Partnering Citizens and Academics to Engage in Deep Citizen Science

Abstract: Many citizen science projects involve employing large groups of citizens to collect data for projects that require expansive data collection that would not be feasible (or cost-effective) for the Ph.D. scientists to gather. Here, we provide an essay that describes a different type of citizen science, where the citizen is equally partnered with the scientist in carrying out and reporting the scientific results. We call this “deep citizen science” because it requires a deep and extensive engagement by the citizen. We think of the citizen as a full research member of the project, similar in many respects to how undergraduate students are equal partners in their thesis research. Indeed, there is a large number of intelligent and scientifically literate citizens who can participate at such a level or beyond. Many are retired from technical jobs involving engineering or medicine. Others are high school students, undergraduates, or recent graduates, hungry for engagement within the research enterprise. All are deeply committed to making a contribution to science where they are creating new knowledge alongside a Ph.D. research science mentor. We find that the popularity of on-line MOOC courses in technical areas provides a unique arena to recruit these talented citizen scientists. Bench scientists benefit from the exposure to novel perspectives from the citizens and by being able to complete more research faster. We describe in detail a number of projects that have been completed or are ongoing within this deep citizen science model.

Introduction

The pursuit of research in science takes on many forms, as does the work of the citizen scientist. Some research projects require significant labor or wide-ranging data collection---too much for a handful of Ph.D. researchers to manage---and these lead naturally to an ideal marriage with citizen scientists who wish to contribute to such work, especially if the data collection does not require significant training. What we want to discuss in this essay is a different model, one that involves citizen scientists who contribute on a par with Ph.D. scientists, working hand-in-hand on (nearly) all aspects of the project. Such a partnership is not for everyone, but there are many technically adept citizen scientists who are able to contribute in this fashion. When they can be mentored by the right Ph.D. scientist, then another ideal marriage can be made which will help advance science, educate the public, and improve attitudes toward supporting research.

Our path toward "deep citizen science" has two origins. First, at Georgetown University, we run a program (called Georgetown University Research Opportunities Program, or GUROP) to involve undergraduates in research early in their college careers. The student involvement need not lead directly to a jointly authored manuscript but is designed to involve them in the research process. As a result, faculty often look for small contributions students can make to advance their research program. Second, one of us (Freericks) launched a MOOC on edX.org called "Quantum Mechanics for Everyone" which is designed to teach high-level ideas of quantum mechanics without requiring a significant math background (Freericks, 2017, Freericks, et al., 2019). Interacting with students in the discussion forum showed how some students engaged with the material at a very high level and with much creativity. These students appeared to be capable of deep engagement with research.

Following completion of the course, alumni were sought to serve as alpha testers for a book on quantum mechanics that continued where the course left off. This group of citizen scientists were contributing to research just as undergraduate students do in Georgetown's GUROP. It was not much of a leap to then engage some of these students in deeper activities that could lead to research publications. The talent pool was deep and the participants willing.

We want to describe how five such partnerships were made and how two research projects were completed. We anticipate more similar stories to follow, and we believe this can serve as a new model for how to engage citizen scientists in deep research.

The idea for the first project germinated as chapters for the book were being written. One set of exchanges between citizen and academic led to an "aha moment" where a chapter being developed had to be reworked now with new understanding brought up because a citizen kept asking the questions of why and insisting that the writing clarify subtle points that had been glossed over. It was quickly recognized by the academic that the exchange was breaking new ground, and this suggested that the work be expanded and written up as a novel pedagogy to be used in introductory quantum mechanics classes. It turned out that the citizen scientist was a retired communications engineer who was technically savvy, but not formally trained in the research field. Nevertheless, with appropriate mentoring, a manuscript was recently completed and now is under its second round of review at the *American Journal of Physics* (Courtney, et al. 2019).

Could the work have been completed without this partnership? Probably. *But it was much better because of the partnership.* It is precisely these kinds of win-win situations that will enable more deep research partnerships between a citizen scientist and a Ph.D. scientist. In fact, three more research projects are already currently active with alumni from the MOOC, and one more has already completed and published (Weitzman and Freericks, 2018).

