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Civic Education and Citizen Science: Definitions, Categories, Knowledge Representation

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Abstract

The first goal of this chapter is to propose a slight re-framing of citizen science, which will contextualize the information presented in the rest of the book. The authors propose a perspective on and a definition for citizen science (which is alternative to the numerous previously documented definitions) as: “work undertaken by civic educators together with citizen communities to advance science, foster a broad scientific mentality, and/or encourage democratic engagement, which allows society to deal rationally with complex modern problems”. By explaining the rationale behind this definition, the authors also hope to raise awareness of the role that the meaning of words and phrases (semantics) plays in understanding and supporting citizen science. A second goal of this chapter is to explain how different organizations already use certain

software solutions to organize knowledge about citizen science, how these systems can be classified and how they can facilitate or impede interoperability – the ability of humans and machines to pass information between each other.

INTRODUCTION

According to numerous surveys and news reports (e.g., in the US: Dimock, Kiley, Keeter, Doherty, & Tyson, 2014; Annenberg Public Policy Center, 2014), the mass public appears to know very little about politics, government, policy and the environment. When pollsters ask even simple questions on any of these topics, many people fail to give correct answers. In response to such evidence, the question is “What can be done about it?”

Some people are very critical and frustrated about citizens’ inability to answer basic questions on policy and the environment. In democratic countries, they ask how we can expect ignorant citizens to choose qualified candidates for office or offer defensible views on social or environmental topics. In response to what can be done about this, some seek a constructive approach to the evidence of civic ignorance (Lupia, 2015), and try to open new avenues for civic education. Former US Supreme Court Justice Sandra Day O’Connor, for example, argues that “we have to ensure that citizens are well informed and prepared to face tough challenges. If there is a single child not learning about civics or not being exposed to what they must do as citizens, then all our lives are poorer for that.” (Terhune, 2013)

The extraordinary amount of work undertaken by volunteers in all areas of society across the world is testament to the fact that many people are answering calls for this kind of education. They include researchers, teachers, scientists, issue advocates, journalists, reporters and political campaigners - to simplify, the authors consider all of these individuals and groups as *civic educators:*

Civic educators are people who believe that providing information to others, and/or creating opportunities for others to learn, are paths to greater civic competence and a better future.

Civic educators are principal instigators for the engagement of citizens (e.g., the public) in affairs of public interest (including, but not limited to, scientific research). They develop and implement educational strategies; design plans to provide certain kinds of information to certain people; or, open up opportunities for others to learn in certain ways.

Civic educators’ strategies are diverse. Some write articles. Others teach students. Some seek to draw attention to important facts and causes while working for widely recognized and highly reputable organizations. Others seek educational innovation through startups. Some seek to educate at places of work. Others operate in settings like high schools, colleges, fabrication laboratories and universities. Some educators do many of these things. Educators differ in their ambitions. In the context of this book (citizen science, which the authors define and explore in detail later), civic educators often wish to educate a specific audience (e.g., young adults, fishermen, inhabitants of particular neighborhoods, residents of a particular city) about a specific or a general topic.

Civic educators also have diverse identities. Some consider themselves *advocates*. These advocate educators (e.g. Greenpeace, the Sierra Club, etc.) are motivated by a desire to achieve policy outcomes for social and environmental equity such as a safe and healthy community in which to live; securing appropriate regulatory standards for air and water pollution; and many more.

Others identify themselves as *experts* on a topic rather than as policy-driven advocates. Many expert educators are motivated by ideas from science and do not make explicit appeals for or against specific policies. Instead, these experts seek to involve the public in their scientific endeavors, sometimes to educate audiences about how things or the environment work, and sometimes to collect data for their public interest research. Many academics think of themselves in this manner.

Still other civic educators identify as *advocates and experts*. They not only want to teach audiences about how things or the environment work, but they also wish to enlighten others about how things or the environment could be if certain options were chosen. These educators often provide information or create learning opportunities for the purpose of bringing policy outcomes in line with the lessons of their expertise and their own points of view.

Civic educators see themselves as knowing things that can help others, and believe that greater knowledge will benefit others. Issues for which civic educators are active include world hunger, causes related to health, general environmental topics, and specific environmental issues such as whether land should be preserved, how to monitor natural-waters quality, the early detection and reporting of weeds, and myriad other causes. Many people are civic educators of one kind or another, and in this chapter the authors explore the role of civic educators and "the public" in the emerging domain of citizen science.

So what is "citizen science"? The authors begin with a few illustrative examples, returning to formal definitions and approaches in a later section.

PIGEON SCIENCE

In London, in 2016, you could see pigeons wearing backpacks. As part of an experiment, French startup Plume Labs outfitted ten pigeons with tiny sensors designed to offer a real-time snapshot of the city's ozone and nitrogen dioxide levels. But the ultimate goal was to get humans to wear similar devices, that researchers, in this case from Imperial College London, could use to collect and analyze data for shareable insights, like which route people should walk if they want to breathe the cleanest air. It is presently harder to get insights on air pollution from fixed monitoring stations, which is how researchers and public administrators measure pollution right now (Waxman, 2016).

In Barcelona, later in 2016, you could see people wearing a sensor device. As part of a much publicized citizen-science experiment, the multimillion-euro European project

CITI-SENSE provided several citizens with tiny sensors designed to offer a snapshot of the city's ozone and nitrogen dioxide levels.

Are we witnessing a transition from "pigeon science" to citizen science?

