

Carla Morais

Citizen Science in Science Education



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Foreword

Discussing science, understanding what science is, learning science, and teaching science are distinct yet interconnected topics in the public's understanding, and, for the public, the meaning and significance of science in society have evolved over time. The understanding of science for the public, closely linked to scientific literacy, is now a political issue that features on the agendas and programmes of governments in democratic regimes. It is an issue that spans across contemporary societies, although the way it is approached is diverse, particularly regarding the emphasis placed on it within formal education. It should be noted, however, that compulsory education is a political decision and, accordingly, its duration and content have changed over time in all countries.

In Portugal, compulsory education was set at six years only in 1964, but its implementation on the ground took many years due to a lack of teachers and schools equipped for the new concept, at a time when many parents and, above all, grandparents were illiterate. The type of science intended to be taught then to children coming from disadvantaged backgrounds cannot be assessed by today's standards of scientific culture.

The same occurred with many subsequent restructurings, the most significant of which took place after the revolution of 1974. It took 22 years for compulsory schooling to be extended from six to nine years, as established in 1986 by the framework law on education. This structure has remained essentially unchanged, with occasional adjustments, with the main modification in 2012, when compulsory schooling was extended to 12 years.

The greatest challenge we face today is adapting the educational project to contemporary societies—considering that unreliable information is more readily available and disseminated with the simple click or touch of a screen. Being literate in science and in many other fields is a goal for which researchers in Education are called upon to intervene.

Citizen science, a term whose meaning has evolved over time, as will be discussed further by the author of this book, refers us to two more common concepts, although they are not of linear interpretation: science and citizenship. Do they come together to form a more complex concept? Since this is not the focus of these

introductory remarks, I leave the answer to this question to interested readers. Indeed, I will not address the topic that the author has studied in depth and so eloquently presents, supported by the extensive bibliography she cites. However, it is worthwhile to explore the text before us in order to understand the contributions of citizen science as a means to reflectively engage with and monitor science-based societal issues.

In summary, in this book, the concept of citizen science is based on five main characteristics: “public participation”, “voluntary contributions”, “scientific production of research and knowledge”, “real-world contexts”, and “socio-scientific issues”. In addition, citizen science projects may encompass more extensive levels of scope, enabling the analysis and interpretation of data on a given issue at a local, regional, or national level, or even as a contribution to a global problem.

I have therefore chosen to reflect on science education and its role in fostering critical and reflective citizenship. Considering that science is a borderless body of knowledge, permeating our daily lives, and that society itself no longer has natural or ethically neutral boundaries, we may regard citizenship as the mediating concept between the two—a concept that is increasingly complex, given that both science and society have become interwoven with technology, which has tangible implications for our lives, even for people with no scientific background. Many scientific and technological discoveries and inventions, such as the contraceptive pill in 1960 and the World Wide Web in the 1990s, have profoundly transformed our personal and social lives, demanding new skills and knowledge and, inevitably, requiring us to rethink educational guidelines and strategies.

Teaching science, or any other subject area, cannot simply replicate the teaching strategies of the past, even if those approaches were once effective. Understanding what students think and know about the topics is essential, but not sufficient. Furthermore, science education throughout schooling, while becoming increasingly specialised and in-depth, must enable students to understand that addressing real-world problems requires multiple bodies of knowledge, and it is through their combination that a solution may emerge. A real-life example illustrating this articulation was experienced by all of us during the COVID-19 pandemic. Never had we witnessed a situation in which so many scientists from different fields, working cooperatively, provided explanations about the devastation caused worldwide by the SARS-CoV-2 virus. This real example of open science demonstrated the impact of scientific knowledge on society and, with each passing day, underscored the urgency of developing an effective vaccine.

What is currently known about science learning is the result of the work of many researchers across all continents; yet, in just a few decades, the world has changed in unpredictable ways. Students’ questions in an era of artificial intelligence are not easily answered by a great number of teachers, as many of these questions are themselves unexpected. The same was true at the end of the 1970s, when *in vitro* fertilisation was invented and adolescent students would ask in the classroom how to make a “test tube baby”. Are teachers prepared for the challenges posed by contemporary knowledge?

As there are no simple answers to all scientific and technological questions, this is not what is being promoted, and it is indisputable, for example, that smartphones have had a significant impact in the field of citizen science, enabling participating citizens to access micro-computers equipped with sensors. Mobile applications can help overcome barriers of location and time, which is relevant to certain tasks associated with scientific research. In citizen science, the implementation of mobile applications means that participants can contribute with real-time observations, reporting them and thereby strengthening the connection between observer and researcher. In the future, artificial intelligence algorithms may bring new perspectives to the field of citizen science.

Learning science involves understanding what science is, how it is constructed, and recognising that the public understanding of science is a tool for citizenship and for empowering individuals to participate in public policies with social impact. To achieve this, it is necessary to distinguish science from pseudoscience, data from myths, and knowledge from opinion, making it essential for formal education to include projects developed in real-world contexts. Public understanding of science cannot be achieved by decree; rather, it is the result of a long process of empowering individuals—citizens—which cannot be overlooked by the school, the environment most widely shared by all. Developing creative projects that are appropriate to the context and educational level, and which aim to answer a problem not previously known, is a way to foster an interest in science, as well as in critical and reflective thinking. Understanding what science is goes far beyond learning concepts, laws, and theories; working on projects developed in real-world settings is a means of demonstrating the impact of scientific knowledge on the construction of better citizenship.

Being a science teacher and/or a researcher in science education—the intended audience of this book—requires the sharing of experiences, many of which are grounded in the work of previous teams, whose epistemological, didactic, and psychosociological foundations should be present. The knowledge constructed from specific cases and contexts opens the door to new solutions for these and other audiences. Furthermore, educating in science or educating for science is a highly complex task that demands dedicated research and highly specialised teacher training, with the most significant innovation perhaps lying in the field of science didactics.

Throughout this book, there is ample evidence that student participation in citizen science projects enables the achievement of some of the most important objectives in science education, such as increasing the knowledge of specific content and understanding what scientific research entails—particularly in terms of grasping the nature of science, even if in a simplified manner. Furthermore, and most importantly, citizen science projects help to enhance participants' interest, motivation, and attitudes towards science. These competencies are not acquired through theoretical lectures, but rather through immersion in practice.

Science belongs to everyone and, as such, it should be a shared asset for all.

Isabel P. Martins

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Competing Interests The author has no competing interests to declare that are relevant to the content of this manuscript.

Introduction

The report *OECD Future of Education and Skills 2030. OECD Learning Compass 2030* (OECD, 2018), done by the Organisation for Economic Co-operation and Development, highlights the importance of adaptive and holistic education, in both formal and non-formal contexts, as a means of responding to the rapid changes faced by society. The report emphasises the need to think and act responsibly, for collective well-being, based on knowledge, attitudes, values, and skills, as a major learning goal for the 21st century.

Thus, the OECD Learning Compass 2030 comprises seven inseparable and complementary elements, namely:

1. core foundations;
2. transformative competencies;
3. student agency/co-agency (referring in particular to primary and secondary school students);
4. knowledge;
5. skills;
6. attitudes and values;
7. Anticipation-Action-Reflection cycle.

The following elements are particularly highlighted:

2. *transformative competencies*—three transformative competencies are outlined: i) “creating new value” for a better life, by questioning the status quo, cooperating, and thinking creatively; ii) “reconciling tensions and dilemmas”, by solving complex problems, extending and balancing one’s own positions with opposing viewpoints, and cultivating relationships with respect and empathy; iii) “taking responsibility”, by evaluating one’s own actions based on experience and the ethical aims of education (OECD, 2018, p. 60).
3. *student agency/co-agency*—whenever students are active in what they learn and how they learn, their enjoyment of learning to learn increases, which brings benefits to their own lives and to the life of the community, strengthening their sense of achievement and belonging. In this context, the concept of *student agency* is

understood as the capacity to define a goal, think upon and act responsibly with the aim of causing a particular change. In addition to being responsible for their own learning, students are regarded as agents of change within the educational system and society (OECD, 2018, p. 32).

