of collaborative knowledge production (Bemme and Munke 2020, Bemme and Munke 2022). The portals Wikipedia*[13], Wikisource*[14], Wikimedia Commons*[15], Wikidata*[16] and Wikiversity*[17] are fundamental in the approach to opening cultural data. The bibliographic links of Wikisource and Wikidata have been also central to Jens’ work in general, both on a voluntary (local studies) and professional (librarian) basis. The scientific part of the project therefore extends both in the methods, e.g. the systematic research and source studies, but also through the presentation of the results, such as the lectures at academic events and publications including the reflections on their own Open Data/Open Citizen Science work in collected volumes.

Jens describes his method as “long term open data hackathon”*[18]: using open metadata for cataloguing digitised periodicals and research literature for science communication with ‘Linked Open Storytelling’ (LOST)*[19]. The LOST approach in science communication is developed from the insight that open data are not by themselves rich sources of information. By enriching them with meta-data and linking them with stories, such as historical accounts, and Linked Open Data (LOD) using digital storytelling methods they become valuable and accessible information, much like required by the FAIR scheme - making data findable, accessible, interoperable, and re-usable (Wilkinson et al. 2016).

Hackathons are events for collaborative soft- and hardware development in sprint mode for a few days or longer. Here the research and development is commonly oriented on larger objectives, but still follows individual preferences and curiosity: 1. finding and collecting

forgotten cycling knowledge around 1900 in Wikisource link lists and in Wikidata items with the metadata of publications, historic personalities and cyclists associations in Germany and the Baltics (Fig. 4) and 2. being the first project team cataloguing 47 volumes of an illustrated magazine - 'Die Gartenlaube' - transliterated in the German Wikisource[*20] using open structured bibliographic data in Wikidata[*21]. The project team 'Die Datenlaube' started with the Austrian librarian Christian Erlinger and Jens Bemme. 2021 Matthias Erfurth came into the team, a Dresden based local wiki enthusiast and Citizen Scientist ('Stadtwiki Dresden')[*22]. Both projects are offering the opportunity of long-term crowdsourcing activities using Wikimedia tools. All resulting publications, such as reflections on findings and research processes in blogs, were catalogued openly with open bibliographic metadata in Wikidata and presented with the tool Scholia*[23]. Reflections included the usability of these methods and formats of publication and their suitability for Open Citizen Science communication and open humanities. Participants are between 30 and 70 years old: data-oriented nerds, wikimedians, historians, computer scientists, local historians, and cultural scientists - all Citizen Scientists in changing roles with diverse perspectives*[24].

Figure 4. doi

Gustav Bauer: female cyclist, advertisement illustration, in: Sächsische Radfahrer-Zeitung, Leipzig 1899, 19. August 1899, p. 344, https://commons.wikimedia.org/wiki/File:Radfahrerin,_1899.svg.

The 'Datenlaube' ("data arbor") is a Citizen Science project run by volunteers mainly in Dresden and Vienna since 2019[*25]. During the course of the fellowship, this project was closely linked to the methods researched and described there and consequently benefited greatly from this approach. Open Citizen Science and linked open storytelling helped to unlock "Die Gartenlaube" (Garden Arbor). Starting in 1853, 'Die Gartenlaube' from Leipzig successfully turned an illustrated magazine into an early mass medium with serial storytelling.

By digitising, transcribing and making this 19th century German-language family newspaper openly accessible, the team was able to create an important historical source for cultural studies - an open catalogue of Wikisource texts using Wikidata. These travelogues, health and household tips, reviews, reports from the Reichstag, poetry and novels, portraits of places, plants, and people, obituaries – richly illustrated, with sequels, and sometimes told in long-running series of articles with large illustrations (Fig. 5) – became then the foundations for our own growing bibliographic metadata and hence for linked open storytelling. This metadata is open and structured, therefore machine-readable and is continuously updated since 2019. The still ongoing collaboration resulted partly from typical crowdsourcing activities, partly from more research oriented, informal communities. However, the boundaries are often fluid.

Figure 5. doi

Otto Boyde: Sport-Limonade (poster, Dresden, before 1893), photo by Frank Papperitz, 2019, Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Otto_Boyde_Dresden.jpg.

