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COMMENTARY

The power of the crowd: Prospects and pitfalls for citizen science in occupational health

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Introduction

Citizen science is defined as a voluntary collaboration among scientists and non-specialists to achieve scientific and societal goals. This emerging form of scientific inquiry has grown in popularity recently, particularly in the environmental sciences where crowdsourcing can be leveraged to overcome resource constraints associated with the collection of empirical data. Citizen science is a powerful tool that not only leverages human resources for scientific discovery but also presents an opportunity for outreach, education, and engagement of the public. Citizen science is new to the field of occupational health; however, there are natural alignments between these two disciplines that warrant investigation. This commentary explores the use of citizen science as a potentially innovative and economical approach to protect and promote a healthy workplace. We discuss the various types of citizen science, followed by a series of hypothetical applications that demonstrate opportunities for the practice of occupational health protection. We also discuss potential pitfalls and challenges that may limit the proliferation of citizen science in our field.

The field of occupational health is increasingly challenged by resource constraints. Core activities, like hazard evaluation and risk communication, are limited because many workplaces lack the personnel, technology, and budget to promote employee health and safety to the fullest extent possible. As controversial as this may seem, statements like “we measured every individual’s exposure in the workplace” are not often heard among those practiced in the art.

Budget limitations are particularly daunting. Although many organizations create line budgets for health and safety, very few would be regarded as comprehensive. Consider, for example, that in 2017 approximately 377,000 people were employed as welders, cutters, solderers, and brazers in the United States.[1] These workers represent less than 0.3% of the U.S. workforce. Yet, even using conservative estimates, the cost (i.e., equipment, labor, and analytic fees) to monitor each worker’s exposure to a single metal contaminant in the air (e.g., chromium, nickel, or manganese), just once per year, would exceed $50M.

Although resource constraints make the job of occupational health protection challenging, they also help drive innovation. Similarly exposed groups,[2] job-exposure matrices,[3] Bayesian inference,[4] and hazard banding[5] are examples of innovative, economical approaches to workplace exposure assessment and control. This commentary explores another potentially innovative, economical approach to protect and promote a healthy workplace—citizen science. Our discussion of the citizen-science approach is similar in idea to other worker-led approaches, including self-exposure assessment and participatory ergonomics, that have explored how to implement industry-level changes by incorporating the involvement of industry organizations.[6] Studies in these areas suggest that workers can effectively conduct their own exposure assessment[7,8] and thus advocate for workers’ involvement in the full process from gathering data to analyzing it and helping to solve identified problems from this data.[9]

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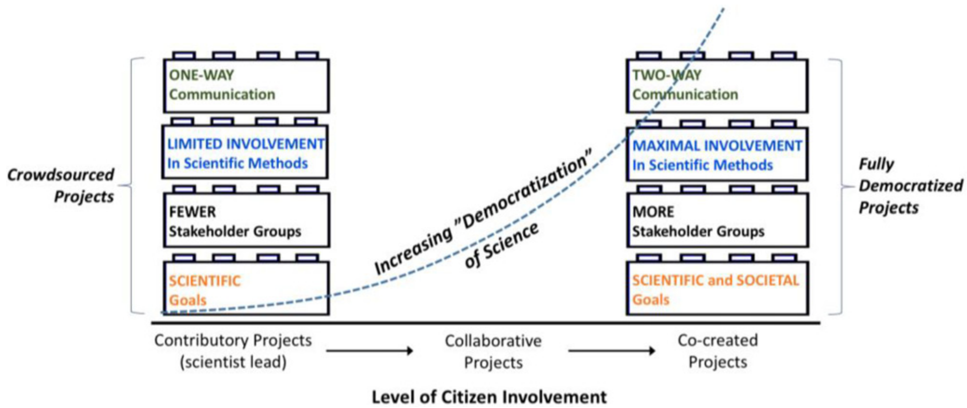

Figure 1. The spectrum of citizen involvement/management of citizen-science projects. The components of a citizen-science project (shown in Fig. 1) are shown here as "building blocks" with varying goals, groups, methods, and communication styles. Contributory projects rely more on simple crowdsourcing for data collection; co-created projects are more "democratized" whereby citizens and scientists share responsibility for the design and execution of the work.

Description of citizen science

Citizen science is defined as a voluntary collaboration among scientists and non-specialists to achieve scientific and societal goals. Citizen-science projects collect and process data, often at large geographic and temporal scales, to systematically investigate observations, solve problems, and generate new scientific knowledge using the scientific method. In occupational health, the "scientist" role may be played by an industrial hygienist, while the "citizens" or non-specialists may represent a population of workers, a worker advocacy group, or a combination of the two.