7. Anticipation-Action-Reflection cycle—it is important that actions taken are intentional and accountable. Therefore, it is necessary to anticipate before acting, foreseeing the consequences and understanding one's own intentions as well as those of others; and subsequently, to reflect on the action carried out, thereby making both thought and action more effective (OECD, 2018, p. 118).

Another OECD report (2018), *The Future of Education and Skills: Education 2030*, emphasises that, in order for students to play an active role in all dimensions of life, they will need to navigate uncertainty across a wide variety of contexts: over time (past, present, future), within the social sphere (family, community, region, country, and the world), and in the digital space. They will also need to engage with the natural world, to understand how knowledge about the world around us is constructed and to appreciate its fragility, complexity, and value.

In the past two decades, citizen science has flourished as a means of engaging citizens, including young students, in scientific research processes, with the aim of deepening and applying scientific knowledge (Eitzel et al., 2017; NASEM, 2018; Vohland et al., 2021). Although public participation in science has its roots in the need to regularly collect information about the natural world (as detailed below), the term “citizen science” was coined in the 1990s and has gained popularity since then (Aivelo & Huovelin, 2020; Bonney, 1996; Irwin, 1995; Vohland et al., 2021). Since 2010, citizen science has been explicitly included in different frameworks of European scientific policy related to more specific areas such as the “Digital Agenda”, “Science 2.0”, “Responsible Research and Innovation” (RRI), “Open Science”, and the “Sustainable Development Goals”. Citizen science is recognised as an important element in the conceptualisation of open science, which has gained prominence as part of the process of rethinking the ways in which science relates to broader social objectives (European Commission, 2016; Hecker, Haklay, et al., 2018b; International Science Council, 2021).

The increasing specialisation and complexity of scientific language, the nature of research and its infrastructures, including the publication system, make it challenging for the general public to access and benefit from this knowledge, which is ultimately generated through public funding. On the one hand, scientists conduct research involving millions of euros, and the legitimacy of this work is sometimes questioned by the public. On the other hand, as a society, we are confronted with pressing issues in social, economic, and ecological contexts that require sustainable solutions—solutions that can be optimised through science and society working together synergistically (Frigerio et al., 2021).

The recognition of citizen science is growing within the fields of science, politics, and education, as well as across society as a whole. Although citizen science is largely acknowledged for its ability to engage the public in science, it has long been regarded as having significant potential in the field of science education (Bonney, Ballard, et al., 2009), being uniquely positioned to foster learning through the active

involvement of students. This involvement may encompass a wide range of activities, such as: defining the problem and formulating research questions; developing hypotheses; designing the study or protocols; collecting data or samples; conducting data analysis and interpreting results; structuring conclusions and communicating findings; formulating new questions and implementing measures to improve the quality of life within both the local and wider community.

Participation in authentic scientific initiatives that take place in real-world contexts represents a potential opportunity for citizen science and is particularly relevant to science learning. This learning extends far beyond content knowledge within a given domain, comprising a deeper understanding of the nature, methods, and processes of science, as well as fostering positive attitudes towards science (Bonney et al., 2016; Phillips et al., 2018; Ruiz-Mallén et al., 2016). The development of scientific literacy, alongside contributing to genuine scientific outcomes, has been a central objective of citizen science (Brossard et al., 2005; Saunders et al., 2018).

Citizen science is also an effective way to address a wide range of social challenges. The explicit engagement of social actors marks a significant difference between citizen science and most standard approaches in scientific research practices (Aivelo & Huovelin, 2020). Furthermore, because citizen science is frequently shaped by emerging socio-scientific issues, grounded in social or community-based activity, and conducive to long-term participation, it constitutes a valuable opportunity for science learning (Makuch Aczel, 2018; NASEM, 2018).

From the students' perspective, many of them consider science to be of little relevance because scientific subjects do not relate to their daily lives (Dohn, 2021; Osborne et al., 2003). According to Osborne, this perceived lack of relevance, when present, limits the development of students' interest in science. The literature suggests that making the study of science relevant to students should be a key objective of science education (National Research Council, 2012; Stuckey et al., 2013).

A promising way to make this relevance explicit is through citizen science, as it enables students to understand science and scientific research practices and apply them, for example, to the detection, monitoring, and resolution of real environmental issues, whether locally or on a global scale, in collaboration with scientists, their teachers, and the wider community (Dohn, 2021; Phillips et al., 2019).

Harlin et al. (2018) systematise the potential of citizen science in science education noting that:

- i. Schools can introduce a large number of citizens, namely students, to citizen science.
- ii. Students feel more engaged in their learning when they participate in authentic scientific investigations that contribute to knowledge and potentially improve the community's quality of life.
- iii. Citizen science projects offer opportunities for the teachers' professional development.
- iv. Teachers have the opportunity to create synergies between the curriculum and citizen science projects; however, they require support to participate in projects that are suited to the needs of their educational contexts.

Citizen science provides a variety of contexts in which scientific learning can take place and has become a substantial contribution to the democratisation of science (Haklay et al., 2021). However, although it offers considerable opportunities, there are also challenges arising from its integration into educational settings which require reflection, and ways to overcome them. At a time when the challenges associated with citizen science are gaining relevance for the pedagogical and methodological renewal of teaching and research—grounded in models of collaboration, co-creation, and knowledge transfer—this work seeks to provide a characterisation of citizen science and to examine its potential and challenges for Science Education in both formal and non-formal contexts.

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Chapter 1

Citizen Science: Origin and Definition



The term “citizen science” refers to a broad range of research practices developed in an increasing number of fields of knowledge (mainly in the areas of environment, biodiversity, health, and astronomy) and characterised by the active participation of citizens in some or several stages of the research process (Eitzel et al., 2017; Pelacho et al., 2021).

Citizen science has its roots in the need to regularly collect information about the natural world. Miller-Rushing et al. (2012) highlight deep historical traditions related to the systematic collection of observations and information by citizens, including millennia-old records documenting natural phenomena over time. For example, winegrowers in France have been recording grape harvest dates for over 650 years (Chuine et al., 2004), while court diarists in Kyoto, Japan, have been documenting the dates of the traditional cherry blossom festival for more than 1200 years (Primack et al., 2009). In China, citizens have been monitoring locust outbreaks for at least 3500 years (Tian et al., 2011). In the United States, some of the oldest datasets consist of records kept by farmers and agricultural organizations documenting the timing of key agronomic events, such as sowing, harvesting, and pest outbreaks (NASEM, 2018).

The definitions, classifications, and terminology of citizen science still retain a certain degree of openness, reflecting the fact that citizen science is an evolving phenomenon (Pelacho et al., 2021). The expansion of citizen science is particularly evident in the increasing number of: i) publications on citizen science in indexed journals over the past two decades (Pelacho et al., 2021); ii) research areas in which citizen science is playing an active role (Eitzel et al., 2017; Mahr et al., 2018); iii) associations and communities of practice that have been established worldwide (Lave & Wenger, 1991; Storksdieck et al., 2016).

The concept of “citizen science” is often attributed to two distinct sources (Hecker, Haklay, et al., 2018b). In 1995, in the United Kingdom, Alan Irwin used the term to refer to an approach in which research objectives were collaboratively

determined by scientists and the public (Irwin, 1995). Around the same time, in the United States, Bonney (1996) began to use the same term to refer to numerous projects at the Cornell Lab of Ornithology, which involved members of the public in bird research.¹

Many definitions have emerged since then, with varying degrees of alignment to these initial roots (e.g., Eitzel et al., 2017; Haklay et al., 2020; Pocock et al., 2017; Strasser et al., 2019). Particularly noteworthy for this work are the definitions put forward by government documents and by other political, scientific, or social bodies relevant to the field (Table 1.1).