These days, both research and teaching in information and library science, as well as librarians themselves are only just discovering the field of 'Wikiverse' - here in particular with regard to digital editions or digital humanities (Fig. 6). And so the team has already taken its first steps here, attending conferences, submitting posters and giving talks, which have been very well received so far. This results not only in increased visibility for the project, but also in valuable feedback for the research process[*26*27]. We want to further increase the connectivity of our 'data mountain' of the data arbor. There is still much to do in terms of data quality and documentation, and thus again in terms of methods. The more users, citizens as well as historians, information scientists and generally people with an

interest in digital humanities join in, the more we learn about further standardisation needs, and research opportunities. In any case, we will continue to write about our work and approach these publications sometimes more low-threshold, sometimes more academic, depending on the target audience. However, it has already been successfully demonstrated that the open tools are a central anchor point for this kind of bottom-up Open Citizen Science initiative. They are the gateway for people who are interested in systematically researching their lifeworld but have not had access to methods so far.

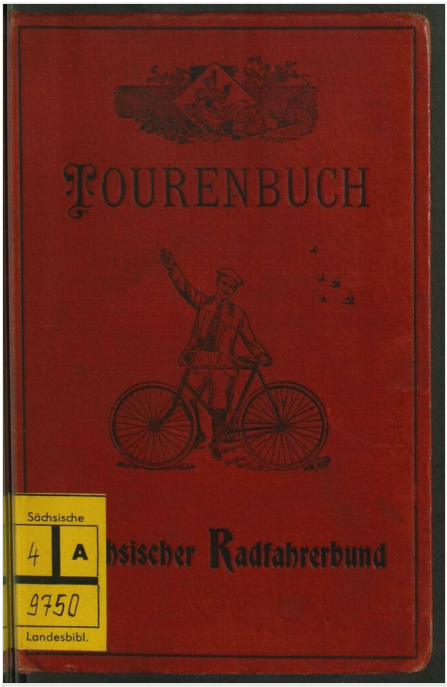

Figure 6. doi

Bernhard Böhm (Ed.): Touren-Buch des Sächsischen Radfahrer-Bundes : umfassend das Königreich Sachsen nebst den angrenzenden Teilen der preußischen Provinzen Schlesien und Sachsen, der thüringischen Staaten, sowie der Königreiche Bayern und Böhmen, Leipzig 1899, SLUB Dresden: http://digital.slub-dresden.de/id407531238.

‘Die Datenlaube’ and its weekly ‘DatenlaubeJam’ digital project meeting brings together diverse participants editing cultural open data in Wikisource and Wikidata especially for historical publications of the Dresden historical society *[28]. Doing so the project team emphasises the following factors for community based Citizen Science and crowdsourcing in this field: perseverance, regularity, openness of data and infrastructure (Open Citizen Science), topics and participants, 'low budget' as an advantage, 'by-catch' in the sense of accompanying and incidental topics, detours and goals that nevertheless enrich collaboration. Moreover, cultural institutions and its members are in the midst of the digital upheaval as part of the digital revolution, historical societies as well as libraries, archives and museums *[24].

Discussion

Both accounts above - even though based on very different motivations, objectives and types of participation - help us now to reflect and analyse the multifaceted nature of open practices in Citizen Science. Even though both projects were co-creative in the type of participation (Bonney et al. 2009), involving citizens in multiple stages of research design and research process, they were following different directions from science to citizens and vice versa. They shifted the boundaries from and to science differently. ESK and DJP, together with their team, elaborated a concept and prototypes for a top-down insect biodiversity analysis: ERGo! opening up science to non-scientists and “inviting” the participation of students into the research cycle, both for data collection and analysis as well as for the creation of biodiversity science literacy. Jens’ team empowered Citizen Science with open cultural data and extensive use of the Wikimedia tools to contribute in a bottom-up participatory fashion to systematic knowledge production that opens new expertise also to academic actors. By discussing their particular challenges of creating open workflows and open data, the authors will now elaborate how these different experiences can be used to improve the processes.

