Reintegrating amateurs into Biology Research

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The Context: The exclusion and reintegration of amateurs from experimental Biology

Amateurism has long played an important role in scientific research. Until the late 19th century, individuals engaging in research were rarely paid and typically self-funded. In fact, the word 'scientist' was not coined until 1833 (Cahan 2003). Many of the most famous figures in biology have been amateurs, including Gregor Mendel, known as the 'father of genetics' for his pioneering inheritance experiments in pea plants, and Charles Darwin, whose 1859 *On the Origin of Species* laid the basis for our understanding of evolution.

As science became professionalized, however, the role of amateurs changed. This transition meant that much of the analytic work involved in scientific research became the purview of those that were paid to do research. Still, amateurs continued to play an important role in the scientific process, though principally as data collectors. In North America, among the first large-scale projects involving the participation of amateurs were the North American Bird Phenology Program started in 1881, focused on classifying the timing of bird migration, and the Christmas Bird Count started in 1900, aimed at quantifying winter bird abundance once a year. This 'crowd-sourced' model allowed for biological research to be conducted on scales never before possible.

Huge progress has been made in recent years, with amateur participation in science increasing rapidly (Bonney et al. 2016). This has been spurred by an increase in the availability of tools and resources, the realization of value to professional scientists, and encouragement from funding organizations (Silvertown 2009).

The growth of large-scale research that integrates amateurs into data collection or processing, has been offset by the increasing professionalisation of Biology over the last centuries, particularly laboratory Biology. In the 19th century distinctions between amateur and professional research Biology were beginning to form, albeit not necessarily along the same lines understood today of full-time paid research with years of university training versus hobbyist with little training (Barton 2003). The 20th century saw the growth of the concept of the research Biologist as a professional who works in a laboratory (Godin and Schauz 2016). In the 21st century community biology labs have begun to open, as independent spaces for amateur research (Kean 2011).

We review the case for amateur involvement in Biology research as well as the barriers and risks. The models of amateur naturalist, Citizen Science and community labs are reviewed before looking towards the future with suggestions for amateur Biology research for the 21st century.

The Need: Science needs amateurs

Professional Biology research is too homogenous and exclusive

Although professional Biology research is more accessible than ever, significant barriers to entry remain. Traditional scientific training is a time and resource intensive process and there is little support for innovation around accessibility, especially for those who engage in non-traditional educational paths. Unfortunately, this lack of availability and entry point diversification disproportionately affects individuals from underrepresented and socio-economically disadvantaged backgrounds, resulting in an exclusive and homogenous professional research community. The homogeneity and exclusivity of professional research Biology further isolates the general public which is becoming poorer and more diverse each year. Enfranchising amateurs can help address current barriers of entry to scientific practice and education, diversifying the research community, and could support democratic scientific discourse in our society at large.

Expanding informal access points for the public to engage in science practice, education, or exploration, can lead to more engagement in creative expression using science as a medium, an increase in the pursuit of careers in science, and improved bilateral communication between academia and the public. Platforms for community engagement outside of academic institutions can broaden multi-disciplinary engagement in science, thus naturally strengthening communication. Creating a well-informed public with the confidence to discuss scientific and technological topics will in turn will help place science and technology issues higher up the social and political agenda. Likewise, academia will benefit from better understanding how the public shapes its perception of scientific research.

Amateurs bring new ideas to Biology and Biotechnology

Traditional academic institutions experience constraints that slow down the implementation of changes to programming that will allow the expansion of accessibility. Informal outlets, for the practice of science are an opportunity to support engagement and can be a conduit for creativity to flourish. A higher level of inclusivity can diversify the range of scientific thought, translating into outcomes that better represent society and its needs. Furthermore, the diversification of individuals engaging in scientific practice can lead to more interdisciplinary contributions in the translation and development of new biotechnologies.

The Risks

Amplifying structural inequalities

By encouraging the efforts of self-assembled community labs we run the risk of amplifying the privilege of an already advantaged minority of the broader population. This is true because several barriers must be overcome before an individual can participate in the efforts of a community lab: money, time and education.

To equip a basic biology laboratory in an experimental field such as microbial evolution costs upward of $200,000. This number does not even take into account the cost of consumables and utilities needed to operate the lab. The communities that can spare this type of capital, whether it is private or public, are few and generally concentrated in large cities.

A potential solution to overcome this barrier may be to make community biology labs a part of the local library system, much like maker spaces, computer labs, and tool lending libraries. These other facets of local libraries make them a community hub and provide access to different types of knowledge, access that can be especially life-changing in low income communities.