The second project involved more complex and advanced physics ideas---using operator methods without calculus to derive the spherical harmonic wave functions. Here, a retired professional poker player, who earned a Master's degree in Physics from Cal Tech, and had a hobby of working through MOOCs in physics and math, was recruited. It was easy to identify his technical skills from the discussion forums because he often served as a community TA on different MOOCs and he discussed his background and skills. This citizen scientist was able to participate at the level of a beginning graduate student and rapidly completed the required work for the project. The paper was published in the Fall of 2018.

Since these two initial projects, a strategy for recruitment became clear. First, the academic identifies talented students by participating in discussion forums of technical MOOC classes. The academic has taken scores of MOOCs to both learn new material and to also provide research on student misconceptions in learning quantum mechanics that will assist him with preparing a book entitled *Quantum Mechanics without Calculus*. It is amazingly easy to find talented students who are capable of guided research participation. Many are yearning for a connection with academic research and the academic community. They often are able to participate in research either as a full partner and co-author, or to provide assistance at a lower level, which is not sufficient to warrant co-authorship. They only have to be asked. Second, the academic determines the skills of the citizen scientist partner and designs a project that can utilize those skills successfully. Following best practices for undergraduate projects includes partnering the project with additional graduate student or postdoc mentors, meeting regularly either on-line or in person to discuss progress, and following through to completion. Unlike thesis projects, however, these projects usually have no end of term deadlines, which relieves much of the pressure associated with completing undergraduate research projects by the end of the academic year. In some cases, citizen scientists may need to acquire additional training or skills which can be provided as they would to any other starting researcher in an academic research group. If the citizen continues with the academic for additional projects, the investment in time will pay off handsomely. Third, because the academic is the Ph.D. scientist, it is likely he or she will need to select the journal to submit to, plan the scope of the paper, and write the first draft. The academic should lean on the citizen scientist partner for additional assistance as needed for figure preparation, literature searches, draft reviews, continuing suggestions, and other supporting activities.

Working along these lines, we initiated three more projects. One is a Penning-trap-based quantum simulation that involves an engineer from Greece who meets weekly via skype and is learning new material to start working on the project itself, which will involve running numerical codes developed by a graduate student in the academic's group. We hope to have the results of this work tested in an experiment by colleagues at the National Institute for Standards and Technology. The second is on novel quantum mechanics pedagogy and involves two local high school students and a community college professor and is currently being written up for publication. And the third is on a new quantum solution for the Hydrogen atom and involves an engineering undergraduate from China who is interested in switching fields and moving from engineering to physics. Clearly, there is ample opportunity to recruit and work with citizen scientists in his fashion. Done right, it is a win-win situation.

Is this just a fluke, a lucky break, or the model for a new way to engage the public? It is hard to tell at this stage, but based on the success of the Georgetown's GUROP program with undergraduates, it seems likely that more partnerships with citizens will be formed in the future. The challenge is how to identify the right citizen to partner with the right scientist for the right project. But, for sure, this type of endeavor entails a different methodology than the more labor-intensive data collection models of citizen engagement.

Details of the Five Projects

We found all of our citizen partners via discussions on the forums of MOOCs. For example, the first citizen scientist (and co-author of this article) wrote the following about a model for how a model of light developed in the course illustrates what happens to light moving through glass instead of air: "I prefer to think that the rotation rate of the arrow stays the same whether it is passing thru glass or air. This is because experiments have shown, I believe, that the rotation rate is determined by the color (frequency) of the light, and light maintains the same color whether it is passing thru glass or air. On the other hand, light takes longer to pass thru a given thickness of glass than it takes to pass thru the same thickness of air. So the photon will experience more rotation passing thru the glass than the air.

These two combine to make it easier for me to understand the phenomenon if I say that inserting the glass increases the "effective length" of the path.