1) Top-down and bottom-up approach to Citizen Science to develop new areas of knowledge

Both projects started from their niches, involving only a few people at the beginning - specialists in their field, be it academic or non-academic. Both teams had to learn a lot about opening the research process, so that not only more people could participate, but also so that reliable knowledge could be produced. Yet, both projects demonstrate how new publics and attention can be gained from niches on the basis of basic open technologies that are accessible to all.

The ERGo! initiative uses a "top-down Citizen Science" approach to study cross-species patterns in photoreceptor sensitivities and to generate unique insights into insect visual ecology. The ERGo! team developed hardware, experimental setup, open-source plug-and-play analysis software, and checked for its feasibility of implementation in a virtual classroom. The ERGo! team chose these students because they had no prior experience with science and had underrepresented identities in science (female, Hispanic/Latinx). ERGo! will proceed to phase two, scaling up toward a global Citizen Science initiative with various research arms investigating basic scientific questions, performing readouts of insect health to study climate change, and local arms for dealing with local questions.

Our primary concern with this project is to make it inclusive for those holding underrepresented identities in science while producing the highest possible quality of data, and developing frameworks along which Citizen Scientists can help tackle large-scale, decentralised problems by focusing on local, place-based manifestations of those problems. The most pressing question facing ERGo! was and is how we could take inspiration from the YPS framework for doing socially-just Citizen Science, especially if ERGo! is a decentralised initiative, and YPS prescribes local and place-based problem formulations and solutions. We described potential use cases for our ERG kit to address

environmental racism and climate change by leveraging ERGs as a nonlethal toxicology readout in animals. For climate change, the ultimate non-localised problem, we note that climate change itself manifests in myriad ways throughout the environment, and that ERGs present an inexpensive and compelling source of hard data for presenting as evidence and advocating for change.

2) Data quality and re-usability

To advocate effectively, ERGo!'s data infrastructure will prioritise transparency and high-quality data while putting the analysis process and authorship for publications into the hands of Citizen Scientists*[29]. This infrastructure will incorporate automated checks of the recordings paired with peer review by the professional scientific community. With this structure in place, we will continue to expand in Pasadena, continuing to work with local public high schools and with majority Hispanic/Latinx populations, with the goal of acquainting our new Citizen Scientists with the otherwise opaque academic process.

The project Datenlaube and the open cultural data for local studies initiative took a bottom-up approach to Open Citizen Science (Bemme 2019). A core team of Citizen Scientists developed an approach based on open tools. One goal is to open up data and knowledge for enthusiasts, but also for social sciences and humanities. To be a 'first mover' is another strong motivation of the project team, to prove the concept of opening up a large amount of historical texts from Wikisource using Wikidata. There is a special effort here to be inclusive toward the scientific community without neglecting Citizen Scientists. So the team engages in social media, blogs about news and methods, designs educational resources and teaches courses in academic and non-academic settings. The weekly project 'DatenlaubeJam' is growing into an Open Data meeting since the beginning of 2022 - especially with the participation of the Dresdner Geschichtsverein e.V. - the Dresden historic association.*[30] There a lot of method transfer happens around the indexing of documents and linking them via open tools. Supra-regional guests from libraries in Berlin and Hessen get to know Wikimedia's tool box and learn to adapt it for their own projects. In the longer-term outlook, many more activities are planned: Applications for grants, writing of more papers, lectures, and networking as well as collaboration via e.g. 'DatenlaubeJam'. In terms of re-usability the re-formatting of data for “Coding da Vinci Nearby” a Cultural Data Hackathon series will be considered*[31]. There is a lot to learn from the project and its surrounding initiatives in terms of fostering Open Citizen Science. The challenge for Citizen Scientists is to manage all of this - data collection, analysis, preservation, communication etc on their own. One wishes to be professionally accompanied for once, in the sense of an accompanying study, to explore all that can be learned from such a project.