We might be, if we consider citizens just as data collectors, data carriers or a crowd that can be used as a new and expanded resource for data or information gathering. There is no doubt that, by engaging large numbers of people over large geographic areas in specific aspects of scientific projects, we can collect larger volumes of data and cover significantly more area than is physically or financially possible when only using more traditional scientific approaches. Researchers cannot physically be everywhere, and enabling non-researchers (i.e. the general public) to participate in a specific resource-intensive aspect of a project, such as data collection, can be time- and cost-efficient, as well as rewarding to both parties.

CITIZEN SCIENCE

Citizen science has many benefits over other research methods and should be seen as a powerful enabler and augmenter for the scientific process. Also, when humans are involved, there is the possibility of achieving significant positive social outcomes through civic education and participation. Individual contributors benefit from enhanced topical knowledge, or knowledge of the scientific research process. Social networks expand; and communities become more resilient, with enhanced capacity to influence research agendas and contribute to public policy dialogues (Haklay, 2015; Bonney et al., 2009; Irwin, 1995). Citizen science can also provide a form of "workplace experience" which can provide pathways to new or even first employment opportunities. In 2008, Stuart Harris, a vineyard worker in Canberra, Australia, discovered a new species of peacock spider. This experience created opportunities for him to work closely with practicing scientists and set him on a path towards a new career in which he has developed many new skills and found a new personal sense of purpose and contribution to society (Vyver, 2014).

Today, "citizen science" is often just a convenient label for certain types of projects. There is no single, agreed-upon definition and typology by all parties involved, despite efforts from numerous researchers over the past 20 or so years.

Existing Classifications of Citizen: Science Projects

Here the authors will present select classification efforts of citizen-science projects to date. These are offered with the caveat that we are living at the dawn of dramatic changes in science, enabled by the internet, which are greatly accelerating scientific research, and empowering civic educators and citizens in transforming the nature of science.

Perhaps the most elusive problem—and also the most important—in describing citizen science originates from the multiple meanings of the concept itself. On a qualitative level this is evident by observing how two distinct meanings have developed in the social and natural sciences respectively since the mid-1990s (Kullenberg, & Kasperowski, 2016). Researchers often distinguish between:

- *1.*

  Citizen science primarily conducted with goals including democratization, public engagement, equity, and justice in the discourse of science and in setting the research agenda (e.g., Irwin, 1995; Irwin, & Horst, 2015);

- *2.*

  Citizen science that is focused on something else, usually on public involvement in scientific research, with members of the public partnering with professional scientists to collectively gather, submit, or analyze large quantities of data (e.g., Bonney, 1996; Dickinson, Zuckerberg, & Bonter, 2010).

While the second approach has often dominated scholarly dialogues over the past 20 years, the dramatic changes in technology that we are experiencing and the maturation of citizen-science communities could favor an increase in significance of the first one, at least if citizen science's stakeholders recognize values in the discipline which extend beyond the value of "pigeon science". Fully appreciating this trend of balancing of purpose within citizen-science communities, as they evolve and mature, requires exploring existing classifications in more detail, to better understand the history of the field and the ongoing discussion.

The examples provided in this chapter are mainly meant to facilitate the comparison among typologies. Most of these classifications are not mutually exclusive; for example, a project could be classified in terms of: governance model; goals and tasks; or intellectual property concern. Additionally, in some cases, the same project may be classified according to a number of classes within a single typology. For example, a project may involve, at the same time and with equal priority, data collection and data processing as the nature of the activities participants engage in. Other times, classifications are designed as exhaustive and mutually exclusive. While project governance models may change over time, no single project will employ two distinct governance models simultaneously (e.g., Shirk et al., 2012).

Citizen-science projects are often classified by the nature of the activities participants engage in (Bonney et al., 2015):

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  Data-Collection Projects: (the National Audubon Society's Christmas Bird Count, numerous projects hosted by the Atlas of Living Australia, scientist-lead ecological projects, etc.), For which contributors who may or may not have any formal training as scientists collect data that can be used in organized scientific research;

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  Data-Processing Projects: (those hosted by the Zooniverse suite, Australia's DigiVol digitization project (Ellwood et al., 2015), etc.), Focused on categorization, transcription and interpretation, enabled by the Internet, and sometimes referred to as "crowdsourcing" or "crowd science";

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  Curriculum-Based Projects: (BirdSleuth, the Basin Champions program in Australia, etc.), Take place in schools or in “informal” youth-development settings, collecting and submitting data to a larger, “parent” citizen-science project;

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  Community-Science Projects: (the West Oakland Environmental Indicators project (California Energy Commission, 2012), The highly successful Waterwatch program in south eastern Australia (Chalkley, Brendan, & Gowland, 1999), etc.), which place local or regional issues at the heart of the research, and typically seek to affect policy or local decision-making for public health, environmental health, or conservation.

Citizen-science projects can also be classified by governance model, or the extent to which the public participates in different parts of the scientific process (Shirk et al., 2012):

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  Contractual Projects: (exemplified by European Science Shops (Jorgensen et al., 2004)), Where communities ask professional researchers to conduct a specific scientific investigation and report on the results;

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  Contributory Projects: (the Christmas Bird Count, Western Australia’s MicroBlitz project (Gruber, 2015), Australia’s Waterwatch program, etc.), Generally designed by scientists and for which members of the public primarily contribute data;

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  Collaborative Projects: (e.g., community-based monitoring of wetlands in Madagascar (Andrianandrasana, Randriamahefasoa, Durbin, Lewis, & Ratsimbazafy, 2005), Generally designed by scientists and for which members of the public contribute data, but also help to refine project design, analyze data or disseminate findings;

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  Co-Created Projects: (e.g., the West Oakland Environmental Indicators project), Designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all steps of the scientific process;

- •

Collegial Contributions: (as exemplified by amateur astronomers, archaeologists, and taxonomists, who often work on their own (Hopkins, & Freckleton, 2002)), Non-credentialed individuals conduct research independently with varying degrees of expected recognition by institutionalized science and/or professionals.

