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Citizen science – bridging the gap between scientists and amateurs

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Abstract:
The European Union has been facing common issues such as early school leaving and lifelong learning for years. They are main targets that remain on the EU agenda and all good practice examples are welcome. Citizen science is one of the approaches that seems to have great potential to draw a wide group of people to science in a popular way. People can easily become a part of a scientific team and contribute to research that could hardly be carried out by one small team. Many citizen science researchers deal with issues that are attractive for people because of their usefulness or application (gathering ticks, taking photographs of surroundings) and/or because of the accessibility of the data (typical for biological issues). This aspect also supports bridging the gap between citizens-amateurs and scientists-professionals, as well as lifelong learning. Chemistry is a natural science subject that is rarely performed in citizen science, and little research is devoted to the educational aspect of citizen science projects. Therefore, we present here a brief overview of an increasing scientific design that is widely used in natural science, although rarely in chemistry. Citizen science seems to be a potentially useful tool for improving chemistry education.

Keywords: citizen science, informal science education, scientific literacy

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Introduction

The phenomenon of citizen science is a civic engagement that expects the public to take an active role in science: amateur scientists (non-professionals) conduct scientific research often arranged by professionals, scientists. The roots of science features can be found far back in history as observation and examination are typical for humans. Enhancing human life has been based on scientific features, such as inquiry, analysis, and synthesis, from prehistoric times. Clearer scientific contours were established in ancient times, but the greatest progress of empirical sciences took place in the 19th century. Until the 20th century when the profession of "a scientist" was established, "gentleman amateurs" were those who performed science, even in the universities of Europe and North America (Connor, 2005). These gentlemen and ladies were comfortably well-off which enabled them to spend their time collecting data and analysing them. Well-known is the story of Charles Darwin, who set off in 1831 on his Voyage of the Beagle. Darwin, 22 years old, was recommended as a companion for the 26-year-old captain, the British naval officer and scientist Robert Fitzroy, who feared the loneliness of command (Desmond, 2018). As a self-financed gentleman naturalist, Darwin could leave the ship for extended periods, pursuing his own interests. And that is what Darwin, in the end, was doing: observing, collecting data, taking notes, making sketches, all within the framework of his natural science education and experience from universities. The voyage, unexpectedly, took almost five years and Darwin collected thousands of items of data that later served as a basis for his works, especially the most well-known, *On the Origin of Species* (1859) (Desmond, 2018). Nevertheless, the first professional scientist is likely to be found even in the 17th century, Robert Hooke, who was paid for an extensive survey of London after the Great Fire of 1666 using scientific methods. However, until the 20th century, science was performed by noblemen and women interested in science who had to have their own resources and also specific prerequisites for scientific work (Silvertown, 2009). Even after the professionalization of scientists, volunteers have still worked in areas such as archaeology (enthusiasts join the excavations), natural science and ecology, where they help national repositories with collected samples (Haklay, 2013). Moreover, with the new millennium and the easy availability of modern technologies and online connections, the ability to engage in professional scientific research is much easier and more diverse. This co-operation between professional scientists and volunteers can result in several forms and has been called citizen science.

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This contribution is meant to be a brief review of an increasing scientific design that is mostly used in biology topics but has potential also in education and educational research. We used the term “amateur” in the title and at the beginning of the article to emphasize the difference, the antonym feature of both words, but with no pejorative connotations (see Edwards, 2014). In the next part, we will use “volunteers” or “participants” as names for citizen scientists.