Table 1.1 Some definitions of citizen science

Entity (Source)	Definition of Citizen Science
European Commission (2020b)	Citizen science [...] encompasses a range of different levels of participation: From increasing public understanding of science, encouraging citizens to engage in the scientific process by observing, collecting, and analysing data, to setting the scientific agenda, and designing and implementing science-related policies.
UNESCO (United Nations Educational, Scientific and Cultural Organization) (2021)	Participation in citizen science has developed as scientific research conducted by non-professional scientists, following scientifically valid methodologies and often carried out in association with formal programmes, scientific initiatives or professional scientists, with web-based platforms and social networks, as well as open-source hardware and software (especially low-cost sensors and mobile applications) serving as important agents of interaction.
OECD (2017)	At the heart of the scientific process, [citizen science] refers to people who are not professional scientists participating in research, that is, co-producing scientific knowledge. This involves collaborations between the public and researchers/institutes, and it also includes governments and funding agencies.
Portuguese Citizen Science Network (2021)	Citizen science involves the engagement of citizens in activities of scientific research activities, to which they actively contribute with their intellectual effort, knowledge, or their tools and resources.
European Citizen Science Association (ECSA, 2020)	Citizen science is an umbrella term that describes a variety of ways in which the public participates in science. The main characteristics are: 1) citizens are actively involved in research, in partnership or collaboration with scientists or professionals; and 2) there is a genuine outcome, such as new scientific knowledge, conservation action, or policy change.
Australian Citizen Science Association (ACSA, 2021)	Citizen science is the collection and analysis of scientific data from the natural world, carried out predominantly by citizens, usually in collaboration with scientists and field experts. Citizens work alongside scientists to achieve scientific objectives.
Citizen Science Association (USA, CSA, 2021)	Citizen science is the involvement of the public in scientific research—Whether community-driven investigations or global research projects.
NASA (National Aeronautics and Space Administration) (2021)	NASA's citizen science projects are collaborations between scientists and interested members of the public. Through these collaborations, volunteers (known as citizen scientists) have helped to make thousands of important scientific discoveries.

¹This and other citizen science projects mentioned throughout this work have websites, which are referenced in the webography.



Fig. 1.1 Five main characteristics considered in the definition of citizen science

In this work, we adopt the definition of citizen science based on five main characteristics (Fig. 1.1): “public participation”, “voluntary contributions”, “scientific production of research and knowledge”, “real-world contexts”, and “socio-scientific issues” (Fraisl et al., 2020, 2022; SDSN TRenDS, 2019). In addition to these elements, the notion of “scale” is also central to citizen science, both in enabling geographically wide approaches to socio-scientific issues and in supporting data analysis and interpretation at levels that can inform decision-making at local, national, and even global levels (Frigerio et al., 2021).

The development of digital tools and the general access to mobile web enable citizens to participate in data collection and analysis in various ways. This, in turn, allows scientists to obtain comprehensive datasets that would not be achievable without the contribution of volunteer citizens. For example, more than 50% of the data in the Global Biodiversity Information Facility, used for biodiversity monitoring, are obtained by citizen scientists (Chandler, See, Buesching et al., 2017).

The National Academies of Sciences, Engineering, and Medicine (NASEM), in their publication *Learning through citizen science: Enhancing opportunities by design* (2018), set out the conditions without which a given project cannot be considered a citizen science project. They state that a citizen science project in which students collect water quality data solely for their own learning and development does not fall within the definition of citizen science. This does not mean that a purely educational project cannot share the strategies and practices of citizen science, but the use of these practices must also serve other objectives which are defining characteristics of citizen science—such as community action or the advancement of scientific knowledge. It is not citizen science unless citizens are aware that they are engaging with real scientific challenges, have some understanding of those challenges and the underlying science, and recognize that their individual contributions

are valuable. In this regard, the NASEM emphasise that, while other terms may be used to describe citizen science—such as “community science”, “participatory science”, “public participation in scientific research”, “participatory research”, and “community-based participatory research”—, none is as comprehensive or as widely used as citizen science, thus suggesting the adoption of this term (NASEM, 2018).

Chapter 2

European Policies and Citizen Science



The development of citizen science, along with its inclusion in European policies, can be situated within the broader context related to the so-called participatory turn (Schade et al., 2021), which took place mainly during the 1980s and 1990s (Fig. 2.1). The right to science (Wyndham & Weigers Vitullo, 2018) was established, within the framework of human rights, as the right to share in scientific advancement and its benefits¹ and, subsequently and more specifically, within the scope of social and cultural rights (UN, 1966). Until the turn of the century, this had been understood primarily as the right of access to information, as well as to the various benefits of scientific and technological development. By the end of the twentieth century, this understanding had already evolved “from the right of access to information and knowledge to the right to participate” (De Marchi et al., 2001), namely toward a form of citizenship that enables individuals not only to access but also to generate scientific knowledge.

The “Open Science” plan, as a political movement aimed at promoting access to knowledge, regards citizen science as one of the key pillars for achieving democratic and open access to knowledge. UNESCO, having led a collective process to develop the *Recommendation on Open Science* (UNESCO, 2021), also provides an internationally consensual definition, as well as a set of shared values and guiding principles for open science. It further identifies a range of actions leading to a fair and equitable operationalisation of open science for all at the individual, institutional, national, regional, and international levels.

Open science has the potential to make the scientific process more transparent, inclusive, and democratic by: i) increasing scientific collaboration and the sharing of information for the benefit of science and society; ii) making multilingual scientific knowledge open, accessible, and reusable for all; and iii) opening up the

¹4.“Everyone has the right freely to participate in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits” (UN, 1948, Art. 27, No. 1.)

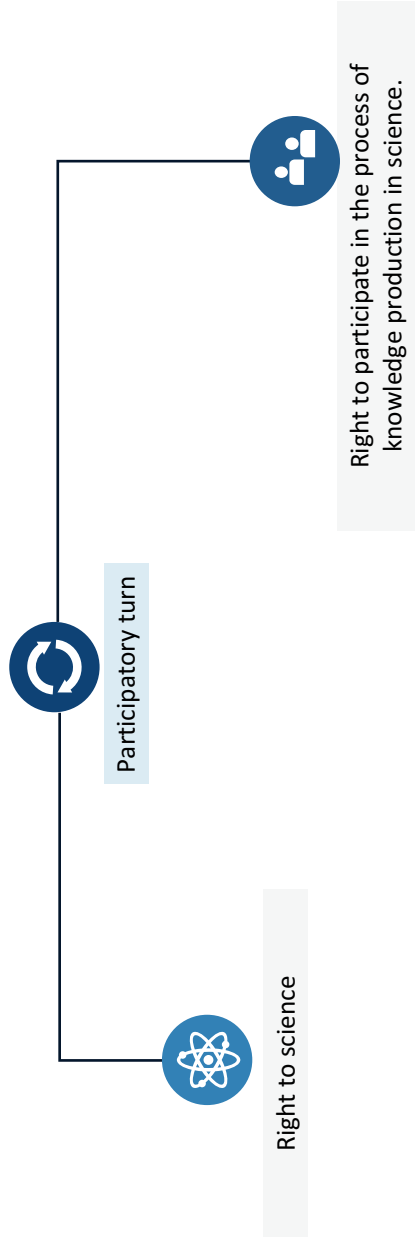


Fig. 2.1 Participatory turn: from the right to information and knowledge to the right to participate in the process of constructing science

processes of creation, evaluation, and communication of scientific knowledge to social actors beyond the traditional scientific community.

The *Recommendation on Open Science* (UNESCO, 2021) also emphasises that citizen science is a key element of this transition towards open science, providing opportunities for open, inclusive, and participatory processes of knowledge access and construction. In a democratic society, this is seen as part of the public's right not only to knowledge, but also to the processes of creating that knowledge (Aivelo & Huovelin, 2020). Contemporary society requires open science to help address complex socio-scientific, environmental, and economic challenges and to achieve the Sustainable Development Goals.