Another classification of citizen science according to governance models, framed as the level of participation and collaboration between professional and non-professional scientists, is offered by Haklay (2013):

- **Crowdsourcing Projects:** (the Christmas Bird Count, the Australian DigiVol project, etc.), In which participation is limited to the provision of resources, and the cognitive engagement is minimal;
- **Distributed-Intelligence Projects:** (e.g., Galaxy Zoo), In which the cognitive ability of the participants is the resource that is being used;
- **Community-Science or Participatory-Science Projects:** (e.g., the West Oakland Environmental Indicators project), In which the problem definition is set by the participants, and in consultation with scientists and experts, a data collection method is devised;
- **Collaborative-Science or Extreme Citizen-Science Projects**: Completely integrated activities, where professional and non-professional scientists are involved in deciding on which scientific problems to work and the nature of the data collection, so it answers the needs of scientific protocols while matching the motivations and interests of the participants.

Other definitions are specific to public participation in certain domains. For example, citizen-science projects have been defined by the degree of local participation in the domain of natural resource monitoring (Danielsen et al., 2009):

- **Externally-Driven, Professionally Executed Monitoring Projects**: Do not involve local stakeholders;
- **Externally-Driven Monitoring Projects with Local Data Collectors:** (e.g., the Citclops project on natural-water monitoring (Wernand, Ceccaroni, Piera, & Zielinski, 2012)), Involve local stakeholders mainly in data collection;

- **Collaborative Monitoring Projects with External Data Interpretation:** (e.g., community-based monitoring of wetlands in Madagascar), Involve local people in data collection and management-oriented decision making, but in which the design of the scheme and the data analysis are undertaken by external scientists;

- **Collaborative Monitoring Projects with Local Data Interpretation:** (e.g., ranger and community-based monitoring of resource use and wildlife in China (Van Rijsoort & Jinfeng, 2005)), Involve local stakeholders in data collection, interpretation or analysis, and management decision making, although external scientists may provide advice and training;

- **Autonomous Local Monitoring Projects:** (e.g., the West Oakland Environmental Indicators project), In which the whole monitoring process -from design, to data collection, to analysis, and finally to use of data for management decisions- is carried out autonomously by local stakeholders; there is no direct involvement of external agencies.

In addition, numerous typologies extend beyond examining citizen science through the degree of public participation. For example, citizen science projects may be defined in terms of project goals and tasks (Wiggins, & Crowston, 2011):

- **Action-Oriented Projects**: (e.g., the West Oakland Environmental Indicators project), Encourage participant intervention in local concerns, using scientific research as a tool to support civic agendas;

- **Conservation Projects:** (e.g., the Missouri Stream Team program on river conservation), Support stewardship and natural resource management goals, primarily in the area of ecology; they engage citizens as a matter of practicality and outreach;

- **Investigation Projects**: (e.g., Citclops) Focused on scientific research goals requiring data collection from the physical environment;

- **Science-Oriented Virtual Projects:** (e.g., Galaxy Zoo), In which all project activities are ICT-mediated with no physical elements whatsoever, differentiating them from the investigation projects in which the physical places of contributor participation was also important;

- **Education Projects:** (e.g., BirdSleuth), Make education and outreach primary goals, all of which include relevant aspects of place.

Citizen-science projects are also defined by the different ways that scientific inquiry can permeate the management of natural resources and collaboration between professional and non-professional scientists (Cooper, Dickinson, Phillips, & Bonney, 2007):

- **Scientific Consulting Research Projects:** (e.g., ranger and community-based monitoring of resource use and wildlife in China), In which knowledge-producing institutions (e.g., universities) function as consultants to community groups to answer questions raised by the community groups;
- **Citizen Science Research Projects:** (e.g., Citclops), Engage a dispersed network of contributors to assist in professional research using methodologies that have been developed by or in collaboration with professional researchers;
- **Adaptive Citizen Science Research Projects**: Involve providing a centralized organizational infrastructure that is specifically designed to promote individual, community, and regional science-based management via an interactive feedback loop;
- **Adaptive Co-Management Research Projects:** Community groups, individuals, and professional land-managers and urban planners work together such that management objectives are carried out and evaluated as “experiments” tailored to specific locations;
- **Participatory Action Research Projects:** (e.g., community-based monitoring of wetlands in Madagascar), Begin with the interests of participants, who work collaboratively with professional researchers through all steps of the scientific process to find solutions to problems of community relevance.

Citizen science may also be classified in terms of issues including *intellectual property* (IP) concerns (Scassa, & Chung, 2015), and many more topics. The existence and use of different classifications suggests that researchers take alternative views regarding what is and is not important to pay attention to in the field of citizen science, and how to structure their vocabularies in accordance with different values.

Existing Definitions of Citizen Science

By highlighting important aspects of the citizen science experience, these typologies lead to the related question of “What is *citizen science*?” Various definitions have been proposed, including:

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  “The participation of nonscientists in the process of gathering data according to specific scientific protocols and in the process of using and interpreting that data; the engagement of nonscientists in true decision-making about policy issues that have technical or scientific components; and the engagement of research scientists in the democratic and policy process” (Lewenstein, 2004).

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  “The systematic collection and analysis of data; development of technology; testing of natural phenomena; and the dissemination of these activities by researchers on a primarily avocational basis” (i.e., done regularly for enjoyment rather than as a job; OpenScientist, 2011).

