



## Current Approaches in Implementing Citizen Science in the Classroom

Harsh R. Shah and Luis R. Martinez\*

*Department of Biomedical Sciences, NYIT College of Osteopathic Medicine, New York Institute of Technology, Old Westbury, NY 11568-8000*

**Citizen science involves a partnership between inexperienced volunteers and trained scientists engaging in research. In addition to its obvious benefit of accelerating data collection, citizen science has an unexplored role in the classroom, from K–12 schools to higher education. With recent studies showing a weakening in scientific competency of American students, incorporating citizen science initiatives in the curriculum provides a means to address deficiencies in a fragmented educational system. The integration of traditional and innovative pedagogical methods to reform our educational system is therefore imperative in order to provide practical experiences in scientific inquiry, critical thinking, and problem solving for school-age individuals. Citizen science can be used to emphasize the recognition and use of systematic approaches to solve problems affecting the community.**

### INTRODUCTION

The term “citizen science” describes public engagement in scientific research with collaboration from professional scientists. The citizens are volunteers who decide to pursue data gathering to assist with a large research study for the love of science and betterment of their community. Citizen science is a mutualistic symbiosis that benefits both the volunteers and the scientists. This interaction allows for public education and engagement in science and research to increase the awareness of problems that affect the community at large. Also, it provides a helping hand to the investigators to make their research efforts progress by collecting more data and meaningful observations than the scientists could alone. Combining citizen science and research involves much more than answering questions about theorized concepts. It emphasizes community education and development. One of the most beneficial aspects of citizen science is its ability to provide youth with practical and real-life opportunities to learn and implement the scientific method to solve problems facing their communities as a complement to theoretical education.

With technological and scientific advancements happening daily, the need for widespread public understanding

of science, particularly among youth in the classroom, has never been greater. Recently, the program for international student assessment (PISA), a survey that tracks the extent to which 15-year-olds have acquired knowledge and skills essential for participation in society, listed the United States in 20<sup>th</sup> place in science education, with 69% of high school graduates unprepared for college-level science (18). Surprisingly, the US, a country with many highly educated parents, ranked 6<sup>th</sup> in education spending per student, suggesting that neither financial nor educational backgrounds are responsible for the weaknesses evident in today’s students (18).

Therefore, curricular development and methodology involving more hands-on experience to enrich students’ scientific skills are urgently needed, as well as better training of school teachers in scientific inquiry and methodology. Citizen-science programs involving experts from higher-education institutions aiming to increase the participation of students and teachers in citizen science in the classroom are an alternative to traditional science education that may be beneficial for all parties involved. Although not all science fields can educate through a citizen-science modality identically or to the same extent, it is important that we implement the core element of citizen science (2)—real-life problem solving—into K–12 learning.

### FOSTERING SCIENTIFIC INQUIRY IN THE CLASSROOM

Scientific inquiry is defined as activities in which students develop knowledge and understanding of scientific ideas along with an understanding of how scientists look at the world (16). In the early 1960s, Joseph Schwab pioneered

\*Corresponding author. Mailing address: New York Institute of Technology, College of Osteopathic Medicine, Northern Boulevard, P.O. Box 8000, Riland Building, Room 027/028, Old Westbury, NY 11568-8000. Phone: 516-686-1271. E-mail: [lmarti13@nyit.edu](mailto:lmarti13@nyit.edu).

a shift in pedagogy, from lecture and text to a more active approach, by having students challenge scientific theories and learn to formulate their own conclusions (15). Several studies have looked at the best ways of promoting scientific inquiry and some of the barriers to science education reform. Science teachers identified logistics such as time, class size, and infrastructure, as well as students' motivation and skills, as the major constraints in implementing inquiry-based teaching (3).