Alongside open science policies, the European Commission (2012) also encourages science education to be guided by the concept of Responsible Research and Innovation, with the aim of fostering joint work among social actors, who are mutually responsible, from the beginning to the end of the research and innovation process, ensuring that both the processes and outcomes of research and innovation are aligned with the values, needs, and expectations of European societies (Laherto et al., 2018). According to the European Commission (2015), science teachers and educators also have the responsibility to incorporate concepts of “Responsible Research and Innovation” directly into their teaching, with citizen science being seen as a potential means of achieving this objective (Laherto et al., 2018).

In the European context, following the Science and Society Action Plan (European Commission, 2002), funding opportunities under the last three Framework Programmes² reflect part of this European incentive to promote relations between science and society (European Commission, 2016; Rodríguez et al., 2019). Since 2011, several citizen science projects have been supported by the 7th Framework Programme “Science in Society” (*Science in Society* (SiS), FP7) (2007–2013), as well as under Horizon 2020 (Fig. 2.2).

According to the report *Citizen Science and Citizen Engagement—Achievements in Horizon 2020 and Recommendations on the Way Forward* (European Commission, 2020a), science education remains the most popular subject, with the highest number of proposals (93). Citizen science, meanwhile, is the fastest-growing theme in terms of proposals (78), more than doubling compared to 2018 (33). Currently, approximately 234 million euros have been allocated to projects that are in some way linked to citizen science. The United Kingdom, the Netherlands, and Spain were the countries that initiated the most projects and received the largest share of funding. At the European level, the current Horizon Europe programme (2021–2027), among other developments, calls for greater interdisciplinarity, increased inclusion, and full openness in research.

In this context, citizen science continues to be recognised as an important element in supporting this strategy and the new priorities. With the aim of deepening the relationship between science and society and maximising their interactions, the

² Science and Society (*Science and Society* (SaS), FP6) (2002–2006); Science in Society (*Science in Society* (SiS), FP7) (2007–2013); and Science with and for Society (*Science with and for Society* (SwafS), part of Horizon 2020) (2014–2020).

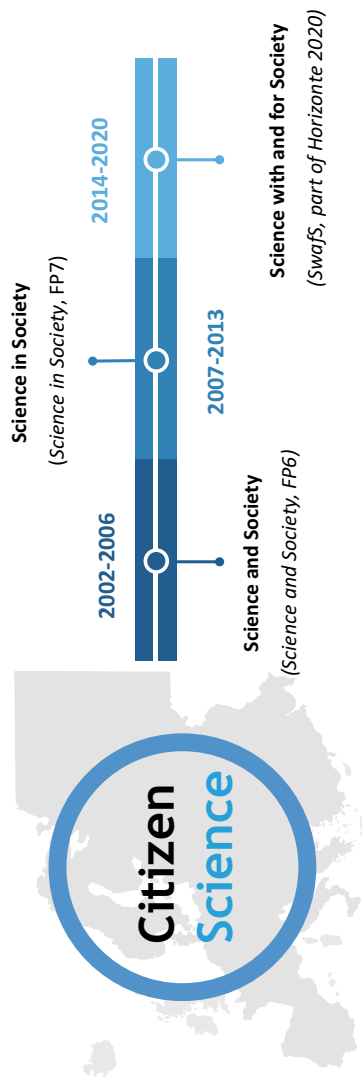


Fig. 2.2 Citizen science and European funding policies: the case of the “Science and Society Action Plan”

current Horizon Europe programme (2021–2027) should actively and systematically involve citizens and civil society organisations in the co-design and co-creation of responsible research and innovation agendas and content, promoting scientific education, making scientific knowledge accessible to the public, and facilitating the participation of citizens and civil society organisations in its activities (European Parliament & Council of the European Union, 2021; Owen et al., 2021).

Within the context of the growth of citizen science, several associations have been established worldwide. Notably, these include the European Citizen Science Association, the Citizen Science Association (now the Association for Advancing Participatory Sciences), based in the USA, and the Australian Citizen Science Association.

In the specific case of the European Citizen Science Association, it was established in 2012 and is based at the Museum of Natural History in Berlin, which continues to host it. In 2015, the association published its *10 Principles of Citizen Science*, which summarise the principles believed to underpin good practice in citizen science (ECSA, 2015, 2020). These principles, in summary, are as follows:

1. the active involvement of citizens;
2. in projects that yield genuine scientific outcomes;
3. in which participant groups benefit from their involvement;
4. they may participate in various stages of the scientific process;
5. they receive feedback;
6. scientists should recognise that citizen science has its limitations, like any other research approach;
7. data generated by citizen science projects are available to all;
8. citizens are acknowledged in scientific publications;
9. citizen science projects have their own forms of evaluation, for example, regarding scientific output, data quality, or participant experience;
10. project leaders take legal and ethical issues into account.

The European Citizen Science Association and its counterparts have highlighted science education as a highly relevant element for citizen science.

Chapter 3

Citizen Science and the Democratisation of Science



The majority of participants in citizen science projects are white, middle-aged, with an average of high income and higher education qualifications (Brossard et al., 2005; He & Wiggins, 2017; Pandya, 2012). However, the core values of citizen science focus on inclusion, meaning that participation in science should be open to all, not just a privileged few. Inclusive citizen science practice encourages the involvement of all members of society, regardless of their social status, socio-cultural background, gender, literacy level, or age (Paleco et al., 2021).

Thus, citizen science projects offer a particularly significant opportunity to reconsider how diverse groups of participants are included at different stages of the research process (Hecker, Haklay, et al., 2018c). As noted by the NASEM (2018), citizen science raises questions about who participates in science; what it means to participate in science; who decides which scientific questions will be investigated; and even what types of knowledge and practice are recognised as science. Bonney et al. (2016) state that if citizen science is truly to contribute to the democratisation of science, it must strive to reach a broader range of audiences and participants. This is why inclusion (in terms of participation) is a central aspect of citizen science and should be analysed across different axes such as gender, ethnicity, socio-economic and socio-cultural status, location, and educational level, along with how these axes intersect with hierarchies and define power relations. For example, with regard to gender, various organisations have developed principles and good practice tools to balance the composition of citizen science teams and ensure that women take on leadership roles in citizen science projects (Puy & Angelaki, 2019).

Understanding the involvement of different audiences in citizen science is essential for the design of projects that generate value, both for participants as well as for scientists (ECSA, 2015). Teachers and students are important participants, and their needs differ from those of other citizen volunteers. Schools and other institutions, such as museums and science centres, have the specific potential to engage a larger and more diverse demographic of participants in science, with educators playing a

key role in facilitating their students' involvement in science (He & Wiggins, 2017; Shah & Martinez, 2016).

3.1 Types of Citizen Science Projects and Participant Engagement

In general, citizens can engage at various stages of the scientific process: in the development of research questions and hypotheses, in data collection, in data analysis, in drawing conclusions, and in communicating results. Bonney, Ballard, et al. (2009) developed a widely used categorisation to classify the types of citizen science projects (Fig. 3.1).

- (i) *Contributory projects*, which are generally designed by scientists and for which participants primarily contribute through data collection.
- (ii) *Collaborative projects*, which are generally designed by scientists and for which participants contribute through data collection, but may also help with the refinement of the project design, the analysis of data, or the communication of results.
- (iii) *Co-created projects*, which are designed by scientists and members of the public working together, and for which at least some participants are actively involved in most or all stages of the scientific research process.

However, the contributions of citizens in most citizen science projects remain of low complexity and with limited decision-making rights, as the majority of projects are contributory in nature (Suess-Reyes et al., 2020). Some criticisms of the contributory (*top-down*) approach in the context of science education will be presented ahead.