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  “The scientific activities in which non-professional scientists volunteer to participate in data collection, analysis and dissemination of a scientific project” (Haklay, 2013; based on Cohn (2008) and Silvertown (2009))

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  “A contribution by the public to research, actively undertaken and requiring thoughtful action” (Simpson, 2013)

- •

  “Scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions” (Oxford English Dictionary, 2014)

- •

  “The collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists” (Oxford Dictionaries, 2014).

- •

A paradigm where “people who are not professional scientists take part in one or more aspects of science—systematic collection and analysis of data, development of technology, testing of natural phenomena and dissemination of the results of activities. They mainly participate on a voluntary basis.” (Park, 2014)

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“The general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources.” (Serrano Sanz, Holocher-Ertl, Kieslinger, Sanz García, & Silva, 2014)

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“The public involvement in inquiry and discovery of new scientific knowledge. A citizen science project can involve one person or millions of people collaborating towards a common goal. Typically, public involvement is in data collection, analysis, or reporting.” (SciStarter, 2016)

In seeking to understand who contributes to citizen science, it is also important to consider that neither civic educators nor citizen scientists are homogeneous groups. Social scientists made the important argument that “the public” as a single entity does not exist. Instead, we have to acknowledge the presence of a plurality of “publics” (Irwin, & Horst, 2015). In this sense, citizen scientists can be characterized as members of “communities.” Such communities are thought to be at the opposite end of the spectrum of the larger “crowd” that is referred to in discussions on crowdsourcing. These communities are subsets of the public with specific and shared interests, whereas the crowd usually refers to a broader citizenry. Citizen-science community members may have some training and expertise; thus, they can be considered “expert amateurs” and not representative of the full suite of potential participants in citizen-science projects (Lukyanenko, Parsons, & Wiersma, 2016).

While existing conceptualizations of citizen science and citizen scientists are helpful points of departure, many of these major understandings and definitions do not exhaust all forms of citizen science that are of relevance for researchers interested in this phenomenon. Some leave out activities not related to the “natural world”, such as activities conducted in the domain areas of health, medical science, and social science. Most of them focus on data and information, and leave knowledge and competence out of the equation. And there are still questions related to citizen science with no easy answer:

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Must citizen science generate data used in science, policymaking, or management planning? Or can experiential learning activities be conducted without an impact on science, management or policy also be citizen science?

- •

Does participation need to be opt-in, meaning that a project mining citizen Twitter feeds about water and flooding would be out of scope?

- •

What degree of community participation is required? Is a project involving the use of camera-traps out of scope if members of the general public participate only in the deployment of the instruments? And what about if they just change the batteries of the cameras once a year? And by the way, who owns the data collected: those who built the (possibly do-it-yourself) camera trap, those who deployed it, those who changed the batteries and retrieved the data, those who reviewed and interpreted the images, or the researchers who designed the experiment?

In addition to the above, there is the question of whether "citizen science" is even the best or most accurate term to use. *Citizenship* is the status of a person recognized under the custom or law as being a member of a country and this status plays no role in "citizen science". Perhaps "community science", "public science" or "participatory science" are better expressions. This is precisely the point made by a group of researchers in the *United States* (USA) who re-branded "citizen science" as "*public participation in scientific research* (PPSR)" in the early 2000s (Bonney et al., 2009). Notably, in the USA some organizations, including the *National Science Foundation* (NSF), still use the expressions PPSR to mean *citizen science* and also *public participation in science, technology, engineering, and mathematic research*. However other leading organizations, like the recently formed *US Citizen Science Association*, the *European Citizen Science Association* (ECSA) and the *Australian Citizen Science Association* (ACSA), use the now *de facto* standard term "citizen science," even while recognizing this nomenclature as problematic.

Finally, there is the issue of defining the relationships between citizen science and related types of open innovation activities such as: participatory mapping; *volunteered geographic information* (VGI); participatory health monitoring; social studies; and bio-medical studies, just to name some of the research and activity areas included in this book.

An Updated Distinction of Meaning

The authors believe that achieving a practical working definition of *citizen science* is less important than communicating and understanding the general characteristics of citizen-science projects. Perhaps it would be more constructive to consider the *role* of these projects, in terms of supporting research, education, and/or public policy.

By synthesizing a number of the above definitions in a context of civic education, citizen science, and *public engagement in science* (PES), the authors suggest that scientific projects in which citizens are engaged in matters of public interest, or in driving social learning, scientific endeavor or policy development, can be categorized into one of two forms:

- *1.*

Instrumental: Projects which involve the public in specific and limited parts of a process, for example data collection. These projects usually take place in a traditional social and political structure with discrete and fixed actors who "engage" with one another in a specific context for a particular period of time, and then resume their separate, business-as-usual existences; and

- *2.*

  Capacity Building: Projects of a scientific nature undertaken by groups of citizens with a common goal or interest, either independently or in collaboration with professional scientists. These projects are not necessarily established exclusively to answer specific scientific questions, but rather are conducted to reach a range of social, scientific, learning, and/or environmental outcomes.

This new distinction of meaning expands and builds upon the approaches presented earlier, which framed the goal of citizen science as encouraging a more informed and active citizenry (developed in the social sciences) or for scaling data collection (developed in the natural sciences) (Kullenberg, & Kasperowski, 2016). Through this new categorization, and slight re-framing, the authors recognize that citizen-science projects are conducted in any domain of interest to society. This categorization also expands the previous distinction of meaning by acknowledging additional benefits of citizen science, including knowledge gains, which were not at the forefront of scholarly discourse when the previous approaches emerged in 1995. Finally, the authors suggest that citizen-science projects of the capacity-building type are generally initiated by civic educators and involve the public as active participants (as opposed to passive data-collectors) in one or more aspects of the project activities.