One further challenge that accompanies both projects is that of data quality and reusability. This is a much discussed topic in the Citizen Science literature (Pivarski et al. 2022, Serret et al. 2019). In science, the quality of data reflects their validity; how they represent reality in regard to the research questions being asked. Now, however, data from the two projects presented are intended to serve many as yet undetermined interests beyond an already formulated research question. That is, after all, the intention of openness in both projects. It is data that should be helpful in the future. Though metadata is crucial for allowing efficient

and effective interrogation, the value of this cultural data trove derives first and foremost from the integrity of the primary data themselves. In the case of the Datenlaube and the opening of the historical cyclist knowledge, the integrity of the primary data is closely linked to the approach to data collection and further data practices. As in the scholarly editing field, the central practices here are digitising, transcribing, and interpreting, e.g. through annotation, and then just equipping historical sources with metadata. Since these practices have already been carried out in the project for the most part on open platforms such as Wikisource, quality assurance could also be taken into account at the same time. For example, the 4-eyes principle was applied for every transcription and annotation and provided much better results by this type of peer review. Each correction could be tracked through the version history. Even if the work was not carried out as strictly according to predefined schemes as in the digital humanities (TEI, XML)*[32], the 20,000 articles thus indexed still represent a rich corpus for scholarly research. Demand for this data is just beginning to increase after the team actively promotes not only the data but also Citizen Science as a new form of “Quellenarbeit” (source work like cataloguing) in the German-speaking library community. However, the communication effort (training for transcription and the tolerance for ambiguity as well as making the project and its data known) is very large, and would not be possible without the enthusiasm of a core team. With this broadening of the community, that is, both toward volunteers and toward institutions - libraries and academia - the new possibilities of a local history of the many perspectives are particularly emphasised. This can not only increase the inclusivity of science, but also ensure the visibility of this manifold knowledge. Another important aspect is that this project serves as an exemplary use case or pilot for crowdsourced open digital data and infrastructures in both the humanities as well as in (local) politics and administration, which is still very new for many, such as funders, city policy or local libraries and museums. The low-cost set up and maintenance - it is now running for 3 years with minimal budget on Wikimedia infrastructure - furthermore, is often met with astonishment. The long-term effects of such “model” projects should not be underestimated: the openness and re-usability of Wikimedia technologies for open cultural data are already taken up in Open Citizen Science approaches for historical research*[33].

3) Experiences with open data practices and making participation more open

Ambitious top-down as well as bottom-up Citizen Science projects require constant supervision by professionals (either scientists or data stewards for data curation, analysis, and publication). In order to set up a workflow that facilitates participation and at the same time allows insect identification or initiates linked open story telling, Citizen Science projects must therefore invest in communication and co-creational strategies. These workflows include data cleaning, processing, analysis, and Open Science practices. ERGo! uses free services from Google as a tractable and effective infrastructure for aggregating data from most places around the world, inspecting them for quality assurance, and engaging Citizen Scientists in the scientific process, getting consent to use their work and names in subsequent publications. Because Google connects several of its services to its

cloud storage service (“Google Drive”), Python scripting can be implemented for future automated workflows that operate on cloud data. These workflows include

1. alerting scientist curators of new data submissions ready for curation and proofing,
2. performing automated analyses, including segmenting experiments into different light presentation epochs and extracting relevant parameters from recorded signals, e.g. maximum amplitude, amplitude attenuation, etc., and
3. emailing the Citizen Scientists who performed these ERG experiments with beautiful data visualisations from their experiments (see Fig. 1).

Giving Citizen Scientists access to preliminary data visualisations enhances their degree of engagement with the scientific questions and insights being synthesised by the supervising scientists. Indeed, the ERGo! team expects that questions and comments about self-collected data will be forthcoming from the Citizen Scientists who collected them, thereby changing their role as authors of the publication(s) that arise from their data. Supervising scientists will also play a crucial role in double-checking the quality of the ERG signal data, as well as reviewing the species identification attempts made by the Citizen Scientists. However, it will be crucial for rapid adaptive measures for pressing issues like climate change and biodiversity loss that science and society work and produce knowledge hand in hand.

What can a Citizen Science initiative that addresses biological rather than sociological questions contribute to society? This was the animating question behind the formation of ERGo!. Society’s connection to academia has frayed, especially in recent years due to the emergence of vocal science sceptics whose falsehoods have endangered lives due to vaccine hesitancy during the covid pandemic (Pierri et al. 2022). We decided that communities that have been excluded from academia must be purposefully included, and that the outcome of our initiative could not start and stop at publishing a paper. Rather, in the span of 6 weeks, we needed to create fully-fledged scientists out of our recruits. At the end of the pilot program our students could claim ownership of their project, including articulating a scientific question, performing experiments and analyses, and, most importantly, explaining it to others.