Definition and typology

Although citizen science, as we understand it today, has been performed for decades, the term was first used in the 1990s. Alan Irwin (1995) and Rick Bonney (Bonney, 1996 as cited in Bonney et al., 2009a) are those who presented it independently, followed by more or less similar definitions which share the same core: it is a collaboration between the public, volunteers, and professional scientists in particular research. Riesch and Potter (2014) distinguish in these definitions a focus on public-participation engagement and a project that communicates science presented by Rick Bonney, while Irwin’s approach develops concepts of scientific citizenship by highlighting the necessity of opening up science policy processes to the public. However, the next definitions differ mostly in the description of what kind of collaboration it is and what its result is (e.g. Bonney et al., 2009b, Defining Citizen Science, 2015[1]). In extreme examples, it can also be understood as public participation in organized research work, where no explicit participation of professional scientists is needed (Bonney & Dickinson, 2012). The European Commission fosters the interaction between citizens, citizen science stakeholders and European Union policy officers, which led to publishing the White Paper on Citizen Science for Europe (based on the previous Green Paper of 2013) that can be used by policy makers when setting up future strategies for citizen engagement in science (Sanz, Holocher-Ertl, Kieslinger, García, & Silva, 2014). According to this document “Citizen Science refers to 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.” In 2015, the European Citizen Science Association published its “10 Principles of Citizen Science”, where the principles believed to support good practice in citizen science are summarized (European Citizen Science Association (ECSA), 2015). These principles are: the active involvement of citizens (1) in projects that have a genuine science outcome (2), where both participant groups benefit from taking part (3). Volunteers, citizen scientists, may participate in multiple stages during the scientific process (4) and they receive feedback (5). Scientists should consider that citizen science has its limitations and biases, like any other research approach (6). The project data are publicly available (7), citizen scientists are acknowledged in publications (8), the programmes have their own evaluations, e.g. on scientific output, data quality or participants experience (9). Finally, the project leaders take legal and ethical issues into consideration (10).

Citizen science projects are designed in many forms, therefore there is an effort to categorize them. Most authors divide the types of citizen science projects according to the degree of volunteer involvement in the project (e.g. Bonney et al., 2009a; Haklay, 2013; Shirk et al., 2012; Wilderman, 2007), but Wiggins and Crowstone (2011) created a categorization according to the type of activity, and Scassa and Chung (2015) according to the type of intellectual property. From the above-mentioned, we will select a classification based on the type of volunteer involvement: Rick Bonney et al. (2009a) and Jennifer Shirk et al. (2012) are members of the Cornell Lab of Ornithology (Cornell University, Ithaca, NY, USA) who presented a classification of public participation in scientific research (PPSR) in 2009 (Bonney et al., 2009a). The categories of PPSR where citizen science belongs were extended with the contractual and collegial categories in 2012:

- *Contractual* projects (2012): scientists perform specific scientific research according to public (usually specific communities) requests. Citizens ask a research question, and in the end discuss the results and ask another question. Sometimes they can participate in the search segment of the research or interpret the data, or try to use the research results in practice.
- *Contributory* projects: the projects are designed by scientists; volunteers primarily collect samples or upload data and provide them to the scientists for further processing.
- *Collaborative* projects: citizens collect data for a project designed by scientists and they also help analyse data, refine the project or disseminate the results.
- *Co-Created* projects: is a higher model of collaboration where citizens help select a research topic, compile hypotheses or analyse data and interpret results, which means that some public participants are actively involved in the entire process of scientific research. Sometimes, professional scientists have more of a consultative role, in the sense they are available at any stage of the project as consultants.

– *Collegial* projects (2012): are those where citizens conduct research that creates scientific knowledge independently of the scientific community.

In citizen science projects, a dual feature of the participants' activity can also be observed. Some projects are based on a passive design where volunteers have to be active only at the beginning: special software that uses unused processing power has to be installed into a personal computer. If thousands of volunteers provide this spare computing power, researchers can exploit it for computing tasks that would never be realized even with the most powerful computer. These distributed computing projects can be represented by, e.g. the project SETI@home whose purpose is to analyse radio signals searching for signs of extraterrestrial intelligence (University of California, 2018). SETI@home was introduced for public access in 1999 and along with MilkyWay@home and Einstein@home, it is one of three major computing projects which have a focus on the investigation of interstellar space as their primary purpose. This kind of participation is an extreme case that is sometimes not regarded as citizen science because there is a lack of active contribution by the participants (compare the White Paper, Sanz et al., 2014). However other authors classify volunteered computing in the first level of citizen science because the volunteers must show at least the will to install the appropriate software and their willingness to contribute to scientific results in the end do help researchers, although only by passively providing computer power. Haklay (2013) puts volunteered computing in the first level ("crowdsourcing") beside projects in which volunteers carry sensors and passively gather data that are later given to researchers for analysis. This design of the experiment is quite controlled, where the reliability of the data can be expected. Haklay's second category is "distributed intelligence" which involves some basic training, after which volunteers collect data or carry out a simple interpretation activity. "Participatory science" is similar to the co-created projects described above: it is mostly community science, common in environmental justice cases, where scientists provide consultations, and help in analysing and interpreting the data. In the last "extreme citizen science" projects, scientists are rather in the role of experts and facilitators, while volunteers perform the entire research project.