However, even if community labs were distributed fairly, equitable participation in this type of endeavour requires not only people with the vision and desire to be a part of science but also the time and energy available to devote to it. Middle to low income households are headed by adults that work at least one full time job outside of the home and often a second full-time job inside the home as caregivers. Therefore, the individuals that have the luxury of time to spare will be much more likely to participate in the efforts of a community lab, and hence benefit from it, are individuals from higher socioeconomic strata.

Lastly, participation in community lab efforts will be much more likely by individuals who have a skill to contribute. In the context of a Biology lab, these types of skills are acquired through high quality education, either at the secondary or post-secondary level. The disparity in access to quality education in the United states is well-documented; schools in low-income high racial diversity communities are consistently underfunded and underperforming. Therefore, individuals from such communities, although they would stand to benefit the most from the experience of working in a community Biology lab, have a much higher education barrier to overcome before they can do so.

Biosafety risks and biosecurity threats

Biological research laboratories have strict guidelines that need to be followed in order to maintain the safety of their workers and their community. Biosafety training, protocols and compliance are mandated by funding agencies and by federal law. Even at institutions with established biosafety protocols and institutional oversight, however, serious lapses can sometimes occur and may result in injury or even death. At community labs, there is currently no agreed model for setting biosafety protocols. The need for oversight has been delegated to a very small branch of the FBI (Wolinsky 2016). Without doubt the size of this oversight will need to be expanded as the role of community labs expands as well. Whether this oversight should and will come from non-governmental organizations coming from the grass-roots of amateur Biology research, or from governmental organizations with substantial punitive powers remains to be seen.

Stifling the creativity of amateur inquiry

A third category of potential risks of reintegrating amateur scientists into the Biology scientific community is the risk of stifling the very source of the unique contribution amateurs can make to science. Amateurs can bring to scientific questions valuable outside perspectives, conceptual or methodological. These perspectives might be thwarted if we entrain them into the formal scientific community, with its biases and rigid procedures.

The Models

Naturalist groups and Citizen Science

Amateur participation in science takes many forms. Bonney et al. (Bonney et al. 2009) first set forth three principal categories that these efforts fall into. The first is 'contributory participation'. These might be considered efforts where participants are contributing data to research, whether those data were collected for the purpose of the purpose of that research (e.g., as part of a larger, centrally organized project) or not (e.g., as part of an observational log). For many hundreds of years, individuals have recorded observations of the natural world. Work over the last several decades has highlighted the particular utility of historical observations made on the timing of seasonal events (known as phenology). Records of the timing of the grape harvest (Chuine et al. 2004) and blooming of flowering plants (A. J. Miller-Rushing and Primack 2008; Primack, Higuchi, and Miller-Rushing 2009) have allowed modern-day researchers to better understand how ecosystems have changed in the recent past. Other efforts have taken a more direct, organized approach to sourcing data. As early as the 17th century , individuals were recruited to collect specimens to contribute to natural history collections (A. Miller-Rushing, Primack, and Bonney 2012). Modern-day data collection efforts, such as eBird and iNaturalist, may now aggregate millions of user observations a year on a global scale, facilitating research on scales never before possible. Still other efforts seek the contribution of participants from the comfort of their homes, asking users to find penguins in images taken from time lapse cameras (PenguinWatch.org) or reorient molecules on their computer screens to better understand protein structure (fold.it). These efforts are what are commonly referred to as Citizen Science or Community Science efforts in recent years, though the terminology varies.

However, participation might move beyond data collection, with a larger role from participants. 'Collaborative participation' involves amateur participants playing a key role in the development of methods and analysis of data. Projects such as the Sala Harvest Sustainability Study, aimed to study the effect of different management efforts on salal (*Gaultheria shallon*), and involved workers that worked in the salal harvest industry (Bonney et al. 2009).

Other efforts may have amateur participants involved in the majority of scientific process, which may be in concert with, or entirely independent of, professional scientists, referred to as 'co-created participation'. For instance, for many years amateur naturalists have played an important role in taxonomic descriptions. These efforts have been such a substantial part of the field that there is now concern that a decline in amateur taxonomists are leading to deficiencies in the field (Hopkins and Freckleton 2002). Other efforts might bring together members of a community around a common cause, such as Reclam the Bay. With the assistance of project scientists, volunteers design and direct hypothesis driven research efforts on ecological restoration, with the goal of restoring shellfish to Barnegat Bay, New Jersey (Bonney et al. 2009).