Citizen science falls within the Open Science paradigm, which embraces collaboration, transparency, and accessibility in scientific endeavors.[10,11] In practice, the scientist relinquishes a degree of control over his or her project (to the citizens) in exchange for resources that help move the project forward. A typical citizen-science project consists of four key components: goals, stakeholders, methodologies, and communication.

Goals

Citizen-science projects typically seek to achieve scientific and/or societal goals.[12,13] Societal goals include such activities as: influencing policy or aiding communities of interest; achieving a greater degree of knowledge, understanding, and scientific awareness among members of the public; and encouraging the adoption of healthy attitudes and behaviors. In occupational health, these types of projects can produce gains in knowledge about workplace safety processes, increase awareness of safety interventions, provide deeper meaning to workers' occupations and positions, achieve policy change, and improve management/employee relationships. On the other end of the spectrum, projects dedicated to achieving scientific goals are generally designed by professional scientists who ask for help in collecting information or making decisions and for which non-specialist groups primarily contribute data (vs. a higher level of involvement).[14,15] Often, the goal of these projects is to collect or analyze large quantities of data (e.g., tracking bird and butterfly populations, assessing water quality, translating Greek transcripts, or monitoring beach litter) in order to better manage resources, educate non-specialists, or develop scientific knowledge.[16–18] This limited involvement by citizens is often referred to as crowdsourcing, a technique designed to accumulate data into a managed framework by "taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an 'open call.'"[19] As it applies to citizen-science projects, crowdsourcing can be seen as scientific research, whereby non-specialist groups participate "often without fully understanding the concepts or implications motivating a research project."[20] However, unlike crowdsourcing alone, citizen science entails a strong research application of the scientific method for developing, collecting, accumulating, analyzing, and sharing scientific data collected by citizens. As such, some citizen-science projects make use of crowdsourcing as a means to generate and share data for analysis. This can be attractive to scientists whose projects are resource limited. Imagine what you might accomplish if you could muster 1,000 volunteers to act on your behalf over a day or a week?

Stakeholders

Citizen science is collaborative and can involve a wide variety of stakeholders. Examples of typical citizen-science stakeholders (with analogies to occupational health) include: citizen scientists or volunteers (workers), professional, or hired research scientists (industrial hygienists, researchers, or consultants), societal groups (unions or worker advocacy groups), and policymakers (management, public health officials, or regulators).

Projects with purely scientific goals may be more likely to incorporate fewer stakeholder groups since such projects are often designed to amass and/or analyze large quantities of data.[14,16] In contrast, projects with educational/societal goals may use more stakeholder groups among collective organizations, such as government agencies, industry, academia, journalists, community groups, and funders, to address their societal concerns and priorities.[3,14]

Figure 1 illustrates conceptually how participant involvement varies across the components of a citizen-science project. Moving from left to right across the chart implies an increased level of involvement and decision making by participating citizens. When a citizen-science project is more *democratized*, it encompasses a greater level of citizen control, whereby professional scientists and non-specialists share control of a scientific project in order to facilitate learning, participation, and collaboration among all stakeholder groups.[21] (The authors note that while the term *democratization* is widely used in the citizen-science literature, the term is not without its limits. Even if the goals, methodologies, communication, and stakeholder representation meet our suggested criteria of fully democratized projects in Figure 1, many citizen-science projects still attract only participants who tend to hold certain characteristics [e.g., from developed, Anglophone countries, well-educated, and male].)

In general, the more a citizen-science project seeks to increase public involvement in and understanding of the scientific process, the more it must include a wider, more diverse range of non-specialists from conception to culmination.[21] Thus, the goal of the project is related to the number of stakeholders. Generally, as the project moves toward more societal goals, the more stakeholders are involved, although this may vary based on the specific project.