Science education in the majority of K–12 public schools consists mainly of factual knowledge acquired through memorization and assessed primarily by multiple-choice or single-answer exams. This is in spite of the fact that the role of inquiry in science teaching and students' learning is widely known (5). Perhaps the best stages on which to promote scientific inquiry are the laboratory setting in schools and nature itself. However, laboratory exercises in the classroom limit students to following a list of procedures in pre-designed experiments and reaching singular, uniform conclusions without any room to think "outside of the box" (11). Although these exercises are important in order to introduce students to the foundations of the scientific method, the students are not truly learning about steps in scientific inquiry other than data collection. A more effective approach would be to create an environment in the classroom that fosters scientific reasoning or encourages students' participation in science fairs, where students can ask their own questions and learn the importance of formulating a hypothesis, analyzing data, and interpreting their own observations.

Teachers are encouraged to switch from presenting science information as facts with no scope for questions or doubts to an environment that facilitates and promotes students' critical thinking without predetermined boundaries. A simple activity that encourages students' reflective philosophy and active learning may involve the discussion of a scientific event in which the students are challenged to analyze the facts and provide possible implications for the future of the field of study. In this type of classroom activity, the teacher serves as a facilitator of the discussion. This facilitator role should avoid portraying science as constant and solid with no flexibility, as this approach limits the true understanding of the field of science, in which there are as many disagreements amongst experts as there are agreed-upon facts. A major limitation for implementation of scientific-based inquiry in the classroom as described is the teacher's lack of experience in empirical techniques. Such constraints limit the ability of classrooms to produce students capable of applying scientific knowledge and processes outside of the big picture or to contribute to the generation of new scientific knowledge clearly connected with or related to a community (9).

### **THE ROLE OF HIGHER EDUCATION IN CITIZEN SCIENCE IN THE CLASSROOM**

Most science teachers have never experienced authentic scientific inquiry in their education (8). Teachers who view

themselves as communicators, and not critics, of facts and knowledge could engage in inquiry-based education. In order to make students capable of applying scientific processes and reasoning in their communities, we must develop educators into conversationalists and not enforcers of science (9). In this regard, school instructors stipulate that inquiry-based teaching must be "full and open" in order to be substantial and totally student-driven, with no organization or structure from the teachers. Local school districts must therefore be proactive and create partnerships in which higher-education institutions sponsor science teachers' training. This will prepare the teachers to develop individual or collaborative research programs that ultimately benefit not only the students and the classroom, but also the community and the higher-education institutions involved.

Short professional development science research workshops can provide school science teachers with the tools they need to build on their current science programs, including a practical understanding of how to guide students through the research process. Participants are exposed to a hands-on, inquiry-based approach to the scientific process that teaches educators the skills of science and research, including how to incorporate them into their curriculum and engage their students in an effort to make learning exciting. Topics in these workshops may include, but are not limited to, 1) the research process for school science students, 2) how to find and correspond with research mentors at universities, 3) the makeup of a successful high school research program, 4) library and Internet research resources, and 5) how to prepare and mentor competitive students for a science fair. Throughout these types of workshops, educators can be exposed and have access to primary literature, such as scientific journals, and educational material that can be utilized to establish and conduct their own research. These workshops are an excellent arena to show teachers how to match their students with researchers from universities. Also, it is a great opportunity for networking with top-notch scientists, and students can be introduced to and request that those investigators serve as mentors. It is imperative that these workshops are taught by distinguished scholars who are engaged in active research and are familiar with student research projects.

The partnership between schools and universities to promote citizen science is a win-win situation that will benefit all the parties involved, including the community. Training teachers in scientific inquiry methodology can result in new frameworks that can be embedded into the school system to explicitly address the influence that norms and values have on science independent of scientific content. Teachers can change the culture of content-based teaching by widening their scope and reframing their programs to embrace the uncertainties and difficulties of generating scientific knowledge. Educators are the key to promoting scientific epistemology that will engage students in their classrooms in genuine scientific practices. In this regard, teachers will be responsible for advising students about the

evolving nature of science, which is subject to change, empirically based, and subjective, relying heavily on inference. Moreover, teachers can be the bridge between K–12 schools and higher education in identifying firsthand the deficiencies of today's students, who potentially will pursue their education in local colleges and universities. This close monitoring of pre-college students will provide these institutions with information that allows them to prepare and modify their curricula to address those problems identified by the teachers in order to improve the quality of their education and graduates. Furthermore, this level of communication allows colleges and universities to identify and attract the brightest students into their classroom.