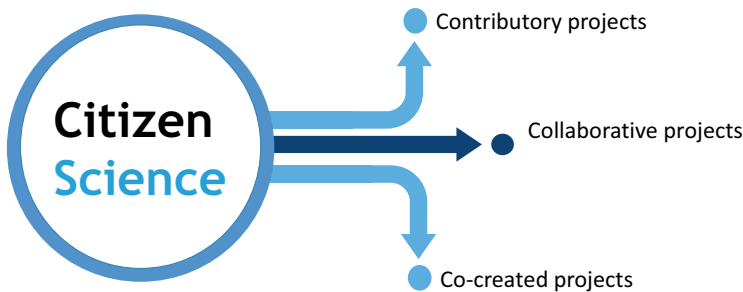


Fig. 3.1 Types of citizen science projects (Bonney, Ballard, et al., 2009)

3.2 Motivations for Participating in Citizen Science Projects

Several studies have been conducted to understand citizens’ motivations for participating in citizen science projects (Curtis, 2015; Land-Zandstra, Devilee, et al., 2016; Land-Zandstra et al., 2021). In many of these studies, the results reveal that participants are motivated by the fact that they are contributing to “real science” or to the overarching goal of the project (for example, the environment, health, biodiversity, astronomy). Another important motivation is often an intrinsic interest in the specific subject of the project, such as birds, galaxies, plants, etc. Other studies have shown that face-to-face interactions with scientists positively influence the level of participation in a project (Havens et al., 2012). Motivations related to social and recreational purposes influence levels of personal investment. Land-Zandstra et al. (2021) and Phillips et al. (2019), drawing on both the literature and interviews with 72 participants across six citizen science projects, conducted a comparative analysis of motivations in different types of projects, grouped according to extrinsic and intrinsic drivers (Fig. 3.2).

The co-created projects cite “environmental concerns” as the main motivation for participation, with 329 references (almost two-thirds of all references). Only the co-created projects mention “political distrust” as a driver motivating participation. Conversely, contributory and collaborative participants were more likely to mention “interest”, “contribution”, and “enjoyment”. Most participants reported multiple motivations, which confirms that participation in citizen science is driven by a range of interconnected factors.

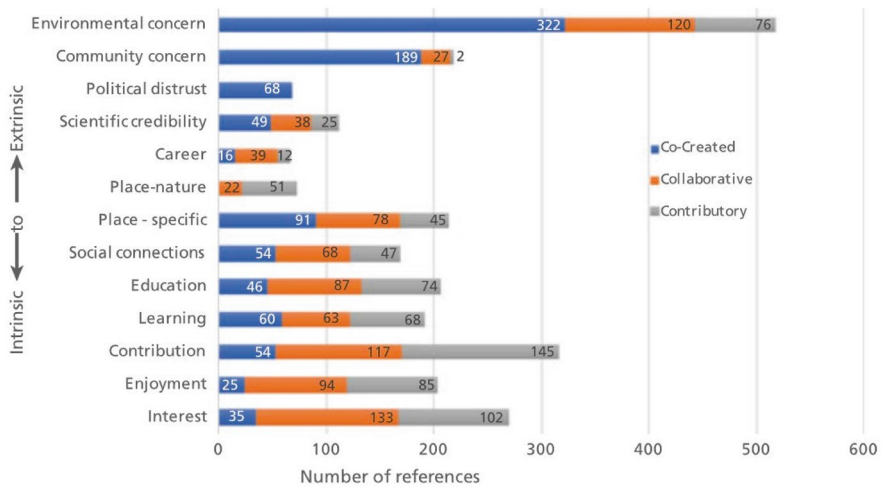


Fig. 3.2 Motivations cited by participants according to project type (Phillips et al., 2019, p. 682)

In addition to achieving a deeper understanding of the motivations for participation in citizen science projects, it is also important to consider how these motivations may change over time (Land-Zandstra, van Beusekom, et al., 2016). Participants who withdraw from projects after a short period present a significant challenge for those responsible for managing them. Some of the reasons for dropping out are linked to the dynamics of participation within a community, which are determined, for example, by culture, age, the level of identification with the project and its objectives, and the sense of belonging. For instance, a group that is homogeneous in terms of age or social status may act as a barrier to new participants feeling integrated. Therefore, welcoming new participants and enabling them to become part of a citizen science community is essential and should be carefully planned. Additionally, designing multiple ways for participants to engage in citizen science projects can support the integration of diverse profiles and encourage heterogeneous, plural, and inclusive participation.

Chapter 4

Citizen Science in a Digital World



The various developments in information sciences, particularly in data processing, graphical interfaces, and web applications based on geographic information systems, have been vital in empowering citizen science (Skarlatidou et al., 2019; Tsivitanidou & Ioannou, 2020). Digital technologies are making science and innovation more collaborative, international, and open to citizens (European Commission, 2016). Digital tools not only facilitate communication and collaboration, but also provide new means for large-scale data access, collection, and analysis (Gadermaier et al., 2018).

This, in turn, requires stable, effective, and easily accessible infrastructures, provided by citizen science platforms. These platforms can catalyse and foster collaboration among key actors and facilitate citizen engagement, while remaining accessible to the general public, public administrations, policymakers, and the media. Citizen science platforms can be designed to enable participants to interact with project data; they may also serve as learning spaces by providing useful resources, including tools and guidelines, best practices, and training modules (Liu et al., 2021; Lynn et al., 2019) (Fig. 4.1).

One of the oldest citizen science platforms is *Zooniverse*. Since then, many other platforms featuring various projects have emerged, such as *SciStarter* and *EU-Citizen.Science*, the latter resulting from the European project of the same name. This is an online platform for sharing knowledge, tools, training, and citizen science resources, by the community and for the community. The vision for the platform is to serve as a hub for knowledge, supporting the growth and popularisation of citizen science and strengthening the impact of citizen participation in research, encompassing the entire scientific process. This platform will not only make projects and data more easily accessible, but will also function as a space for mutual learning, enabling the sharing of tools, guidance, and training and examples of good practice in various languages to assist citizens, scientists, teachers, students, schools, and other relevant actors in participating in citizen science projects both

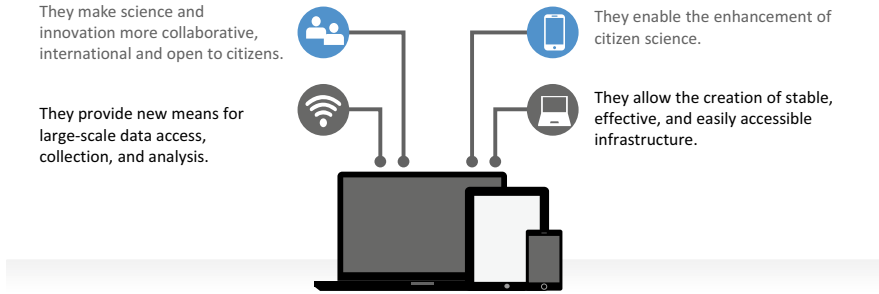


Fig. 4.1 Digital technologies have been vital in empowering citizen science

locally and internationally. Global initiatives such as these will be essential for harnessing the educational and learning potential of citizen science as a far-reaching social innovation.

The widespread use of mobile technologies, such as smartphones, has also created new opportunities in the field of citizen science (Bonney, Shirk, et al., 2014; Newman et al., 2012; Wynn, 2017). With mobile devices, citizens now have constant access to microcomputers equipped with sensors. Mobile applications can help overcome barriers of location and time, which are relevant to certain tasks associated with scientific research. For citizen science, the implementation of mobile applications means that participants can contribute with observations in real time. The immediate reporting of observations and relevant data not only increases the quality of the data provided (in terms of timeliness), but it also enhances the observer's connection to their environment, as the observer is immersed in the field and aware of the context of their observations (Liu et al., 2021).

The greater integration of machine learning¹ and artificial intelligence algorithms—associated with the idea that machines, using large volumes of data (big data), will be able to identify patterns and establish connections between them in order to learn to perform a task without human assistance and in an intelligent manner—may lead to future developments in citizen science. Some examples can be found in tasks involving observation and remote sensing (Ma et al., 2019), image interpretation (Pärtel et al., 2021), and monitoring the quality of collected data (Li et al., 2017; Zhang et al., 2018). In general, when the availability of large volumes of data threatens to overwhelm human efforts to analyse or meaningfully understand useful patterns and rules, these technologies can offer considerable advantages (Antoniou & Potsiou, 2020). Some citizen science projects have already integrated machine learning to perform pattern recognition tasks in data (Sullivan et al., 2018; Willi et al., 2019).