Methodologies

Citizen scientists may participate in any or all aspects of the scientific process (i.e., observation, experimentation, hypothesis formulation, and hypothesis testing). In practice, however, the methodologies adopted by a citizen-science project tend to reflect the nature of its stakeholders' involvement,[22] which range from:

1. *Minimal (or contributory)*—projects are designed by scientists who need help collecting information; participants primarily contribute data;[14] to
2. *Collaborative*—projects are designed by scientists and often governed by a board or group representing as many stakeholder groups as possible[15] or participants contribute data but also help to refine project design, analyze data, or disseminate findings; [14] to
3. *Maximal (or co-created)*—projects are designed by scientists *and* participants who are actively involved in most or all steps of the scientific process, such as establishing the problem definition, developing research questions/hypotheses, designing research protocols, collecting data, interpreting data, and disseminating results.[14,15]

Projects with purely scientific goals often adopt methodologies that require minimal stakeholder involvement in the scientific method, such as those that do not need collaboration or interaction to attain their goals.[23] These contributory projects typically involve stakeholders in data collection and processing. Data collection projects use participants to observe, monitor, or track information at larger temporal and geographic scales than are otherwise possible.[24] Data processing projects leverage the cognitive abilities of volunteers to categorize, transcribe, code, or interpret data.[14,24]

Conversely, projects with educational/societal goals typically require collaboration among scientists and stakeholders to generate data. These collaborative and co-created projects employ methodologies that foster involvement of more stakeholders in the scientific method. Such projects also provide multiple ways to participate at various levels of commitment (as a team leader, moderator, etc.),[21] which increases sustained participation. For citizen science in occupational health, there may be advantages (and disadvantages) to projects that are solely contributory or wholly collaborative in nature. For example, contributory approaches tend to give more control of the project to the scientist while collaborative projects may have greater potential for sustained participation,[25] better understanding of "on the ground" conditions, and a higher chance to improve worker-management relationships through shared knowledge and governance.[26]

Communication

The integrating component of any citizen-science project is communication. The communication style that scientists and stakeholders use to meet project goals varies from one-way to two-way communication. One-way communication is a top-down approach to disseminating information and instructions, typically *from* scientists *to* citizens in the context of citizen science. Such one-way communication is common among projects that simply seek to amass or process data; these projects often require minimal stakeholder involvement and/or feedback in the scientific process, which encourage small-scale contributions from participants.

Two-way communication between scientists and participants lends itself to citizen-science projects with more societal goals (e.g., education, outreach, and implementation) or projects with higher levels of involvement from non-specialists; these projects seek maximal stakeholder involvement throughout all stages. Participant feedback is more involved in two-way communication and, as stated above, can include: establishing the problem definition; developing research questions and hypotheses; designing research protocols; collecting, communicating, and analyzing data; or disseminating and modeling results.[14,15,27] Additionally, these projects often include contributions such as suggesting improvements, developing help tools and resources, discussing ideas, creating artwork, or developing outreach activities.[28] Most citizen-science projects involve at least some two-way communication. For example, data collection projects like Planet Hunters (www.planethunters.org) or Foldit (www.fold.it) contain active and successful forums that provide scientists leading the projects with constructive feedback.

Citizen science opportunities in occupational health

In the following hypothetical case studies, where we include hypothetical data to increase the realism of the cases, we use the components of citizen science (i.e., goals, stakeholders, methodologies, and communication) to present possible applications of citizen science to the field of occupational health.

Imagined case study 1: Peer crowdsourcing for hazard anticipation

- *Goal: Fill knowledge gaps*
- *Stakeholders: Industrial hygienist and peer network*
- *Methodologies: Crowdsourcing*
- *Communication: Two-way, initiated by industrial hygienist*

Management at an injection-molded plastics company has decided to expand into additive manufacturing for several of its flagship products. Neither management nor the industrial hygienist has much familiarity with the potential hazards posed by rapid-prototyping machines. Similarly, the scientific literature on these devices is scant.

The industrial hygienist decides to employ crowdsourcing, that is, a modern way to network among experts and gather their opinions on this topic. Fortunately, there is a strong network of occupational health professionals in this region who keep in touch using social media. To leverage this network, he creates an essay contest that challenges entrants to describe the hazards of production-level additive manufacturing machines in 150 words or less. Entries are submitted to the group's Facebook page, and members are asked to vote on the winning entry (who receives a $250 gift card). With more than 50 entries submitted, the industrial hygienist has leveraged hundreds of hours of diverse expertise at a fraction of the market cost. From these responses, the industrial hygienist begins the process to update the company's health and safety plan in anticipation of the incipient production line.

Imagined case study 2: Worker crowdsourcing for hazard recognition

- *Goal: Hazard prioritization and validation*
- *Stakeholders: Industrial hygienist, workers, consultant group*
- *Methodologies: Crowdsourcing*
- *Communication: One-way, initiated by industrial hygienist*

A large machining and assembly plant recently hired a consulting firm to develop a prioritized list of physical hazards on the factory floor. With the firm's final report in hand, the industrial hygienist would like to review the list for accuracy and completeness. However, there are more than 100 categories of potential hazards (falls, slips, lockout, electrical, etc.), each of varying severity and probability of occurrence, that apply to nearly 100 different equipment areas; this list describes more than 10,000 individual hazards across the 100,000 m^2 plant.