Where, what and how to do citizen science

The rise of projects that enable volunteers to contribute to scientific research goes hand in hand with the improvement of technological personal devices and the accessibility of wi-fi. Many recent projects are based on recording the data online with specific software for which a mobile phone with internet access is needed. The project topics reflect mostly those in which the data can easily be collected and/or recorded and are interesting or challenging for volunteers in some way. The topics are often biological, environmental and astronomical where there is an easy way to use the citizens' power, such as recording observation data, or analysing or categorizing photographs. In the natural sciences, fewer projects can be found on chemistry topics (e.g. mapping aerosols Snik et al., 2014; specific projects are mentioned in the next chapter) or mathematics (e.g. Cranshaw & Kittur, 2011). Follett and Strezov (2015) analysed all published articles concerning citizen science (excluding crowdsourcing projects) from 1997 until 2014 available on the Web of Science and Scopus, which means in peer-reviewed journals. The majority of the projects were biological, namely avian and terrestrial invertebrates. The number of articles was rapidly increasing (years 1997–1999: 3 articles, 2012–2014: 333 articles) and we dare to state that the trend was similar in the last four years, 2014–2018. This indicates that citizen science projects are becoming popular and/or available to the broader public (due to the accessibility of smartphones and wi-fi) and that professional scientists have accepted the citizen science research design and the reliability of the data that are produced in such projects.

Volunteers have many opportunities where to find a possibility to contribute to scientific research. In the last decade, several associations gathering ongoing projects or stakeholders have been established. For Europe, the European Citizen Science Association is relevant (ECSA, 2018). The ECSA provides contacts to organizations that perform citizen science in Europe. The popular international project platform Zooniverse.org (2018) was developed by the Citizen Science Alliance (CSA, 2018), a collaboration of scientists, software developers, and educators. In the United States, an official government website supporting citizen science across the U.S., Citizenscience.gov (2018) has been established. Its catalogue enables one to choose from dozens of projects according to one's desired topic. Citizenscience.org (2018)is a platform that brings experts in citizen science together, such as the Cornell Lab of Ornithology, and publishes an open-access, peer-reviewed journal, *Citizen Science: Theory and Practice* (CSTP, 2018). The last example, SciStarter.com (2019), is a platform supported by the National Science Foundation and Arizona State University's Center for Engagement and Training in Science and Society. SciStarter provides more than 2000 formal and informal projects and events, moreover it offers a place to record contributions or gain tools and instruments that can be used in citizen science projects.

Citizen science projects are a good opportunity for collecting a vast amount of long-term data or data spread out over a large area. Such data are impossible to collect for a small team of researchers, but informed citizens can contribute a great deal of data that can be used for further analysis. The Cornell Lab of Ornithology is a department at Cornell University that has more than two decades of experience in leading citizen science projects. In 2009, Bonney and colleagues (2009b) published a model where 9 steps for developing a citizen science project are described. First of all, it is important to choose a scientific question, preferably with a large spatial or temporal scope (1). Then it is essential to set up a team of experts from various disciplines, such as scientist, educator, technologist or evaluator (2). Most of the projects use protocols and supporting educational materials that have to be developed, tested and refined into a final form (3). The recruitment of the participants (4) is a key point of the project, as a lack of cooperating volunteers decreases the success of the project. Participants must be supported with project materials and trained in data-collection (5). This training can be very simple, according to the nature of the project and the type of data, in the form of text and eventual demonstrations. For more complex projects, participation in a workshop may be required. Once the project is active, the data collection phase begins (6), for ornithological projects, maps with occurrences are typical. Analysis and interpretation of data (7) are usually performed by experts. The dissemination of results (8) is the next important part of the project: not only in professional journals but also through technical reports, popular literature, newsletters and other channels. An integral part is the discovery of project impacts (9), not only in the field of scientific contributions but also in science literacy in the public.