¹A branch of computer engineering and computer science related to artificial intelligence, which can be defined as the ability of computers to learn without being explicitly programmed, through the construction of algorithms. In this way, computers can make predictions.

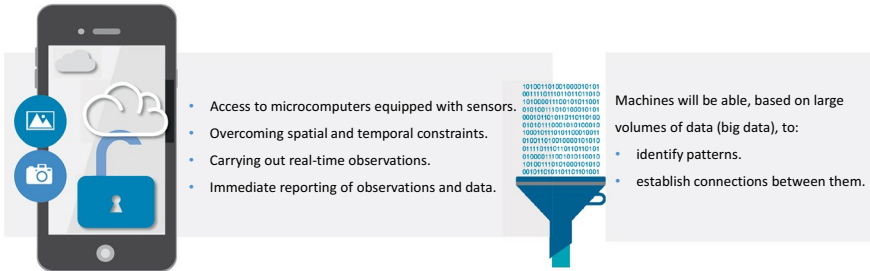


Fig. 4.2 Technologies create new opportunities for citizen science

The introduction of these technologies into citizen science projects is not intended to replace human beings. For various reasons, humans are and will always be necessary in the decision-making process, providing their intuition, imagination, and reasoning, which cannot be replicated by algorithms (Heaven, 2019).

Tsivitanidou and Ioannou (2020) conducted a survey of 15 citizen science projects, facilitated by digital technologies and integrated within the context of formal and non-formal education, to enable student engagement in the scientific research process. In this study, the authors sought to identify the types of citizen science projects, the learning outcomes resulting from students' participation in these projects, and the types of digital technologies used. Also Silva et al. (2016) report on the use of the citizen science application *Cell Spotting*, developed within the framework of the European project *Socientize*, which enabled the participation of hundreds of students (aged 15 to 18, from Portugal and Spain, who took part in the citizen science project as part of their regular classroom activities) in the analysis of large datasets related to cancer cells. The use of digital technologies offers potential benefits for student learning, as it provides new ways of investigating, collaborating, and communicating, with positive cognitive, social, and emotional effects (Aristeidou & Herodotou, 2020; Buchanan et al., 2018) (Fig. 4.2).

Chapter 5

Data Quality in Citizen Science



As noted by Hecker, Luckas, et al. (2018), data quality and ensuring the sustainability of citizen science projects are critical issues to consider. Many citizen science projects produce high-quality data (i.e., accurate, complete, relevant), but some projects reveal shortcomings in their data collection and analysis practices, such as lack of accuracy, absence of a standardised sampling protocol, poor spatial or temporal representation, and insufficient sample size.

This is not exclusive to citizen science: a 2016 *Nature* survey involving 1500 scientists showed that more than two-thirds had failed to reproduce at least one experiment conducted by another scientist, and half had even failed to reproduce one of their own results (Baker, 2016). Balázs et al. (2021) identify five categories which, while not exhaustive, are recognised as corresponding to the main issues surrounding data quality in citizen science. Four of these issues are related to data collection protocols: i) data collection protocols are not followed by participants; ii) they do not correspond to the project's objectives or are not properly adapted to the participants; iii) they are incorrectly implemented; iv) they are not comprehensive and are used by stakeholders with different levels of expectation regarding data quality. The authors refer to a final category: v) the data collected are not the most appropriate.

Ensuring data quality requires a set of strategies that should be considered before and during project implementation, as proposed by Balázs et al. (2021) (Fig. 5.1).

The following strategies are considered before and during implementation:

- (i) Study of participant profiles during the data collection and analysis process to understand the quality challenges that may arise throughout the project.
- (ii) Pilot tests with scientists and participants, involving the collection of sample data prior to the start of the project. This can help identify unforeseen sources of error or other issues that can be addressed in a timely manner.

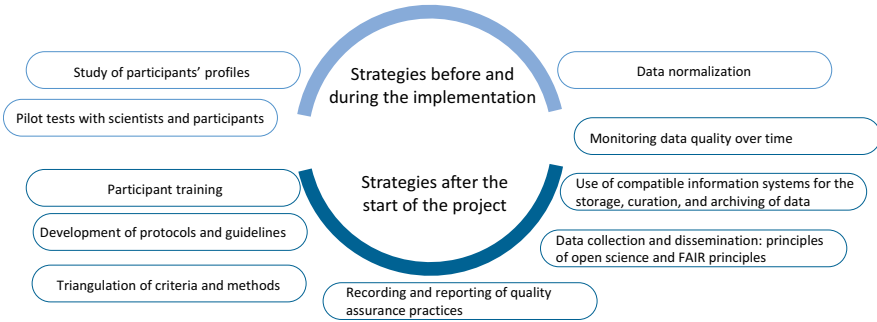


Fig. 5.1 Strategies before and during implementation and strategies after the start of the project

(iii) Data normalisation, which ensures that the expected data are stored consistently and allows for efficient access through a relational database. This normalisation reduces redundancy and the likelihood of data becoming inconsistent.

Quality control of data after the start of the project includes a set of strategies (Balázs et al., 2021), such as:

- (i) Training of participants to ensure they understand data quality and follow the minimum quality requirements for each citizen science project.
- (ii) Development of protocols and consistency standards to make data consistent and homogeneous. The use of protocols and standards should not negatively affect participant engagement levels or the openness of activities.
- (iii) Triangulation of criteria and methods to ensure data quality.
- (iv) Monitoring data quality over time to identify uncertainties and variations. Monitoring reports can be used to maintain or improve data quality and to provide feedback to project participants.
- (v) Use of compatible information systems for the storage, curation, and archiving of citizen science project data.
- (vi) Collection and dissemination of data in accordance with principles of open science and FAIR (Findable, Accessible, Interoperable, Reusable) standards, which were defined in 2016 by a consortium of scientists and organisations in the publication *Scientific Data*, relating to the curation of digital data.
- (vii) Recording and communication of quality assurance practices. This information should be provided in the description or metadata of a project so that similar failures can be avoided in the future.

Data quality issues are rarely shared between citizen science projects, which makes it difficult for new projects to learn from existing ones in terms of best practice approaches. Unfortunately, this means that the same data quality problems continue to appear. Furthermore, it is also necessary to communicate successful approaches related to data quality; in addition to contributing to credibility and trust, they also foster higher levels of citizen engagement and long-term project sustainability (EPA, 2019).

5.1 Challenges of Citizen Science: Informed Consent and Data Protection

Some challenges in citizen science are related to participant privacy, data protection, intellectual property rights, and the sustainability of projects (Fig. 5.2).

Data produced in citizen science projects can be generated by large communities, both in-person and online, with participant numbers that are constantly changing and expanding, making it difficult to recognise and identify thousands of individual contributions. The formal recognition of citizens’ contributions can also raise questions regarding data quality. Efforts to incorporate citizen-generated data into scientific publications are sometimes met with concerns from scientists, both as authors and reviewers, regarding the reliability of data collection and, ultimately, the quality of these data (Burgess et al., 2017). Furthermore, it may occur that the results of citizen science projects are published through alternative forms of communication aimed at reaching the general public, rather than being restricted to peer-reviewed scientific journals (Gadermaier et al., 2018).

Additionally, formal acknowledgements can be crucial motivational factors, helping to attract and retain volunteers, as well as to enhance accountability in research. Thus, as recommended by Tauginienė et al. (2021), it is important to discuss, directly with the participants, the possibility of co-authorship or formal recognition as early as possible in the research process. With the rise of user-oriented technologies, web 2.0, and the era of big data, informed consent will need to pay greater attention to a dialogical relationship between key agents and to give citizens more control over their own data.

It is also important to consider the need for continuous updates to the terms of reuse for data collected in scientific research projects. Moreover, with regard to participant protection, the need for training to conduct research in certain types of projects imposes restrictions on the use of citizen science. Considering the various aspects mentioned, through dynamic-informed consent (Tauginienė et al., 2021), allows for increased accountability and transparency in research and an overall enhancement of ethical literacy (Rasmussen, 2019).