Therefore, the industrial hygienist decides to employ a citizen-science approach to validate the report. She designs a survey for workers around this statement: rank the 10 most significant hazards at your workstation/work area and categorize each with a relative rank of "severity" and "probability of occurrence" using a Likert scale. One hundred employees across ten plant areas are randomly selected and asked to participate. The industrial hygienist also decides to conduct a walkthrough of five of these areas for the sake of independent validation. Results from the survey are then used to answer the following safety-relevant questions.

1. How well did the hazard rankings provided by the consultant match with the rankings developed from the employee data? Did they match well in some areas and poorly in others?
2. How well do employees recognize the hazards that surround them in the workplace?
3. Should some hazards be prioritized for education and training given the survey's responses?

In this example, the industrial hygienist melded a small dataset of known quality (her own walkthrough analysis) with two larger datasets: one developed by outside experts and another developed through a citizen-science approach. The sum of these datasets is much greater than the parts since they complement each other. By comparing each dataset, the industrial hygienist can evaluate not only the extent, probability, and severity of potential workplace hazards but also employee recognition and understanding of those hazards. Together, these datasets may provide a more precise direction for resource expenditures on hazard control and workplace safety training.

Imagined case study 3: Worker/workplace partnership for hazard evaluation

- *Goal: Identify potential noise hazards in a production line*
- *Stakeholders: Workers, management, and health/safety committee*
- *Methodologies: Co-created project; collaborative data collection*
- *Communication: Two-way, initiated by the workers*

Employees at XYZ Manufacturing become alarmed after learning that one of their competitors was recently cited by the Occupational Safety and Health Administration (OSHA) for exposure limit violations related to employee complaints of hearing loss. Products at XYZ are created using a similar manufacturing process, and the company's employees suspect that their noise suppression systems are also the same as the cited company's. Several employees raise concerns with the Health and Safety Committee and, together, the company and its employees co-create a citizen-science experiment. More than 300 employees work near the production line (which spans 5 areas and 7 acres); the committee is at a loss as to how to survey personal exposures quickly and cost effectively since its exposure consulting group is quoting a $100 per worker per day cost for noise exposure monitoring. Several concerned workers point out to the committee that a free sound-level meter application is available online for download to a smartphone.[29] Although the app is not approved for compliance-based monitoring, early research has shown that its results can be accurate within 1–2 dB.[30,31] The committee, in collaboration with the concerned workers, recruits 100 production-line employees to download the app to their phones and monitor their own exposures across several work shifts. Training for app use and monitoring is done through a YouTube video tutorial that is posted to the company's intranet. In parallel, the committee recommends that a subset of volunteers (n = 20) is randomly selected to undergo traditional noise dosimetry to provide some ground-truthing (and validation) of the app method. The careful conduct of two-way communication is necessary to disseminate these results and to ensure that data interpretation is correct and consistent across stakeholders.

Results of this citizen-science approach reveal several actionable outcomes. The accuracy and precision of the smartphone sensor (when compared to the reference dosimeters) varied from about 1–3 dB. However, the reference measurements clearly demonstrated a logarithmic variation in personal noise exposure (an inter-quartile range of 25 dB was observed among different workers). Given this wide heterogeneity in noise exposure, data from the smartphone sensor were used to create similarly exposed groups and hazard maps that helped to identify high-risk areas/groups speedily and economically. Furthermore, employee buy-in to the study allowed for transparency and increased organizational trust.

Pitfalls and barriers

These imagined case studies highlight several positive outcomes: more cost-effective exposure assessment, more efficient hazard mitigation, and a more educated and engaged workforce. Citizen science can leverage human capital in ways that could dramatically augment the efforts of a single occupational health professional. The potential for citizen science to increase stakeholder engagement is also compelling as our field has long sought strategies that help create a shared "ownership" of health and safety through employee-employer partnerships. Despite these prospects, many barriers exist that may prevent citizen science from producing impact in occupational health and safety settings.