The democratising force of Citizen Science runs counter to the prevailingly exclusive nature of formal academic science because it puts agency to perform and add both to science and to knowledge about the life worlds into the hands of those who have not traditionally had it. Due to a long history of redlining and gerrymandering (among many other harmful policies), Pasadena has a disproportionately high number of private schools per student in the country, with the public high schools majority Latino. ERGo! admitted students to a pilot cohort comprising exclusively Latinx and Asian students from public high schools in Pasadena via the Upward Bound Precollege support program at Pasadena City College (N=7 students, 2 did electroretinogram projects, and 5 did electromyogram, electroencephalogram, and multiunit extracellular electrophysiology projects). By creating a framework for Citizen Scientists who can talk about and advocate for science in their community, we aim to strengthen the connection between science and society. As environmental protection measures need more global support ERGo! hopes to incentivise

young citizens to participate actively in research. Eventually, this could improve our understanding of the environment with its complex mechanisms and how Citizen Science can contribute to its conservation.

What can ERGo! learn from open cultural data: ERGo! needs to incorporate Open Science tools for improved transparency and data curation. It will be essential for ERGo! to reach the stage where everyone can contribute with ease while ensuring high data quality. Consequently, digital versions of the experiments for easy accessibility for everyone (similar to Fig. 3) can help for an improved understanding of cutting-edge research. To learn from the open cultural data project ERGo! wants to incorporate better Open Science tools in its workflow and data pipeline. Ideally, Citizen Scientists get familiar with Wikimedia tools to curate and share their favourite recordings and insect pictures or drawings on Wikidata*[34] and Wikimedia Commons*[8].

On the other hand, opening up historical local knowledge could be interesting for schools and higher education in general. Lupschina remarks that students get the skills to write about history on such open platforms, they learn how history is “made”*[35], [36]. ‘Digital Heimatforschung’ could learn and certainly benefit a great deal from efforts in designing open learning materials and protocols for student participation. Similarly 'Die Datenlaube' is more than just an open educational source for materials, it is a space to “write history”*[37].

Open Citizen Science with open cultural data in Wikimedia environments offers access to digital tools, open data collections, formalised user groups and informal user communities and their collaborative methods and procedures. These approaches are widely underrated in traditional academia. At least Open Science advocates and communities explore and use the open infrastructures of Wikimedia increasingly for reaserch projects, reflections on Open Science methodologies and community building. Nevertheless, academic competition regarding Wikimedia based research approaches, data, methods and software solutions is still low. Some universites research libraries and other GLAM institutions are starting to make profit out of them. For example Wikimedia in residence programmes testify to this*[38].

Both projects - whether top-down or bottom-up - learned how important it is to stick to some general principles when setting the common grounds for Open Citizen Science and creating and maintaining sustainable knowledge production.

Transdisciplinary learnings for open Citizen Science

Scientists have to get close to citizens to experience what Citizen Science means, to not only get people interested in a subject matter, but also to create a participatory experience which not only benefits the citizens in their daily lives, but also the scientists to better understand the situatedness of local knowledge production.

Top-down and bottom-up approach to Citizen Science to develop new areas of knowledge

Questions to ask when co-creating new knowledge areas with open cititzen science: Is the aim to open science for citizens or to open citizen knowledge for science and other fields? Is the focus of the design co-creational and should it be based on citizen experience and data quality: what is interesting and feasible to citizens? What benefits do they expect or were they promised? What expectations of scientific (and other) reuse are guiding their actions? How can data collection and interpretation be organised in line with these expectations?

Data quality and re-usability

The objectives and (social) impact of the Citizen Science project should be communicated and documented transparently, project interfaces, results, documentation and educational materials should be easily accessible. While these materials should be open for everyone, it is impossible to communicate all aspects for everyone in an understandable way. On the contrary, priority should be given to design these open materials specifically for target groups, such as students, cyclists, librarians, etc.