In analogy, think of a jogger who always runs at 30 paces per minute. Suppose that when she is on the open road, her stride length is 3 meters per pace, and so she covers 90 meter in a minute. Put another way, it would take 30 paces for her to jog 90 meters. Now suppose she gets near an intersection that has a traffic light that is red. She keeps jogging at the same pace, but she shortens her stride length to 1/2 meter per stride so that she can keep exercising at the same level of exertion until she sees the light turn green. Her speed has fallen to 15 meters per minute, but she is still running at 30 paces per minute. Now it would take her 6 minutes to jog 90 meters. Put another way, it would take 180 paces for her to cover 90 meters. If you let one "pace" be one rotation of the arrow, let "paces per minute" be frequency (color) of light, let "open road" be air, and let "near an intersection" be glass, the analogy is complete, and it gives an easy to understand explanation of the effects of inserting the glass. The frequency (rotation rate) stays the same but it takes more rotations to get thru the thickness of glass compared with air."

This level of dialog clearly shows that the citizen has a firm grasp of complex ideas and is able to creatively construct new ways to apply their ideas. Indeed, this conclusion proved to be correct, as the citizen scientist was a key participant in a research project within six months of writing this dialog.

We are not aware of other means to identify such participants that allow the academic to screen citizen scientists for their research capabilities. Perhaps further essays can describe other techniques employed to identify appropriate partners as the popularity of deep citizen science increases.

Of course, one does not simply leap from a few conversations in a discussion forum to writing a paper. One needs to find ways to test the waters and verify whether a citizen scientist is capable of participating in deep citizen science. Here is where having lower-level activities for the citizen scientist to participate in provides ample opportunities to verify their skills. For example, we used course alumni volunteers to carefully read through chapters of a book being developed by the academic. Feedback was sought about the level of the material, how well complex ideas were being conveyed, and about improvements to the text. Alumni excelling at these tasks often illustrated that they also have the ability to contribute to research. A number of citizen scientists were found through this process.

Another one was identified after he described how he had gotten a Master's degree many years before and how he was interested in doing research, but never had the opportunity to complete a project. We find that simply listening to discussions present many opportunities for identifying qualified citizen scientists. Sometimes it is possible to even meet these remote citizen scientists in person, as we show in Figure 1.

Figure 1. The academic mentor met with two deep citizen science participants during the 2018 March Meeting of the American Physical Society in Los Angeles, California. Left panel, J. Freericks (left) and W. Courtney (right). Right panel, J. Freericks (left) and M. Weitzman (right).

Key to success is finding the right problem for the right partner. We engaged in dialogs with citizen scientists to determine what they knew, but more importantly, what they did not know. By matching their skills with the needs for a given research project, we are able to successfully initiate and complete many deep citizen science projects.

One other item to pay attention to is that citizen scientists have lives of their own. They do not need to complete the project they are working on. Sometimes life intervenes and makes it difficult to sustain the effort needed to complete a research project. Here, one needs to engage in continual dialog to determine whether progress will wax or wane. Partnering with other members of the research group helps guarantee that a project will be completed. At that stage, one needs to determine whether the citizen scientist effort rose to the level of co-authorship. We recommend erring on the side of inclusion if there is any doubt.

Oftentimes, one may worry that mistakes by a citizen scientist might ruin the academic's scientific reputation. We view this dilemma as the same dilemma one might have when mentoring an undergraduate thesis project. As with any work one is responsible for, one needs to ensure there is quality control that guarantees the work is correct. We know how to do this with junior partners in our research groups. The situation here is no different.

Impact of Engagement in Deep Citizen Science

To paraphrase Neil deGrasse Tyson, we need a scientifically literate citizenry, for they are the ones who decide how science is funded. While it is clear that the citizen science partner will emerge from a deep citizen science project with a renewed understanding of the complexity of research and how science is truly "done," this effect is likely to stretch much farther. How many family members, friends, and colleagues will also learn about this experience? How many will insist on robust science budgets and the need for scientific research? We feel the impact will only be positive here.