The interaction with scientists will provide teachers and students with an opportunity to have access to information within the field of study, adding considerable structure and preparation to complete the proposed research. Previous studies have found that providing materials and tools to science students prior to an investigation strongly influences student planning, how an investigation is framed, and the timing of ideas shared among participants (13). The scientists and teachers can participate in open discussions about the nature of the science related to the existing curriculum. Most likely, the curriculum within the classroom will be influenced by the topics investigated by the proposed research. Research methods and results can be incorporated into lectures and discussions as concrete examples of more abstract concepts and theories discussed in the textbook, increasing student retention of the material. Citizens' involvement in the research will also serve to enhance curriculum, as teachers and students advance their own knowledge within the field.

Enhancements to the classroom curriculum should be further augmented by introducing the participants to the responsible conduct of research (RCR), since the integrity of science has recently been under attack due to the increasing number of research misconduct cases exposed by the media. Students and teachers participating in the projects must undergo RCR training, thereby increasing their attentiveness to and understanding of the ethics involved in performing research. Fostering awareness of the ethical issues surrounding research will impact and inform the research activities of the participants well beyond the span of the project. This is important because science is based on generating reliable forms of evidence from which conclusions can reasonably be drawn (1). Furthermore, most research undertaken is funded by taxpayers who are increasingly scrutinizing and becoming more critical of scientists due to access to information through public communications.

Citizen science is a way to contribute to a community. Scientists in colleges and universities rely on civilian hands to collect data and address important questions concerning the local community. For example, local teachers and students can assist scientists in gathering data, while the investigator teaches them about experimental design and data analysis and interpretation to answer the logical question at hand.

However, scientists must be willing to compromise in order for the citizen research to be successful, by giving up control of their research while offering advice and guidance to the participants (9). Developing an appropriate level of understanding among citizens of how science is carried out, as well as employing sufficient rigor to produce meaningful data and information, requires a considerable amount of time on the part of the scientist, regardless of their enjoyment of the outreach. Likewise, for the data generated through citizen-science partnerships between local schools and academia to be strong when externally examined (9), the participants must develop tools that foster the ability to critique evidence encountered and generated through their projects. For example, significant findings from the research can be submitted for peer-reviewed publication and conference proceedings with authorships accurately reflecting the contributions of research team members. Also, results can be shared with the scientific community via conferences, science fair presentations, and invited talks. This information can simultaneously be shared with the public via informal discussions, websites, and newspaper articles. Finally, the research team can share experimental protocols, resulting publications, primary data and metadata, physical collections or any other supporting material generated during the course of the project with others upon request. These are reasonable methods to assess impartial feedback that allows the research team to reflect on their performance and educate the public at large.

## **ENGAGING YOUTH IN CITIZEN SCIENCE**

Studies have shown that introducing interactive, research-based models of education can greatly improve classroom performance and retention (21). Students need to understand that science does not follow a procedural model, nor does it have predetermined questions and conclusions. In this regard, the Internet has facilitated opportunities for citizen science, allowing scientists to develop, manage, and utilize internet-based citizen-science projects for the purpose of furthering science itself, as well as the public understanding of both science and of the scientific process. For example, the Massachusetts Institute of Technology (MIT) Open Courseware, through its Highlights for High School website (<http://ocw.mit.edu/high-school/>), provides resources to improve science, technology, engineering, and math (STEM) education at the high school level. Teachers have access to videos of demonstrations, simulations, and animations on STEM subjects to help maximize educators' engagement and rapport with students. Students have access to tools that allow them to understand the scientific method and explore advanced college-level material through lecture videos, experiments, and notes, igniting their passion for science overall. This initiative bridges the gap and creates an easy transition for students between high school and college. However, there is a wide range of citizen-science projects that can be appropriately implemented at

different school-age and academic levels (10). Appropriate examples of citizen science projects for students at every school level are described in Table I. The common goal of all these projects is to motivate students' scientific inquiry, literacy, and imagination to examine the world around them at a young age.