While this re-framing is similar to the presentation of goals and tasks advanced by other researchers (Wiggins & Crowston, 2011), in this case the authors are not looking at the primary purpose of a particular project; rather, they are exploring how the paradigm of citizen science itself is framed. In other words, the authors are seeking to explain the ultimate and overarching value of public participation in scientific research:

Citizen science is work undertaken by civic educators together with citizen communities to advance science, foster a broad scientific mentality, and/or encourage democratic engagement, which allows society to deal rationally with complex modern problems.

This definition shifts the focus from the action-oriented, data-centered point of view of *collect*, *participate* and *contribute* (e.g., the instrumentalist point of view) towards a re-framing, based on civic education, of how science and society should respond to a call for *openness*, *inclusiveness*, *responsiveness, democratic engagement, consultation, dialogue* and *commons* e.g., the capacity-building point of view). The definition reflects the values civic educators see in citizen science, which usually include some of the following: supporting and advancing scientific research; public engagement in scientific discourse; public engagement in informing policy at various levels, from local to international; desire to achieve a particular environmental, social or policy outcome; increased capacity to respond to community needs, such as concerns about water quality or access to scientific information; and enhancing lifelong learning/education about the scientific process, and the world around us.

By explaining the rationale behind this definition, the authors hope to raise awareness of the role that semantics, or the meaning of words and phrases, plays in understanding and supporting citizen science and civic education. Semantics is important in human conversations, when diverse speakers and listeners must rely on shared or interoperable vocabularies to get their points across. Semantics is even more important in conversations between humans and machines, or between machines.

In the rest of this chapter the authors will show how different organizations use software solutions to organize knowledge about citizen science, how these systems can be classified, and how they can facilitate or impede interoperability. Following this discussion, the chapter explores different processes for representing knowledge. Attention is devoted to knowledge representation through human consensus-building, and to the introduction of semantic technologies to a non-technical audience. Finally the authors will examine how developing a formal knowledge representation can be used as a strong basis for:

- *1.*

  Developing better designed, more robust, more interoperable software solutions for citizen science;

- *2.*

  Making the work of civic educators more functional towards a contribution to research.

CITIZEN SCIENCE, KNOWLEDGE REPRESENTATION, AND INTEROPERABILITY

Modern research, in which citizen science has a role, demands new *applications* (software solutions or systems for citizen science), and better integration within and among different organizations collecting and using scientific information. Concurrently, we have seen a significant increase in individuals, groups of individuals, and formal organizations related to citizen science projects (mainly small ones) who provide modern services and solutions to today's citizen scientists.

Coordination among these services and solutions is important because there can be a large number of local research projects that emerge around community concerns. Communities usually need a local anchor for participation to be meaningful, as well as means of being able to choose which project or solution is most appropriate for lodging their data or for them to participate in. Some citizen scientists working in these projects hope to collaborate with other organizations to achieve complementary goals, and thus require clear and open communication channels to share information. Civic educators dealing with *software solutions for citizen science*, which are a fundamental part of communication for most projects, are realizing they must satisfy the needs of a wide range of organizations and develop applications tailored to each niche. This involves the daunting task of understanding differences among existing software solutions (David, McCarthy, & Sommer, 2003), and also identifying the differences resulting from various scientific research segments, and associated disciplinary standards.

The types of systems that will be described below are characterized by their *knowledge organization*, or a consistent way of describing and organizing knowledge within the software domain. These systems also require standardized *knowledge representation* of concepts and relations in the domain of citizen science. Knowledge representations refer to taxonomies and other classifications that are understandable by both humans and machines, and aim to support communication among them (for example, by ensuring that two humans in dialogue understand important words to mean the same thing; and, by enabling two artificial intelligences to exchange and understand data sets between themselves without human facilitation or intervention).

Both knowledge organization and knowledge representation are valuable to citizen science for a number of reasons.

Knowledge Organization

The authors categorize citizen-science software solutions—in other words, the variety of technical tools for supporting work processes, and achieving project goals—into:

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  Those with no overall organizing rationale;

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  Those with inward organization;

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  Those with outward organization, or the ability to communicate and interact as communities.

Systems with No Overall Organizing Rationale

These systems do not incorporate any organizing principle for their data, information and knowledge. Instead, information is collected in an irregular or ad-hoc manner. These systems may work when an individual or community is not concerned with sharing data with external parties, such as researchers working to support scientific research or drive public policy. Some curriculum-based projects, which may take place in schools or in “informal” youth-development settings, are examples of systems with no overall organizing rationale. These systems are irrelevant to conversations of interoperability, and outside of the scope of this analysis of knowledge organization in citizen science.

Systems with Inward Organization

More advanced software solutions for citizen science, such as iNaturalist (Pimm et al., 2015) or Citclops (Wernand et al., 2012), incorporate an organizing principle (such as one that builds upon a standard-based metadata schema) to bolster their categorization and processing capabilities. They standardize data-collection procedures and knowledge representation, and provide methods to access data in these standardized formats. By enhancing communications, these systems have facilitated the growth of international models for citizen-science data and information exchange. However, these systems impose constraints on adopting organizations: many of these systems are inflexible, and organizations seeking to use them must adapt to them, rather than the other way around. As a result, some organizations are struggling to implement these more advanced solutions to achieve better functionality, but integration using this approach may be difficult and expensive. If certain systems -such as iNaturalist or CitSci.org (Wang et al., 2015)- become widely adopted (because projects cannot always build their own software solutions, even if they may wish to, and thus need systems such as these), these systems with inward organization will likely become, at least temporarily, the *status quo* as software for citizen-science projects' data and metadata management. It should be noted that systems with inward organization can transition, and in some cases are already transitioning, to become systems with outward organization.