As with all win-win situations, there are plenty of benefits for the academic. First, these deep citizen science projects can expand the research enterprise without requiring additional research funding. Second, for agencies like the National Science Foundation, they can provide robust outreach and education projects required for funded grants. Third, citizen scientists bring fresh new perspectives to a research project, because they are not already experts in the field. These new ideas more often than not provide important insights into the research project and can improve the work.

Of course, deep citizen science may not be for everyone. Clearly, theoretical research is easier to engage in remotely than is experimental work, although it is hard to find experimental work that is devoid of the need for some theoretical work. These projects often require data analysis, visualization, and interpretation, and for these remote engagement is not a hardship.

Other Models for Deep Citizen Science

Although deep citizen science is still not common, there are other projects that have successfully tasked citizens at levels usually reserved for serious undergraduate students or beyond. Several examples of deeper-than-usual projects are described in a popular science article (Cohn, 2008). The lead example involved citizens situating, setting up, testing, and managing motion-sensitive cameras and their captured images to record animals in the forests near the Appalachian Trail. Volunteer citizen scientists take one day of training during which they are paired with staff to help determine the expected reliability of the data that will be gathered. Cohn briefly describes four other projects and gives some lessons learned from the projects on how to run a successful citizen science project requiring differing levels of sophistication and responsibility from the volunteers, and delivers quite favorable reviews on the accuracy of the data they collected.

In (Trumbull, et al., 2000), we obtain lessons learned anecdotally from a medium-size ornithological study (approximately 375 volunteers) to determine dietary preferences for different seeds among wild birds. The paper is based on unsolicited letters sent by the volunteers to the academic principals. Most interesting for the purposes of this paper, are the initiatives that the citizen scientists took to help the project succeed, the curiosity they expressed, and the reasoning they applied to come to their own tentative conclusions about what they observed. While gathering the data according to the protocol they were given, the volunteers applied pre-existing knowledge (many were experienced bird watchers) to formulate hypotheses about observed behavior and suggest further questions every bit as interesting as the those that were the *raison d'etre* for the original study. Some volunteers described changes they made to the protocol that enabled it to succeed without invalidating the data. In some cases where volunteer-initiated changes did invalidate the data, the reasons given by the volunteer would have been reasonable if he or she were conducting a solo experiment, but that would contaminate the aggregated data were they included. Even the errors suggest that there is a reservoir of talented and trainable citizens eager to participate fully in scientific progress.

A very exciting citizen science result is given in Straub, 2016, that describes an unexpected result of the Galaxy Zoo project. Galaxy Zoo was a crowdsourced project involving approximately 200,000 volunteers in the study of approximately 1,000,000 images containing galaxies. The goal was to have the volunteers classify images of galaxies as fitting one of three pre-defined types: spiral, elliptical, or other. A forum for the volunteers was set up so that they could discuss findings, ask and answer questions, etc. As with our deep citizen science projects, the forum was vital to the process and to the remarkable outcome. Within weeks of the start of the project, one volunteer made discoveries of two unusual types of objects. Professional astronomers attached to the project almost immediately ran with one of the discoveries and published refereed papers about it. But the other discovery, that of "Green Pea" galaxies, was left to the volunteers. The Green Pea thread in the forum attracted 105 of the volunteers, and of those, 13 volunteers wrote 80% of the postings. For approximately a year, this group remained fully self-coordinated and applied more and more devotion and sophistication to the analysis of these unusual objects. Some of them consulted outside experts regarding spectral data. Another wrote SQL queries to be launched against the Sloan Digital Sky Survey to search for further examples of the Green Pea galaxies, others searched for earlier research reports that might describe Green Peas. The group formulated a list of strict quantitative characteristics of these objects. They provided explanations of their characteristic spectrum. They, in other words, made an interesting astronomical discovery.

The efforts of this group stimulated the publishing of a learned paper in a refereed journal (Cardamone, et al., 2009). The paper had 17 authors, but those authors chose not to include among their number any of the Galaxy Zoo citizen scientists who first discovered the Green Pea galaxies, who searched for (and found) more examples, and who made the initial analysis that defined the Green Peas. However, the 13 citizen scientists were mentioned in the paper's acknowledgements.