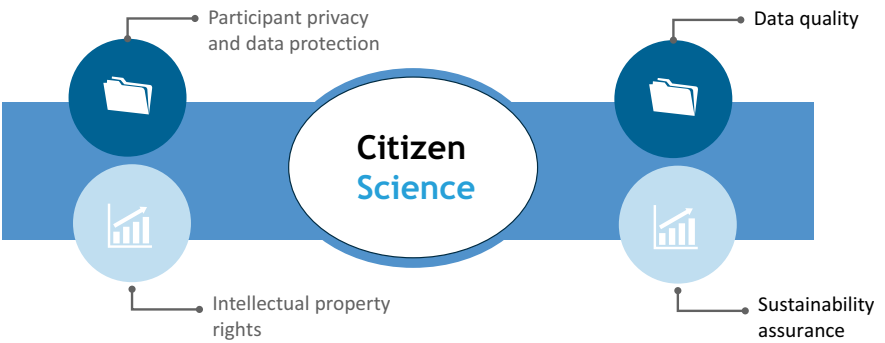


Fig. 5.2 Some challenges in citizen science

Furthermore, several authors (Resnik, 2019; Tauginienė et al., 2021; Wiggins & Wilbanks, 2019) suggest that, from the outset of citizen science projects, it should be clearly discussed with citizens what type of knowledge, form of dissemination of information, and type of recognition they prefer. Issues relating to privacy and data protection in citizen science must also be continuously safeguarded.

These factors help to promote the credibility of (citizen) science through responsibility, transparency, respect, and integrity, not only in the development of a dynamic-informed consent (adaptable to the needs that arise throughout the duration of the projects), but also throughout the entire process of scientific research involving citizen participation (Tauginienė et al., 2021).

Chapter 6

Contributions and Challenges of Integrating Citizen Science into Science Education



Citizen science is a growing field of research and practice that has generated new knowledge and enhanced understanding of the world around us, through the collaboration of citizens in scientific research. Compared to other practical scientific activities, the appeal of citizen science lies in the authenticity of scientific research, conducted in a participatory manner and with the potential for global reach (He & Wiggins, 2017). Citizen science initiatives, in various cutting-edge areas of science, are often developed to address socio-scientific issues, emerging problems, or pressing research questions (Tsivitanidou & Ioannou, 2020). It creates opportunities for citizens to take an active role in their communities (Mueller & Tippins, 2012), putting into practice active citizenship, given the fundamentals of participatory democracy, civic responsibility in science education (Mueller & Bentley, 2007) and shared activism (Boyd, 2001). The concept of active citizenship is closely aligned with the *Incheon Declaration: Education 2030: Towards inclusive and equitable quality education and lifelong learning for all*, by UNESCO (2015), which seeks to ensure inclusive, equitable and quality education on a global scale.

Several authors argue that participating directly in the scientific research process through citizen science is an excellent way to increase scientific knowledge and literacy (Bonney et al., 2016; Queiruga-Dios et al., 2020); to understand the process of scientific knowledge construction (Trautmann et al., 2012; Trumbull et al., 2000); to develop positive actions for the environment (Bopardikar et al., 2021; Lewandowski & Oberhauser, 2017); to improve attitudes towards science and the ability to engage in science; and to increase interest in science as a professional career (Queiruga-Dios et al., 2020). Citizen science has broad potential for transdisciplinarity and for integrating physical and natural sciences with health sciences, humanities, arts, economics, and social sciences (Kloetzer et al., 2021; Pykett et al., 2020; Tauginienė et al., 2020). It can also contribute to Sustainable Development, as advocated in the UN goals (Fraisl et al., 2020; Fritz et al., 2019; Queiruga-Dios et al., 2020), as it covers a wide range of relevant areas (e.g. water and air quality,

Fig. 6.1 Citizen science has proven to be promising for scientific research and educational practices



marine debris, biodiversity, health and gender issues), providing data and indicators for the achievement of the established goals (Fritz et al., 2019). Therefore, citizen participation is crucial for obtaining data and monitoring changes occurring at a global level. This data must be freely accessible, so that citizens can make informed decisions (Lu et al., 2015).

Participants in citizen science projects are involved in a learning process (Kloetzer et al., 2021), not only related to the development of the skills necessary for their participation, but also associated with a deeper understanding of scientific concepts and processes. Therefore, citizen science has increasingly been regarded as promising for scientific research and educational practices (Kloetzer et al., 2021) (Fig. 6.1).

In fact, citizen science projects are becoming globally popular for improving science education (Ballard, Dixon, et al., 2017; Bonney, Ballard, et al., 2009; Bonney et al., 2016; Heiss et al., 2021; Kelemen-Finan et al., 2018; Koomen et al., 2018; Koomen et al., 2016; Mueller & Tippins, 2012; Paige et al., 2015; Roche et al., 2020).

The integration of citizen science into formal and informal education contexts strengthens students' understanding of scientific abilities and science research skills through active participation in authentic research (Bopardikar et al., 2021; Shah & Martinez, 2016), relating daily life to science and bringing science, the scientific community and society closer together (Kelemen-Finan et al., 2018). The National Academies of Sciences, Engineering, and Medicine, in their publication *Learning through citizen science: Enhancing opportunities by design* (2018), provide a systematization of these ideas and suggest that the scientific context of a citizen science project can support learning in at least three ways:

- (i) *authentic scientific endeavour*: by definition, citizen science projects are authentic scientific endeavours, meaning they involve ongoing research into a scientific phenomenon conducted with a specific purpose. This authenticity provides an additional opportunity to engage in scientific practices and learn about the nature of science. Authenticity can also serve as a motivating factor for participation and learning;
- (ii) *natural environment and the real world*: most citizen science projects investigate phenomena in the natural environment, with fewer projects taking place in simulated (computer-generated) contexts that occur on observable scales. Taking place in a real-world context provides an opportunity to motivate learning based on relevance;

- (iii) *the centrality of data*: citizen science opportunities generally involve participants in data collection and analysis. The priority given to data in citizen science projects creates an opportunity to learn about the role of data in scientific research (the nature of science) and an opportunity to learn how to perform data analysis (a scientific practice).

In collaboration with scientists, students can have the opportunity to learn fundamental concepts and develop a deeper understanding of the nature of scientific research by engaging in scientific practices, including planning and conducting research, formulating research questions, collecting, analysing and interpreting data, constructing explanations and models, and reporting their findings to various key actors, including scientific and local communities (Bopardikar et al., 2021; Hayes et al., 2020; Houseal et al., 2014; Trautmann et al., 2012). Citizen science projects are contexts that promote the social construction of knowledge—teachers and students participate as part of a community of practice to examine issues of social importance (Gilbert et al., 2011).

6.1 Educational Research in the Field of Citizen Science

Over the last 20 years, educational research in the field of citizen science has sought to understand the individual learning outcomes resulting from citizen participation—such as school-aged children and young people participating in citizen science projects inside and outside school—as well as to obtain indicators related to their participation, motivation, interest, attitudes and behaviors (Ballard, Dixon, et al., 2017; Jennett et al., 2016; Perelló et al., 2017; Phillips et al., 2018). Kelemen-Finan et al. (2018) report evidence that some of the most important objectives of science education, namely, to increase knowledge, interest, motivation, and shape behavior and attitudes, can be achieved through the participation of young students in citizen science projects. However, as highlighted by Harlin et al. (2018) and Dohn (2021), there is considerably more literature on the learning outcomes of general public participation in citizen science than on student participation. Research on public participation reveals the development of motivation and skills related to scientific research among the participants (Brossard et al., 2005; Jones et al., 2018; Phillips et al., 2019; Price & Lee, 2013). Literature on student participation in citizen science projects highlights improvements in students' understanding of scientific content and research (e.g., Araújo et al., 2020b; Araújo et al., 2021a; Bonney, Ballard, et al., 2009; Brossard et al., 2005; Perelló et al., 2017; Trumbull et al., 2000; Williams et al., 2021), as well as in their motivation to care about environmental issues (Groulx et al., 2017; Hiller & Kitsantas, 2014; Kelemen-Finan et al., 2018; Silva et al., 2016). In the following topics, we will explore some of these aspects in greater detail.