Demographic and educational aspects of citizen science

Until recently, citizen science was presented mostly in the terms of the scientific results that were obtained due to the contribution of citizen scientists. Background information about the participants and potential research on them was not the centre of interest. However, there were a few research projects that analysed secondary information (e.g. Trumbull, Bonney, Bascom, & Cabral, 2000). Edwards (2014) reviews the educational background information and concludes that from a lifelong learning research perspective, deeper research concerning, e.g. motivation, educational qualification or subject background needs to be performed. However, we do have research that studies the background of the participants in citizen science projects. Raddick et al. devoted two studies to participants in the Galaxy Zoo project. In an earlier study (Raddick et al., 2010), 12 motivation categories for contributing to a project were identified. In a later online survey (Raddick et al., 2013), the motivation, together with the demographic data of more than 11,000 volunteers, were studied. More than 82 % were men, with a significant number of male participants between the ages of 50 and 65. The authors discuss the reason for participation which points to the topic studied – astronomy, because such age group is prominent also in participants in amateur astronomy (Price & Paxson, 2012 as cited in Raddick et al., 2013). Other demographic results state that volunteers came from countries with higher levels of per capita gross national product (the USA and UK, home to 65 % of volunteers) and more than 50 % of participants graduated from tertiary education. Other studies focused on the demographical data of volunteers (Hurley, Wilson, & Christie, 2008) in various civic movements show that age, education, gender, and socio-economic status play a significant role in the participation in volunteering. Raddick and colleagues (2013) were also surprised by the results on motivation: 40 % of volunteers simply wanted to contribute to research, 12 % were interested in astronomy, but only 1.6 % wanted to learn something new or be a part of a community (0.2 %). This does not correspond to the results of a study made by Rotman et al. (2012), who focused deeply on motivation: their sample had 142 responses and 18 of them were later interviewed. The results of Rotman et al. show that especially initial interest is mostly related to egoism (they want to improve their personal scientific knowledge of a specific domain). On the other hand, it seems that personal interest and the personal gain of the volunteers' motivation can change rapidly, even after a partial task. Therefore, it is crucial to facilitate the volunteers during the project so that they stay on and contribute to the project continuously, and what is even more important: they will be open to contributing to another project.

Another two aspects of citizen science are lifelong learning and early school leaving: two phenomena that have evolved in recent years in the context of the demographic development of European society and the transformation of the labour market. Reducing early school leaving below 10 % is one of the key objectives of the Europe 2020 Strategy (European Commission, 2018). In 2018, the average percentage of early school leavers across the European Union was 10.6 %, with the most in Spain (17.9 %) and Malta (17.5 %); the Czech Republic had a percentage of 6.2 % who quit basic education (Eurostat, 2018). The concept of citizen science, where the public engages in real scientific research, seems to have great potential for popularizing science among the general public, including in younger pupils, which may well be reflected in compulsory schooling. Similarly, citizen science may encourage lifelong learning, although Edwards (2014) feels there is a lack of evidence. During participation in a citizen science project, it is often necessary to become familiar with relevant information on the topic and to follow a prescribed methodology. The research of Trumbull et al. (2000) shows how non-scientist participants cultivate their scientific thinking. During a Cornell Laboratory of Ornithology project, namely a seed preference test, researchers received 700 informal letters, most often describing data collection experiences. Nearly 80 % of these letters showed characteristics of thinking processes similar to those used by professional scientists.