Conclusions

It is clear that successful projects are born out of finding a research problem that can match the skills and talents of the citizen and the scientist. This can only be done if one can identify both participants and find a common ground for them to work together. Having scientists engage citizens in a way that allows them to identify scientific talent and having a means to provide training in skills where needed to be able to complete the project are also important. Keeping lines of communication open is critical as is finding problems that lend themselves to citizen scientist participation. After all, research involves creating new knowledge and this is quite different from a student-teacher relationship where one is conveying already created knowledge. We feel the time is ripe for us to find ways to make such partnerships successful. Successful deep citizen science may be challenging at first, but we feel the challenge is worth the effort!

Indeed, there are many highly talented citizens eager to be more involved in science. Some are retirees who worked in technical fields but now have the time to develop their passion for science. Some are amateurs who have always worked on science but lacked formal training and mentoring by professionals. Some are high school students wanting to have the opportunity to engage more deeply in subjects they excel in. Now is the time to ask, how can we make new partnerships that benefit all? How can we employ deep research engagement of citizens to advance science? Will you mentor the next citizen scientist to engage in a deep research project?

Acknowledgements

We would like to acknowledge the other citizen scientists with whom the academic has worked, including Apostolos Christou, Xinliang (Bruce) Lyu, Mark Weitzman and David Wolf.

Funding Information

JKF is supported by the National Science Foundation under grant number PHY-1620555. In addition, JKF is also supported by the McDevitt bequest at Georgetown University.

Competing interests

The author(s) has/have no competing interests to declare.

Authors' contributions

Both authors participated in all aspects of the manuscript from conception of the idea to drafting the article.

References

Cardamone, Carolin, Schawinski, Kevin, Sarzi, Marc, Bamford, Steven P., Bennert, Nicola, Urry, C. M., Lintott, Chris, Keel, C. M., Parejko, John, Nichol, Robert C., Thomas, Daniel, Andreescu, Dan, Murray, Phil, Raddick, M. Jordan, Slosar, Anže, Szalay, Alex and VandenBerg, Jan, 2009, "Galaxy Zoo Green Peas: discovery of a class of compact extremely star-forming galaxies," *Monthly Notices of the Royal Astronomical Society* **399**: p. 1191-1205. DOI: http://dx.doi.org/10.1111/j.1365-2966.2009.15383.x

Cohn, Jeffrey P. 2008, "Citizen Science: Can Volunteers Do Real Research?" *BioScience* **58**(3): p. 192-197. DOI: http://dx.doi.org/10.1641/B580303

Courtney, William F., Vieira, Lucas B., Julienne, Paul S. and Freericks, James K., 2019, *submitted to American Journal of Physics*.

Freericks, James K., 2017, "Quantum Mechanics for Everyone," edX MOOC. https://www.edx.org/course/quantum-mechanics-everyone-georgetownx-phyx-008-01x

Freericks, James K., Vieira, Lucas B. Cutler, Dylan, and Kruse, Anna, 2019, "Teaching Quantum Mechanics to over 22,000 nonscientists," *The Physics Teacher*, in press.

Straub, Miranda C. P., 2016, "Giving Citizen Scientists a Chance: A Study of Volunteer-led Scientific Discovery," *Citizen Science: Theory and Practice* **1**(1): p.5. DOI: http://dx.doi.org/10.5334/cstp.40

Trumbull, Deborah J., Bonney, Rick, Bascom, Derek and Cabral, Anna, 2000, "Thinking Scientifically during Participation in a Citizen-Science Project," *Science Education* **84**(2): 265-275. DOI: http://doi.org/10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.0.CO;2-5.

Weitzman, Mark and Freericks, James K., 2018 "Calculating spherical harmonics without derivatives," *Condensed Matter Physics,* **21**(3): 33002. DOI: http://dx.doi.org/10.5488/CMP.21.33002