Systems with Outward Organization

These systems are based on standards that are already accepted or in use. Outwardly organized software solutions for citizen science, such as the databases and knowledge bases of citizen science projects being developed by ECSA, CSA, ACSA, Atlas of Living Australia, CitSci.org, and Woodrow Wilson International Center for Scholars, support not only the work of a single organization and immediate collaborators, but also facilitate future interaction between diverse organizations by providing data to other participants in predictable and mutually agreed upon formats. In some cases, systems with outward organization are based on the specifications of a single system (with inward organization) that became accepted over time. For example, the way that information is structured in the SciStarter database has influenced how shared standards for citizen-science project metadata have evolved. Newer project databases (including the US Federal Crowdsourcing and Citizen Science Catalog developed by the Woodrow Wilson International Center for Scholars; and the Atlas of Living Australia), have taken SciStarter's structures as model to build upon and expand.

At the most basic level, projects with shared outward organization can share data through a set of custom-designed APIs. One benefit of systems with outward organization, and a more explicit specification of a shared conceptualization, is that they are readable by a computer and can enhance inter-organizational communication by focusing on a standard set of definitions based on a single, machine-readable format like RDF/XML OWL (a family of knowledge-representation languages for authoring ontologies in a Web environment) or on the *JavaScript object notation for Linked Data* (JSON-LD, a method of encoding Linked Data using JSON) allowing uniform integration of data elements.

Future software solutions for citizen science in a semantically-rich context may go even further by utilizing common, independently-viewed definitions. For example, a system that captures water-quality data could give the citizen, via an app, information for the improvement of scuba-diving activities (*citizen-app view*), while the research organization involved could use the same data to contribute to ocean-color research (*research-organization view*). These systems increase storage efficiency and this is especially valuable in resource-poor environments. If a particular citizen-science project experiences a lapse in funding, data storage through integrated systems will ensure that data collected by this project do not become inaccessible to other researchers. These solutions with outward organization are typically based on existing ones that capture detailed semantics about, for example, environment biodiversity, resources, characteristics and events, as envisioned in a Web services context.

Knowledge Representation

In order for humans and machines to reason and communicate with others in a semantically-rich way, a formal representation of important concepts and relations is required. For example, many individuals and organizations can act as civic educators, or conduct citizen-science activities, without explicitly labeling their actions. But, in order for these people to find each other, enter into dialogue, share information and learn from one another, it is necessary to utilize common forms of knowledge representation. The difficulty of representing knowledge is evident in the struggle to find a single definition of “citizen science” in a way that resonates with the experience of diverse researchers, practitioners, and contributors in the field. In the following, the reasons for which knowledge representation is valuable to citizen science are presented.

Shared Knowledge Representation Indicates a Shared Ontological Commitment

While there may never be absolute agreement, a high degree of consensus regarding how knowledge is represented within a domain—or, a shared *ontological commitment* among citizen science researchers, practitioners, and communities—shows cohesion and solidarity. People who are committed to reaching a shared understanding of domain knowledge are not only making it easier for people within the domain to communicate, but are also distinguishing themselves as a broad citizen-science community of practice distinct from groups of citizens cohered around other topics.

Along these same lines, a shared ontological commitment, e.g. a shared vocabulary, can help newcomers to the citizen-science domain understand what is important in this paradigm. If parts of the vocabulary are developed in more details, for example by one group having spent years developing a set of scales to articulate and measure the educational benefits of citizen science (Phillips, Ferguson, Minarchek, Porticella, & Bonney, 2014), a new researcher can see that these scales are broadly used and cited, and understand that the citizen-science community considers their work valuable not just for the scientific benefits, but for social and educational benefits as well.

A shared ontological commitment helps researchers studying the field of citizen science understand each other’s contributions, and pose new research questions that build upon and extend previous work. As described earlier, researchers already categorize key aspects of citizen science, such as the range of participation goals and tasks (Wiggins, & Crowston, 2011), governance models (Shirk et al., 2012; Haklay, 2013), and intellectual property concerns (Scassa, & Chung, 2015). When the same categorizations are widely accepted and understood, they provide a shared point of reference for exploring new research questions. For example, one group of researchers used an established typology of governance models to ask and answer a research question about how different outcomes relate to projects of different “types” (Bonney et al., 2015).

A Common Knowledge-Representation Helps Citizen-Science Researchers and Practitioners Explain Their Work to Domain Outsiders

Data quality is an important and frequently debated topic in citizen science, as in many other domains (Bonney et al., 2014). Developing a way to communicate about data quality that is specific to citizen science (covering mechanisms to support data quality *before* research, like through contributor training; *during* research, like point-of-capture standardization and validation; and *after* research, like through human-based or automated validation strategies) can help different citizen-science researchers understand each other's work. Some mechanisms for supporting data quality, like contributor training, derivations of new data from combinations of existing data, and automated real-time validation, are common to a number of sub-domains. Other mechanisms, such as using existing species distribution maps to assess the plausibility of a new sighting, may be specific to application sub-domains such as biodiversity monitoring. Additionally, developing a vocabulary to represent data quality in citizen science that matches (or is compatible with) the vocabularies used by researchers outside of citizen science can help to integrate citizen-science contributions with other research contributions, and increase the likelihood that citizen-science data are incorporated into other formal research and policymaking systems.