All of this evidence is heading towards a presumption that citizen science improves scientific literacy. However, the research conducted on this is ambiguous. As mentioned above, Trumbull et al. (2000) detected evidence of scientific thinking in more than 700 letters sent to the research team during the seed preference test project. Nevertheless, the first phase of the study, when participants answered one decontextualized item, did not show any significant difference between participating and nonparticipating citizens in scientific literacy. Cronje, Rohlinger, Crall, and Newman (2011) argue that existing studies such as Trumbull et al. (2000) and Brossard, Lewenstein, and Bonney (2005) or others (see references in Cronje et al., 2011) may suffer from a lack of an instrument that would be sensitive to the gains that citizens embrace in projects. Therefore, their team developed four-item contextualized instrument with an open-ended format to assess scientific understanding during the monitoring of an invasive plant species. They also used the non-contextualized item from the Brossard et al. (2005) to compare the results. Before and after the two-day event, 57 participants answered the questions and so did the control group (90 participants interested in the project, but unable to attend the training session). The pre-tests of the control group and trainees were not significantly different in the non-contextual or contextual items. Also, no shift was detected in the results of the post-test on the non-contextual item. Yet, the post-test scores on contextualized items were significantly higher than on the pre-test. The results indicate that more emphasis should be put on the assessment instruments so that the results are more sensitive (Cronje et al., 2011). On the other hand, Cronje et al. agree with Brossard et al. (2005) that the results can reflect the participants' motivation: they participated in the project probably because of the issue itself rather than to learn about the scientific process. Similar findings can be found in the Crall et al. (2012). The data was collected before and after a one-day training session within a citizen science programme on invasive species (166 participants, 48 non-participants). The positive changes in content knowledge, science literacy, process skill and intention to pro-environmental activities were found in context-specific measures. No changes in attitudes toward science and the environment were explained by the fact that the citizen scientists themselves have positive attitudes toward the environment compared to the general public, furthermore, changes in attitudes among adults require more interventions over a long period of time (Crall et al., 2012).

Even though it seems citizen science projects cannot guarantee improvement, they have a possible positive impact on scientific literacy and, finally, represent a method for public informal education. This feature can be utilized in science education where authentic science learning is welcome.

Citizen science in science/chemistry education and educational research

In her essay (2011), Linda Jenkins discusses approaches to science classes: she argues that the traditional method of transmission of facts mainly results in "non-science" people failing to understand science. She divides students into groups of "scientist", "excluded" and "non-scientist" and stresses that science educators will have to change their way of teaching if they want to change how science is perceived by non-scientist students. In her opinion, science classes taught with a humanistic philosophy will clarify the role of science outside the classroom. In her experience, one way to make science relevant to the larger population can be including citizen science in science education, because then even abstract concepts, such as pH, become more meaningful for students (Jenkins, 2011).

For a better understanding, we can sum up and reduce the principles of citizen science relevant for science education: citizens/students contribute to a scientific research project mostly by collecting the data and/or analysing the data. They stay in quite close contact with scientists who are providing feedback and therefore the students get to know the relevant scientific problem and how the scientific process is employed. This approach should represent a win-win strategy, because scientists gain data that could hardly be collected by a small research group and this data afterwards forms a unique science outcome. On the other hand, students see the relevance of science studies and in some projects the relationship with citizens is more individual: scientists share their expertise and professional experience with middle- and high-school students so that young people can imagine themselves as engineers or scientists. It can have a positive impact on students' motivation to engage in science and their later career choice (see Bombaugh, 2000). The positive effect on students' motivation and all social cognitive constructs was studied in a citizen science programme on horseshoe crabs and using six different scales it was confirmed that informal natural science learning increases student achievement and career motivation (Hiller & Kitsantas, 2014).