Community labs

In 2010 a new model for amateur Biology research was put to the test with the opening of physical locations for GenSpace, in New York City, and BioCurious in San Jose. These are what we refer to in this review as community labs, physical spaces equipped with instruments and supplies sufficient to carry out laboratory biology research or biotechnology research and development. Since 2010 other community laboratories have opened across the US including BosLab in Boston, HiveBio and SoundBio in Seattle, Denver Biolab in Denver and Counter Culture Labs in Oakland. Of these some spaces have already closed, while a number of communities are currently looking to secure and manage their own space in the near future, such as ChiTownBio in Chicago and Xinampa in the agricultural technology hub, Salinas, CA.

The vision and purpose of these community spaces is often compared to the garage computing movement of the 1970s (Kean 2011) or the Maker movement, rarely to the perhaps more obvious comparison Citizen Science. This may well reflect the spirit of independence reflected in the diverse management, systems and operations of each community lab, all of which are determined at the local level by the founders and volunteers of the community labs, largely free from the influence of Universities, large biotechnology companies or government funding agencies. Some community labs, such as Biocurious, focus on biotechnology start-up incubation, but also host community initiated and managed research projects as well as workshops and corporate events. Others eschew the incubator-space model and focus instead on community projects and educational programming. In many cases, use of the equipment of the lab and participation in any research projects requires the payment of a membership fee.

Examples of community projects carried out at community labs include The Open Insulin Project (https://openinsulin.org/) and Real Vegan Cheese (https://realvegancheese.org/). In contrast to Citizen Science projects these community projects were designed by amateurs and amateurs are involved at all stages, not restricted to data collection and data processing (Bonney et al. 2016). In addition the project goals include technology development, and hands-on exploration of a method or organism without any explicit research goals. Thus both the goals and the role of amateurs in community projects carried out at community labs is quite different from most Citizen Science projects.

Compared to Citizen Science the field of community labs is little developed. There are several national conferences held around the world for Citizen Science (Bonney et al. 2016), hundreds of registered projects, millions of participants, and millions to billions of dollars of investment (Theobald et al. 2015). A community resource (https://sphere.diybio.org/) lists 19 community labs in the USA and 56 worldwide. No information is available on total users of community labs and dollars of investments, nor is there any standard accepted definition of a community lab, and very limited academic literature on the subject. This deficit makes any discussion of community labs highly conjectural, and highlights an area where further academic attention should be paid, for the reasons outlined in this review.

The Barriers:

Training

Adequate training is essential for amateur participation in even the simplest Citizen Science projects involving a data collection or data processing tasks. For some cases this training can take the form of a written document, video or other material worked through by the participant in their own time. Such an approach is unlikely to be adequate for more complex data collection and processing tasks, or for amateurs to be able to successfully design and manage research projects as well as merely participate under the guidance of a professional. How then should training be delivered? Several community labs offer workshops or multi-session courses providing training in a range of laboratory skills or data analysis methods. In addition the MOOC format may be appropriate for training in aspects of experimental design and analysis, or to impart the topic-based background knowledge necessary to form insights that are the base of a new scientific question or technology. However, professional scientists, whether in academia or industry rely heavily on one-on-one or small group mentoring over extended time periods to reach a high level of proficiency. Currently, mentoring, where provided, is provided by professional scientists or people with an advanced science degree. Professional-to-amateur mentoring at scale requires money to compensate the professional for their time, and if the money is paid as a fee by the amateur this introduces an access barrier, so ideally funds for compensating mentors would come through other means, such as community-embedded mentoring as part of professional development paid for by employers. Efficient use of mentor time, such as through video-call meetings, or small group mentoring would reduce the costs involved.

Access to literature

A particular barrier to amateur participation in Biology research is access to peer-reviewed academic literature. Journal articles and conference proceedings are for many fields of Biology the primary format for disclosure and description of research findings. Access to this body of literature is important both to build domain-specific knowledge and gain an understanding of current understanding and approaches to a particular topic of field. One barrier to access is financial, with fees charged to access literature if a user cannot access via an institutional subscription. A 2017 analysis found that 28 million downloads had been made from illegal journal article distribution platform SciHub (Greshake 2017), illustrating the level of interest in avoiding journal paywalls. Fortunately, an increasing proportion of Biology articles and journals are open access, free at the point of use (Tennant et al. 2016). However, another barrier is that the use of jargon in academic literature requires a certain amount of prior training in order for the contents to be comprehensible.