Opening participation

Openness and participation need a lot more time than traditional research processes. This needs to be considered and flexibility to adapt to unforeseen challenges should be already planned from the beginning (especially in top-down Citizen Science projects).

Furthermore, Citizen Science needs to go beyond successfully establishing the "'ability to participate' of laypersons in research processes. Rather, all participating actors need to establish a 'capacity for cooperation', whereby both the level of individual professional and non-professional researchers is important as well as the collective level of scientific and other organisations" (Göbel et al. 2020, p.10) as well as infrastructures.

Conclusions and Outlook

Citizen Science reflects a very broad movement that lives from a diverse set of initiatives led by volunteers and socially engaged scientists. Although Citizen Science is already well known in the scientific community and in research policy, it is still too little known - and taken up by society, the media, and especially local politics - which could benefit most from it. We argue that open practices, such as open tools and infrastructures for data collection and curation e.g. from the 'Wikiverse', provide the grounds for bringing together different types of knowledge and formats of expertise. Showcasing the two Wikimedia Fellowship projects aimed thus to demonstrate how much Citizen Science can benefit from a further opening of methods and data. Open practices thus establish and strengthen the possibilities of social innovation both within science and society to support social change. Environmental and societal challenges we are facing today and in the future could be

better tackled on the basis of socially robust evidence and culturally inclusive epistemologies (Jaeger et al. 2022). Therefore, we need to further develop and scale up knowledge production also outside the already established channels, which are, after all, often blind to “marginalised perspectives” (Harding 1992). Inclusive and Open Citizen Science, along with open data and open methods could support the production of socially robust knowledge (Nowotny et al. 2001), in that this knowledge is not only relevant, credible and accepted, but also accessible and re-usable.

One lever for the effectiveness of public investment in Citizen Science is the joint expertise of citizens in their digital practices in their daily lives - for example, reading, querying, evaluating, linking, multiplying, remixing, and subject-didactic use, possibly with the help of automated processes and in topics of their concern. Crowdsourcing data collection, interpretation, and Citizen Science in general can multiply and at the same time democratise these effects of newly generated as well as retro-digitised knowledge corpora (Munke and Bemme 2021).

Both projects show that it pays off to work with already existing open technologies or to develop new ones. For professional scientists and Citizen Scientists alike it is learning by doing, slowly professionalising openness, and reciprocally actively receiving/deepening/enriching/criticising/improving collaborative knowledge production. Academic prestige and the traditional reward system take a back seat with Citizen Science, and motivations are instead guided by environmental and social urgency, curiosity, reflexivity, and creativity. However, such collaborative research processes require more resources for communication between participants and reflexive personal and institutional practices that do justice to these increased and often complex communication efforts. Even though academic prestige and merit is not a priority, these efforts also need adaequate acknowledgement by the communities and visibility to strive further.

By establishing a relational paradigm across the research cycle and among the research fields, Citizen Science benefits from “linking data thinking” in not only creating accessibility, findability and interoperability, but also in re-using citizen generated data*[39]. With open access to publications and research data, still underestimated open metadata, open citations, linking to open content, open infrastructures, open educational materials and so forth, Citizen Science and especially citizen generated data can innovate science (Bemme 2021). On the other hand, openness in Citizen Science also means that participation should be designed as inclusive as possible, that the data, methods and results should add value to the participants, and that participants and scientists should also be able to communicate on an equal footing. Last but not least, openness in Citizen Science should also make new collaborations possible. Institutions such as museums, libraries, science centres, local meeting places, city halls have long served as spaces where diverse expertise can gather, where diverse approaches and systematic logics can cohabit. Therefore, Citizen Science - whether top down or bottom up - should reach out and collaborate with those institutions and not only build on their communicative and participative tradition, but also broaden it.

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Author contributions

ESK, JB, and KM created the first draft of this publication. Furthermore, ESK and DJP elaborated ERGo!. JB elaborated Heimatforschung with open cultural data. KM contributed to the description of Heimatforschung, the discussion of results and conclusion. DJP contributed to language editing. All authors wrote the manuscript together and revised it according to the reviewer suggestions.

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