Probably the most relevant project for chemistry and science education is the GLOBE (The Global Learning and Observations to Benefit the Environment) programme, established in 1995 (GLOBE, 2019). Although it was not classified as a citizen science programme, the goal and vision of GLOBE is without a doubt within the framework of citizen science principles: students and the public can participate in data collection and the scientific process that create real scientific outcomes that help foster an understanding of the Earth's system and the global environment. Students can collect data in different "spheres": atmosphere, biosphere (land cover), hydrosphere, pedosphere (soil); and the Earth as a system. Each study area requires a different amount of sampling, from simple measurement to daily measurement. The programme offers rich support not just for participants (mostly students) but also for teachers, such as a teacher's guide or classroom activities. Other examples of science, namely chemistry projects can be found on the website SciStarter.com, where 84 projects concerning chemistry can be selected. Projects differ in project skills, average time, age group or the type of activity, as well as the frequency of sampling. For example, the Northwest Wisconsin Groundwater Monitoring Project (SciStarter.com, 2019) gathers samples of private well water collected just once, to obtain the data on fluoride and selected metals. Another project, AQTreks (SciStarter.com, 2019), focusing on air pollution, takes part outdoors and the samples are to be collected every few days by a Personal Air Monitor. This project also requires participants to buy the monitor. A third example of a SciStarter project can be the iWittness Pollution Map (SciStarter.com, 2019) that gathers eyewitness reports and photos of pollution in Louisiana, in the United States. These three examples show the variety of the projects, e.g. regarding the equipment: some projects provide essential equipment (a sampling kit in Groundwater), in some projects participants have to buy the equipment themselves (a personal monitor in AQTreks), or no equipment is needed (iWitness). Some projects are based on objective analysis (Groundwater, AQTreks), others focus on subjective measurement (iWitness). A different example of a citizen science project that collects subjective measurements can be CITI-SENSE (CITI-SENSE.eu, 2019) coordinated by the Norwegian Institute for Air Research (NILU).

All citizen science projects have the same feature: the participants, citizen scientists, learn to understand the nature of science, knowingly or unknowingly. When we focus on students, they learn how to perform the experiment – such as how to ask questions, search for the answers, and suggest hypotheses. Most of the activities are carried out in the natural world, as an extra-curricular activity, in the natural context of ordinary lives.

Many of the citizen science projects are global, nevertheless, within an educational context local projects are welcome. Students contributing to science on the local level can be more in personal contact with experts and in fact shadow the scientific process. As mentioned above, this may have a crucial impact on the students' career choices. A tip for such school-university cooperation can be project-based learning that involves an experimental part: e.g. a project based on waste sorting can measure, for example, how many kg of waste have been sorted and therefore what and how can be converted to some chemical quantity (e.g. a mass of element, a percentage of an element or compound wasted). Monitoring of food waste can be an interesting topic as it can be related to the consumption of pesticides and fertilizers in agriculture. Food waste means the wasting of nutrients (carbohydrates, fats, proteins) on one hand, while the soil suffers from the lack of nutrients. Chemical aspects are present in environmental measurements (the pH of precipitation) or environmental topics – climate change, carbon dioxide production, acid deposits. Citizen science projects enable a holistic view of a certain topic where chemistry is not an isolated sum of facts, but is contextualized within a real-life problem.

Moreover, the citizen science concept can also be used in educational research. Data collected on the present state of chemistry/science education can form a relevant basis for formal improvements in education, such as revisions in school plans or revisions to the national curriculum.

Conclusion

Citizen science has been an increasing method design that plays an important role in informal science education. The technological boom at the end of the 20th century supported the design of rather passive projects, recognized as volunteered computing. Later, when personal smart devices began to become affordable, many active projects emerged. Participants in such projects collect the data via specific applications that send the data to creators of the applications, researchers. The results that are widely collected all over the world can, therefore, be analysed and interpreted on a deeper level because of their number, heterogeneity, and authenticity. The involvement of the public in the scientific process has several advantages. It is a source of a great amount of data, that could not be collected by a single research team. Moreover, the engagement of citizens increases scientific literacy, lifelong learning and bridges the gap between the professional scientist community and the public.

Once students experience cooperation with professional scientists, they become familiar with their methods and some may consider being a natural scientist as a potential future job.

For (chemistry) educators, citizen science represents a methodology that brings new qualitative data regarding, e.g. the educational beliefs of learners, parents and educators. The results of such research will broaden the reflection of scientific education and could even be used in educational policy.

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Notes

1 "...projects in which volunteers partner with scientists to answer real-world questions".

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