Now, using the power of smartphones, tablets, and other gadgets, mobile applications (apps) can turn just about anyone into a citizen scientist (14). Apps offer individuals on any continent the opportunity to gather any type of data imaginable as they go through their everyday routines. The main advantage of wireless devices is that they can be programmed to capture all sorts of information, including images, audio, and transcripts, while accurately keeping track of the specifics of an event or observation. Citizen science falls into many categories, and educators can utilize these applications to promote interest in a variety of scientific fields, including, but not limited to, life sciences (e.g., Project Noah), molecular biology (FoldIt), climate change (Lichen AQ) and pollution (Beach Health Monitor), geography (Google Earth) and astronomy (Galaxy Zoo). The website SciStarter ([www.scistarter.com](http://www.scistarter.com)) lists more than 600 active citizen-science projects around the world, approximately 200 of which are run using mobile technology. Involvement of high school students in these types of citizen projects helps them to identify potential careers and become immersed in subjects they may major in at college or pursue as a hobby. In addition, students rapidly develop an

interest in what they are observing and the community for which they are recording the data; thus, they cultivate the desire to care for the community.

Social media is another tool that can be used to engage high school students in citizen science. In today's technological era, students learn differently and are highly influenced by the latest social media websites and apps. By promoting classroom experiments and scientific activities through social media such as Facebook, Snapchat, Instagram, Vines, and Trivia Crack, we can greatly encourage student inquiry and passion about science. For example, Appleton East High School in Wisconsin has implemented social media apps in its educational methods (19). Using Vines, students participate by posting six-second videos of science experiments to promote science research to the public. It may be challenging to incorporate these smartphone apps into instruction, given that many schools prohibit cell phones on their grounds and some students are not familiar with these apps. However, students need not be required to use smartphones in class; many teachers have opted to reserve the use of apps for homework assignments.

### DEVELOPING A CITIZEN-SCIENCE PROJECT

The development of a functional citizen-science project depends on numerous elements (2). The quality of the experiment and its data should not be compromised, but meeting

TABLE I.  
Examples of citizen-science projects appropriate for school-age students.

Education Level	Title	Description
Elementary School	Journey North <a href="http://www.learner.org/jnorth/">www.learner.org/jnorth/</a>	Students investigate global wildlife migration and seasonal changes.
	FeederWatch <a href="http://www.birds.cornell.edu/pfw/">www.birds.cornell.edu/pfw/</a>	Students set up bird feeders and observe when the birds are feeding. Data collection on the types and number of birds.
	Bee Hunt <a href="http://www.discoverlife.org/bee/index.html">www.discoverlife.org/bee/index.html</a>	Students inventory pollinators at a selected site using photographs to identify insects and plants.
Middle School	Encyclopedia of Life <a href="http://www.eol.org/">www.eol.org/</a>	Students take wildlife photos, comment, research, and write about the species on Earth.
	Galaxy Zoo <a href="http://www.galaxyzoo.org/">www.galaxyzoo.org/</a>	Students examine images of space and classify them according to their shape, allowing scientists to understand galaxy formation while students gain exposure to astronomy research.
	S'Cool <a href="http://scool.larc.nasa.gov/">http://scool.larc.nasa.gov/</a>	Students observe clouds at particular times focusing on types, height, percentage cover, and thickness.
	World Water Monitoring Day <a href="http://www.worldwatermonitoringday.org/">www.worldwatermonitoringday.org/</a>	Students use test kits to monitor the health of local water bodies by measuring pH, dissolved oxygen, temperature, and turbidity.
High School	FoldIt <a href="http://fold.it/portal/">http://fold.it/portal/</a>	Students become familiar with synthesis and breakdown of proteins including how structure affects function.
	Nature's Notebook, USA Phenology Network <a href="http://www.usanpn.org/home">www.usanpn.org/home</a>	Students observe and identify specific plants and animals in a region to determine the effects of global climate change on vegetation and wildlife.

the learning objectives for the participant and public education must be prioritized. Citizen-science models should be founded on a well-designed research question. These projects should be particularly aimed at answering questions with a broader aim. For example, studies requiring detection of patterns or changes over time and space are especially well suited for citizen science (4). Also, it is essential to have a multidisciplinary team of trainers ranging from active research scientists, to classroom educators, to professional outreach staff in order to achieve the objectives of the study. Adequate guidance and rigorous training in experimental procedures, data collection and analysis, and scientific inquiry should be developed and provided by the advisory team (4). For instance, web training modules for both students and teachers or training modules that allow for teacher instruction of students in the classroom can be exceptional resources for citizen-science implementation. Perhaps the best learning outcome of a citizen-science project occurs when the participants feel that they are important contributors to the study (4). Hence, it is important to make students participate in every stage of the process to maximize their learning experience.