Colleague networks

Colleague networks provide professional scientists with opportunities for ongoing training and mentoring, sources of new ideas, critical feedback, and motivation. Amateur naturalists, even if working in isolation, have access to conferences and colleagues with whom they can communicate regularly. Community labs could provide a locus for the formation of effective colleague networks but this will not necessarily happen if users access the space at different times of the day and work individually or in small groups. The Community BioSummit (https://www.biosummit.org) has provided a meeting place for amateur Biology research enthusiasts from across the world for the last three years but is currently the only such venue.

Facilities, equipment and supplies

A smartphone or camera and computer are the only requirements of many Citizen Science projects, and although widely available these instruments are not universally accessible. The barriers are far higher for any laboratory research. Firstly, a space into which access can be controlled, is required for any work with biohazards or hazardous chemicals. Secondly, equipment must be obtained for example Thermocyclers, microscopes, incubators and freezers. And then many fields of research require access to costly consumables, such as Enzyme preparations, chemicals or DNA primers. There are a number of commercial providers of low-cost instruments designed with community labs in mind such as OpenTrons and OpenPCR, and academic or non-profit organizations designing low-cost solutions for reagents (https://biobricks.org/freegenes/, https://openbioeconomy.org/) and software (https://biobricks.org/bionet/).

Motivation

The success of Citizen Science projects and the increasing number of community labs opening over the last decade suggest that demand from amateurs to participate in Biology research matches or exceeds the availability of opportunities. However, in order for amateur participation in Biology research to not exacerbate structural inequalities, participation should be spread across social groups and currently this is not the case. Secondly, long-term motivation requires positive feedback. For professional scientists this feedback comes in many forms beyond merely financial compensation, examples include praise from colleagues, recognition through publication in peer-reviewed journals or selection to present at conferences or receipt of an award or fellowship. Constant positive feedback is a feature of the fold-it Citizen Science game that is important to maintaining user motivation.

The Opportunities: Visions for the future

After the formalization of science into academic institutions, examples of recognition given to amateur scientists for contributions are few and far between. For the most part, amateur scientists remain distant from opportunities and resources that formal scientists have access to, such as funding, training, mentorship, equipment, publication, and recognition, despite the level of expertise and ability of amateurs to conduct rigorous investigation. Independent from any necessity to impose formalization, providing support to community labs that facilitate its practice is crucial for the protection of independent thought and discovery. Amateur science is valuable to society due to its potential to engage, inspire, and enfranchise the public to be creative students and independent makers or entrepreneurs outside of the constraints and barriers to entry that characterize academia.

With support and investment provide safety and legitimacy without sacrificing the autonomy of the amateur research community. An opportunity exists for formal institutions to dialogue and collaborate with amateour scientists to decreasing intimidation around entry. More involvement means that points of entry and on-ramp procedures are explored and improved, thus resulting in better programming and potentially, a higher success rate of public retention and engagement. In addition, this can result in developing highly flexible training programs that engage people who have varying levels of expertise and training.

With increased funding and support, community labs have the potential to both innovate STEM-related learning experiences and secure sufficient levels of formalization that broaden, rather than constrict the possibilities of collaboration and engagement in more complex scientific inquiry. Due to their informal nature, community labs have the capacity to offer flexible programs that can onboard a wide range of members with diverse backgrounds. From K-12 programs, to biotechnology workshops, with the right resources, space, and equipment, informal spaces for amateur scientists have the necessary freedom to implement new approaches and changes to educational components, something that academic research limits due the incentive structures, bureaucratic limitations, and time constraints. This very freedom allows community labs to implement targeted levels of standardization that convert informal training into efficient and meaningful learning experiences for the public. Investment in these spaces will also support the implementation of biosafety and security standards with increased training and access to safety protocols, and increased vigilance. Despite the lack of large-scale oversight, amateur scientists can and should have access to appropriate safety and security training.

Community labs that serve as loci for a wide range of amateur researcher models such as private equipment use, start-up incubation, or community projects, can serve as a testing ground for novel approaches that have the potential to increase the robustness of inclusion, enfranchisement, and diversity in science. In addition to financial support, informal platforms for science integration require institutional allies that can guide, mentor, and incorporate the public in scientific discourse and practice. Although the ability of amateur scientists to design and conduct large-scale independent research projects is limited, the possibility of collaborating with amateurs should not be overlooked. In the past, citizen science based projects have proven to be successful avenues for discovery to flourish. Further approaches should be explored in order to strengthen collaboration from universities and granting agencies that would support amateur science and the spaces that cultivate this new approach to education and exploration.

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