Certainly, not all citizen-science activities align with the goals of policymaking systems or potential downstream applications for their data. For example, if one community wants to secure new, more appropriate regulatory standards for air and water pollution, this group might prefer to develop their own metrics for what constitutes high-quality air and water, and propose alternative ways for measuring and communicating about air and water quality and contamination (e.g., Ottinger, 2011). In some cases, the decision to reject an existing knowledge representation can be associated with a suggestion for a re-framing of policymaking and engagement. Groups who suggest alternatives to existing standards and frameworks for science-related activities still need to explain their work to outsiders, and thus should provide a clear and complete documentation of their choices and activities that shows where they depart from existing knowledge representations (e.g., in terms of metadata), and why.

Knowledge Organization and Knowledge Representation Can Offer Value Through Classification

There is an overwhelming number of software solutions for citizen science that support activities such as contributor recruitment and management, data collection, data analysis, data storage, and data retrieval e.g., GEO BON's "BON in a Box". Formal knowledge organization and representation allow either humans or machines to better survey existing software solutions, identifying the most promising ones to suite a project's needs. If organizations and project managers can better understand available citizen-science systems, they can quickly narrow their search to a category that supports their needs, either by adopting a single software application that supports all processes, or by compiling a range of applications into a systems assemblage (Prestopnik, & Crowston, 2012) where different solutions are combined to serve a set of goals.

Knowledge Representation Can Support Increased Adoption of Citizen Science

One route to increased adoption of existing technologies is for developers of citizen-science software solutions to identify closely related research niches and modify their system to become compatible with these niches. For example, citizen science has been traditionally focused on species observations; thus, models such as iNaturalist have been *limited* to manage biodiversity-related questions. However, there are projects (e.g. Citclops, CITI-SENSE, Air Quality Egg, among others) that use sensors to measure a variety of environmental parameters, to monitor, for example, water quality, land cover and disease-vector species; there are projects that collect and manage non-environmental variables (e.g., Agent Exoplanet, Galaxy Zoo, ARTigo, among others); and there are projects managing just metadata, including citizen-science project repositories. Therefore, robust and proven architectures and representations of existing software solutions focused on biodiversity could be adapted to include data about projects, instruments, devices and new types of variables.

Knowledge Representation Can Support Coordination Among Web-Based Portals

By creating software based on semantically-rich technologies and formal knowledge representations, and operating it through their portals, citizen-science portal providers (iNaturalist, SciStarter, Atlas of Living Australia, among others (Beaman, & Cellinese, 2012)) can offer additional services such as coordinating relationships among related sites and organizations. Taken to the extreme, this model could result in a global community of citizen scientists working together.

Citizen-science software-providing portals may debate whether to develop complete information solutions, which span the full range of project activities, or focus on core competencies such as supporting a specific type of data collection. If the latter occurs, the need for inter-portal communication standards will be critical to a portal's success. If different portals streamline inter-organizational communication, the data could be stored once and then made available to all interested parties (e.g., citizen-science communities, researchers, and policymakers). For example, records of natural-water quality could be used by: citizens, focusing on users of the beach ranking the best beaches; researchers, who could use these same records to perform analyses on water quality in different lakes; and policymakers, who could use this information to manage lake-water demand.

Paths Towards Knowledge Representation in Citizen Science

Citizen science is a specific domain. While there is some overlap of citizen-science knowledge representation with other domain ontologies and general, top-level ontologies, many key concepts are articulated in a way that is unique to the citizen-science domain. This section briefly explores different methods for categorizing and representing knowledge that are currently being used in citizen science, before exploring the opportunity for additional work.

Acquiring and representing knowledge in citizen science are difficult tasks, which have to balance two elements. On the one hand, because domains like citizen science are constantly evolving to reflect real-world changes, knowledge representation must be considered an ongoing task (for example, contributors' gender was once classified as binary but no longer is). On the other hand, in order for knowledge representation to successfully support communication between machines, a certain level of stability and agreement is required.

Knowledge acquisition is a process where domain information is collected for use in knowledge representation (e.g., Sowa, 1999; Jakus, Milutinović, Omerović, & Tomažić, 2013). Methods of knowledge acquisition rely on the capabilities of human domain-experts, and also machines. Different methods of knowledge acquisition, which comprise elements that are peculiar to citizen science, include:

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  Knowledge Elicitation: Human domain-experts pool their individual knowledge to reach a shared understanding of what is important to model in a particular domain. Knowledge elicitation may take place through: brainstorming sessions, including workshops; the ongoing activities of working groups; real-world application, learning, hypothesis testing and validation; and/or the use of folksonomy web-platforms where the general public is encouraged to submit and vote on different terms. It can often be difficult for domain experts to say what they know, or to make tacit knowledge explicit. Techniques designed to elicit tacit or procedural knowledge, such as observation or card sorting, may be used to augment the declarative knowledge that is more easily shared. In citizen science, knowledge elicitation has typically occurred through workshops (e.g., Bowser, McMonagle, & Tyson, 2015) and the activities of working groups (e.g., the Data and Metadata Standardization Working Group of the Citizen Science Association). Web and mobile technologies have expanded social knowledge-elicitation, thanks to the way they link people together and facilitate collaboration. An interesting form of knowledge elicitation is being explored, for example, through YAMZ and other folksonomies (e.g., Hotho, Jäschke, Schmitz, & Stumme, 2006), platforms that use internet-based collaboration on information architecture to elicit and evaluate different metadata terms within the domain of ontology and taxonomy construction.

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  Knowledge Discovery: Information is automatically extracted from digital sources, for example through different types of data mining. To date, knowledge discovery is an under-utilized tool for knowledge representation in citizen science. To demonstrate the value of knowledge discovery, a database of citizen-science tools—compiled by SciStarter and the Woodrow Wilson International Center for Scholars—utilizes a knowledge-discovery process for determining relevant metadata used in the description of citizen-science tools and technologies.