### EVALUATION OF CITIZEN SCIENCE PROJECTS

Studies have shown the positive impact of citizen science on the public's scientific literacy. A postsurvey of 700 citizen scientists showed that 78% of the participants felt that the project had led to processing scientific thinking as a result of making observations (20). Citizens have described significant increases in scientific literacy scores posttraining, indicating that science projects can succeed in improving understanding of scientific methodology, status of the field, and reasoning (4). An assessment of individual learning gains of participants is a critical aspect of evaluating a citizen-science project. This assessment must emphasize the acquisition of awareness and knowledge, an understanding of the scientific method, and increased motivation and interest in science (12). A comprehensive assessment of the broader outcomes of citizen-science projects at the community level should also be undertaken. Programmatic outcomes should evaluate the contributors' improvements in understanding natural systems, the community issues, and their dynamic interplay (12). Furthermore, the evaluation of citizen science should focus on measuring its impact on the community's social capital, scientific aptitude, economy, resources, and trust of scientists (12). The success of a citizen-science project depends on constant, honest, and thorough assessment of the components in order to identify any room for improvement, including monitoring the evolution of learning in K–12 classrooms.

### CHALLENGES IN IMPLEMENTING CITIZEN SCIENCE IN K–12 PROGRAMS

Although implementing citizen science in the classroom can generate numerous positive results, critical

issues can arise (17). The difficulty of implementing these projects increases if the scientific question asked requires specialized skills and knowledge, because exhaustive participant training may be required. Thus, questions must be tailored for school-age students and take into consideration the fact that they are most likely to successfully follow a simple methodology involving basic technical tasks. Similarly, previous student training in data collection might be required to avoid bias—the tendency to over-report some occurrences and under-report others—which may affect the study's expected outcomes (17). Moreover, teachers incorporating citizen-science models into their curriculum should be cognizant of not overloading students with additional schoolwork, since such an excess might lead to students' demotivation and indifference; instead, the academic load of participants should be modified to accommodate the projects in order to maximize students' participation and learning. Lastly, a lack of initial financial support and human resources for organizing and managing a citizen-science project by school districts could potentially impair their implementation. However, school administrators should understand that once the infrastructure of a project is in place, the citizen-science model is cost-effective and sustainable (4). In addition, they should be aware of the existence of state and federal funding mechanisms (e.g., the Discovery Research PreK–12 program, [www.nsf.gov/funding/pgm\\_summ.jsp?pims\\_id=500047](http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=500047)), which seek to significantly enhance the learning and teaching of STEM by PreK–12 students and teachers.

### CONCLUSION

Citizen science in the classroom instills community awareness, critical thinking, problem solving, and a practical experience in students. The challenges of implementing citizen science in the classroom can be overcome through the incorporation of novel and sophisticated resources. These include faculty training, involvement of higher-education institutions, and attracting youth participation in the scientific enterprise by integrating technological applications. Inquiry-based science education through citizen-science projects should be designed to nurture independence, persistence, creativity, and determination in the minds of young students to prepare them to solve community problems with a systematic approach. Regardless of the method used or type of question investigated, hands-on experience is the most important aspect to emphasize when exposing K–12 students to research. Additionally, the dedication of teachers, administrators, and scientists, as well as an open-minded public, are critical components for the advancement of citizen science in the classroom (7). This includes access to scientific knowledge and methods by all parties involved (6). Focusing on citizen-science initiatives in the classroom can potentially stimulate the advancement of scientific research, aid in the development of well-trained professionals, and further public education and involvement.

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