Liabilities

Organizational cultural barriers may present challenges to citizen science in the workplace, especially when it comes to approval by management. Organizational fear of non-compliance with exposure limits may be a significant barrier to large-scale exposure assessment (i.e., the more samples collected, the greater the probability of an overexposure). There may be additional legal risks associated with a situation where crowdsourced samples are collected and shared with a facility and no action is subsequently taken.

However, one can also argue that citizen-science approaches are already well established in the workplace. Almost all workplaces host annual retreats, periodic training exercises, or other form of "all hands" meetings. The concept of citizen science for occupational health is analogous: an inward-facing, concerted effort by all company stakeholders to promote health and productivity. Individual industries can look to existing industry groups that take ownership and promote participatory approaches to help ensure long-term adoption of a citizen-science approach.[6] Unions and industrial hygienists are just such groups; they care about worker health and safety as well as industry survival.

Data quality

In addition to liabilities, issues of data quality often arise from citizen-led projects.[24] *How can we trust these data if they are not collected by professionals?* We need to examine this question closely as we explore the cost/benefit of large datasets that may carry greater imprecision/bias vs. current norms. Those who wish to measure compliance with a permissible exposure limit will probably not espouse a citizen-science approach due to perceived skepticism about data quality, sample integrity, and chain of custody assurance. Existing studies, however, speak to the technical capability workers have in accurately assessing their own exposures.[7,8] Further, strategies are available for improving data quality: continuous refinement of protocols; ongoing volunteer training; use of standardized and calibrated devices; verification of targeted data by experts; data replication and repeated measures; and statistical weighting of volunteers' skill level.[32] Data management is a process that must occur throughout the lifecycle of any citizen-science project and thus the credibility-building strategies listed above should be implemented within each of the three stages of the scientific process: planning (early actions), data collection (in the field), and data interpretation and analysis (in the office).[33,34] Further, as citizen-science projects tend to favor larger datasets, there will be need for industrial hygienists to refine and develop their data science skills.

Technology

Exposure assessment technology itself, for example, is still very expensive and complicated. Capturing a personal breathing zone sample requires the use of specialized (and costly) equipment that is prone to failure (or bias) if not properly deployed. And even if the costs of exposure measurement can be reduced, the costs of laboratory sample analyses are still high (especially if sample sizes were to increase by 1–2 orders of magnitude). These technological barriers suggest a need for further research and innovation in the field of exposure science.

Job security

Technological hurdles aside, citizen science may also be perceived as a threat to the industrial hygiene field. *If technology can be developed that does not require a professional to deploy, do we still need the professional on hand?* This possibility is likely more of a threat to the current paradigm of workplace hazard identification than it is to the careers of occupational hygienists. Employees might also perceive citizen science as "budget" health and safety; however, we anticipate that the potential benefits of citizen science (which complement existing health and safety programs) would eventually offset these fears. Instead of replacing the industrial hygienist, citizen-science samples would provide valuably needed data to enable the practitioner to make better risk-management decisions.

Communication

Communication is central to the success of citizen science in occupational health. The practice of industrial hygiene has always required effective communication skills, but a citizen-science approach to occupational health will present new communication challenges to industrial hygienists. Misinterpretation of scientific data is common among those untrained in the art; with more individuals participating in scientific data collection, the probability that results will be misunderstood increases. Concepts like lognormal exposure variability, for example, can be challenging to explain. Finally, there may be unintended outcomes from increased worker participation in occupational health and safety: loss of private or confidential information (i.e., personal health data), negative social outcomes following unexpected findings (loss of trust in the organization, peer alienation, added workplace stress), and the potential for loss of productivity.

Conclusions

The concept of citizen science has always been implicit in the practice of occupational health. Since the birth of our field, industrial hygienists have collaborated with workers to create and maintain a healthy workplace. Citizen science can be a powerful tool not only because of its potential to leverage human resources for scientific discovery, but also because it presents an opportunity for outreach, education, and engagement with non-specialist groups. In an era where scientific consensus is increasingly challenged through public discourse, the need for scientists to educate and engage the public is greater than ever. Such issues are no less important to the field of occupational health. The tools of citizen science, adapted to the workplace, provide a new means to bring together the industrial hygienist and the worker with a shared goal of health and productivity. Benefits to the community include larger datasets (to support the recognition and control of hazards) and increased awareness and engagement among occupational health stakeholders.

Having raised several potential barriers to organizations adopting citizen-science approaches, we cannot say which barrier is most onerous without further work. However, we recommend that future work investigate whether the stated advantages of citizen science can produce tangible benefits to occupational health (and whether the pitfalls and barriers perceived here are real and surmountable).

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