Knowledge representation is a process where, typically, an individual or committee drafts up a general guideline for the construction of an ontology (or an equivalent construct; see description of related technologies below), which acts as a skeleton that plans the shape of the ontology. It takes into account the goal of the ontology and the data that are to be within its scope, and attempts to represent it within a tree. Rigorous rules are laid down for fleshing out that skeleton, to ensure that the initial population and subsequent addenda are internally consistent. If this is done properly, the result is a coherent and consistent ontology. A well-constructed ontology is not trivial to create. The Cyc top-level ontology (Reed, & Lenat, 2002), for instance, has been factored and re-factored over the years as its creators have learned through hard experience the way of organizing commonsense knowledge.

The classic ontology has a steep learning curve for construction and maintenance. Guidelines have to be both well-planned and rigorously adhered to. For example, The Atlas of Living Australia tried to implement RDF OWL vocabularies and ontologies between 2009 and 2011, and found it to be extremely difficult to build them in the biodiversity domain. Implementing RDF OWL representations in citizen science has proven to be a major hurdle due largely to the resources required and complexity in building comprehensive vocabularies and ontologies, and in mapping and defining the relationships between the concepts, making machine inference unrealistic in most cases.

Newer and perhaps more implementable web technologies, such as:

- *1.*

  JSON-LD (Lanthaler, Sporny, & Kellogg, 2014) with numerous major players such as Alphabet, the BBC, HealthData.gov, Yahoo!, and Microsoft already deploying its specification in production,

- *2.*

  Internet-of-things technologies, and

- *3.*

  Authoring technologies empowering users to become contributors, appear to be getting traction and could represent the basis for the next step for knowledge representation in citizen science: working with data that are important to stakeholders and have to interoperate across the Web.

NEXT STEPS FOR CITIZEN SCIENCE

With civic educators and citizen science’s identities established, the question becomes “What kinds of information should be conveyed and in which form?” Decision-makers working with small and large projects depend on the provision of the right information, and the right representations of information. By mapping the terms used in existing active datasets and relevant legacy datasets to a standardized ontological framework, the authors seek to help civic educators develop more effective and efficient educational strategies. This can have consequences in re-education, cultural-change management, and systems which handle terms translation for information exchange.

Providing better-represented information will:

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  Increase people’s knowledge of complex modern problems, and how these problems may be addressed through science and policy;

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Provide pathways for related paradigms, such as the do-it-yourself/maker/hacker movement, to become more integrated into citizen science thanks to a better interoperability with their own “language”;

- •

  Offer ways to formalize citizen science information, to support better decision-making;

- •

  Help scholars of the citizen-science topic to improve the accuracy and value of their research;

- •

  Uncover common errors in representation in citizen science, for example errors arising from outdated conceptualizations of the paradigm, and help to fix them; enabling these corrections to make subsequent action and scholarship more useful to educators of all kinds.

Information restructuring is also the consequence of a paradigm shift. Previous definitions of citizen science focused on how the public participated in the research and policy-making processes; the authors’ definition shifted the focus from an earlier distinction between scientific activities and public policy, to emphasize citizen science as a comprehensive strategy towards a shared social and scientific mentality and new level of competence. This shift is related to what civic educators consider important, and how they model key features of the citizen-science domain; and any ongoing re-framing of the domain will trickle down to impact a wide range of knowledge-organization and knowledge-representation terms.

CONCLUSION

This chapter’s central proposition is that greater knowledge of the topics dealt with in citizen science can empower civic educators and researchers to more effectively:

- *1.*

  Lead prospective learners to knowledge that matters;

- *2.*

  Increase the value of the information they deliver to others; and

- *3.*

  Open up opportunities for others to learn.

In the first part of the chapter, the authors analyzed the numerous existing classifications and definitions of citizen science, and proposed a slight re-framing of the topic and a definition for citizen science that is alternative to existing ones. The second part of the chapter showed the role that the meaning of words and phrases (semantics) plays in understanding and supporting citizen science. Here, the goal was to explain how different organizations already use certain software solutions to organize knowledge about citizen science, how these systems can be classified and how they can facilitate or impede interoperability – the ability of humans and machines to pass information between each other. The third and final part of the chapter introduced the idea that providing better-represented information will:

- *1.*

  Increase people's knowledge of complex modern problems, and how these problems may be addressed through science and policy;

- *2.*

  Provide pathways for related paradigms, such as the do-it-yourself/maker/hacker movement, to become more integrated into citizen science thanks to a better Interoperability with their own "language";

- *3.*

  Offer ways to formalize citizen science information, to support better decision-making;

- *4.*

  Help scholars of the citizen-science topic to improve the accuracy and value of their research; and

- *5.*

  Uncover common errors in representation in citizen science, for example errors arising from outdated conceptualizations of the paradigm, and help to fix them, enabling these corrections to make subsequent action and scholarship more useful to educators of all kinds.

This final part of the chapter focused on knowledge-representation complexity. By complexity, the authors mean that the domain of citizen science has diverse and occasionally contradictory components, experienced by an equally diverse range of communities; and, when a domain is complex, educators and researchers have to choose how to frame it (i.e., they have to choose how to formally represent it and what parts of the topic to emphasize). Choices about how to frame issues in citizen science will impact the effectiveness of the communication and exchange of information, and determine whether or not that information has any subsequent effect on others' knowledge and competence. In this respect, the authors offer a vision in which, even if citizen science moves towards more and more formal knowledge-representation and the ability to carry out automatic reasoning by machines, humans are responsible for checking whether any given knowledge representation is still an accurate reflection of reality.

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