6.2 Learning of Specific Scientific Content

Participation in citizen science often requires some familiarity with the scientific content in question and often asks participants to engage with new or unfamiliar content. According to the National Academies of Sciences, Engineering, and Medicine (2018), there is evidence that learning scientific content takes place within citizen science projects. For example, many projects dedicated to monitoring air and water quality require participants to develop specialized knowledge in identifying and documenting species or other natural phenomena and in collecting and organizing data. This can range from simple visual observations or routine measurements, at fixed times or locations, to more complex activities, such as identifying and providing scientific evidence for observed cases; or even patterns of discernment and prediction to optimize the probability of sampling irregular or unusual cases. To carry out these activities, participants need relevant disciplinary knowledge.

An example of a project that developed content knowledge in the field of biochemistry is *FoldIt* (Cooper et al., 2010). In the 1990s, scientists made significant advances in understanding the biochemical composition of proteins. However, describing their structure remained a challenge. The shape of proteins is important, because it determines their function and interaction with cells, viruses, or other proteins. Traditionally, expensive methods are used to determine the shape of proteins: X-ray crystallography, nuclear magnetic resonance spectroscopy or electron microscopy, with millions of protein structures still to be determined. This citizen science project emerged in 2008, and had participants work in the computationally challenging field of protein structure prediction. This project, presented in the form of an online game, is one of the most prominent and dynamic citizen science projects, as it updates its objectives to the needs of society. For example, a new challenge was recently made available, where players can test how antiviral proteins can be designed to bind to SARS-CoV-2.

Some authors argue that gamification is considered an effective strategy to further incorporate citizen science into non-formal education contexts, namely through in-game rewards that can be designed to prioritize the collection of good quality data (Piper, 2020; Tippins & Jensen, 2012).

A study by Williams et al. (2021) evaluated the effect of a citizen science project, integrated into a formal education context, on students' content knowledge, scientific identity, and connection to nature. Although scientific identity and connection to nature did not change significantly, content knowledge increased significantly. In addition, motivation towards the theme proposed in the project was positively associated with increased knowledge. According to the authors, their results support the widespread evidence that student participation in citizen science projects has the potential to promote content learning, but they caution scientists and educators to moderate expectations regarding students' connection to nature and the construction of scientific identity.

Kermish-Allen et al. (2019) sought to understand how scientists, community members, and elementary school students interacted to promote learning and

collaboration within an online learning community as part of the *WeatherBlur* citizen science project, which aimed to share, analyze, and interpret data on the local impact of climate change. In addition, the study examined the effect of student participation on their learning outcomes in the subject of earth sciences. The results suggest a high level of interactivity across all ages and groups and an increase in understanding of the content they studied.

Araújo et al. (2020b, 2021a) also report on the development of a citizen science project—*PVC: Perceiving the Value of Chemistry behind water and microplastics*—which sought to involve students in monitoring the physical-chemical parameters of coastal water quality by detecting microplastics in these waters, in addition to the qualitative identification of plastic contaminants on beaches. The project was developed during the 2018/2019 school year and involved 442 elementary school students between 12 and 14 years of age, who were attending Portuguese schools, and nine chemistry teachers in the northern coastal region of Portugal. Data on learning outcomes were collected through knowledge tests administered after the project's completion and compared with data collected up to six months later in a test of knowledge retention. In addition, interviews were conducted with participants, and field notes were also collected. Data analysis suggests the PVC citizen science project promoted conceptual learning of chemistry related to the analysis of physical-chemical parameters of water (pH, temperature, turbidity, salinity, nitrate and nitrite concentrations, and dissolved oxygen), as well as polymers (types of polymers, formation, and structure). Evidence of knowledge retention was found a few months after the project's completion.

6.3 Learning about Scientific Practices, Processes and Competencies

Building knowledge and developing skills related to scientific practices and processes in a specific content domain is known as procedural knowledge, sometimes described as “know-how” (Heyworth, 1999). In science, procedural knowledge enables the implementation of procedures and tasks within scientific protocols. This competence may involve the development of laboratory skills, measurement techniques, field methods, or analytical skills such as organizing, analysing, and presenting data. Although procedural knowledge is sometimes condensed into a fixed set of standard procedures—and there is certainly scientific value in maintaining consistent methods and protocols—,functional competence and active problem solving in science typically require adaptability and flexibility in application, which in turn requires a deeper understanding of why procedures and practices take a particular form and what are the implications of contextual variations. Therefore, it may take time for students who are new to science to understand that the measurements and evidence they provide are developed according to community norms, rather than being direct and obvious representations of the world (Manz, 2015). It

may take even longer for students to feel they can contribute to these standards, especially if these standards are presented as the “exclusive property” of scientists. According to the National Academies of Sciences, Engineering, and Medicine (2018), citizen science can also provide a useful context for learning about the use of scientific tools, practices, and processes. Indeed, the “real-life” nature of many citizen science projects provides an opportunity to use project-specific tools, protocols, and methods, allowing for a real experience of “doing science”.

One example of how citizen science can provide a learning context related to scientific tools, practices, and processes (along with scientific content knowledge) is the *Acadia Learning Project*. This is a citizen science project developed exclusively to form partnerships between teachers, students, and scientists. There are several sub-projects within the broader project (e.g., examining the presence of mercury and the nitrogen cycle in river basins), with data collection and analysis activities designed to be integrated with curricula. This project also implemented initiatives aimed at the professional development of teachers. In this regard, Zoellick et al. (2012), in a study conducted as part of this citizen science project (with the collaboration of 11 schools, 20 teachers and thousands of students), showed that some teachers and students needed additional support to carry out basic scientific work; however, they valued their involvement in a real and complex project. This was resolved with more professional training for teachers through regular online and face-to-face interaction in initiatives with scientists and summer institutes. Many training initiatives also focused on helping students develop good research questions and scientific skills related to ongoing research.

The National Academies of Sciences, Engineering, and Medicine (2018) note that many scientific tools and practices are linked to data sets and processes associated with collecting, organizing, representing, modelling, and interpreting that data. The power of data to improve our understanding of the natural world and to solve significant problems in our local and global communities is one of the factors that inspires people to participate in science. Although understanding and working with data is a subset of participation in scientific practices, the National Academies of Sciences, Engineering, and Medicine (2018) highlight these specific practices because of their centrality to citizen science.

The opportunities to learn to understand science and do science through active engagement with data are rich, abundant, and diverse. Repeated experience in representing data variability, combined with reflection on possible explanations for that variability, can help students better understand what drives good practice in the planning and implementation of data collection methods. Experiencing these situations in a real research context can help students become more attentive to the data collection process or even suggest some changes, such as improving observation conditions, using reliable instruments, using multiple samples to reduce the error rate in the collected data, among others (Lehrer & English, 2018).

Aivelo and Huovelin (2020), in their study with high school students in a citizen science project on urban rats, report that students described their perceived learning, including factual, conceptual, procedural, and metacognitive knowledge. Overall, the results related to conceptual knowledge were less significant than in previous

studies on learning in citizen science projects, while the results on procedural knowledge were more significant. According to the authors, their findings support the idea that citizen science can be a valuable opportunity for formal education, particularly with regard to incorporating authentic research practices into everyday classroom practice. Furthermore, student participation in a study coordinated by external partners (i.e., scientists) is seen as more valuable than experimental work done at school, especially in cases where data collection takes place outside the school context.

Moreover, Araújo et al. (2020b, 2021a), in their research within the PVC citizen science project, also state that, in terms of procedural knowledge, students learned laboratory techniques (sieving, filtration, and crystallization) and how to handle laboratory materials. In addition, teachers recognized that their students' participation in the PVC project fostered the development of their argumentation skills, as well as their reflection and critical thinking abilities. The authors also reported students' ability to communicate ideas and results, along with the development of their digital skills.

6.4 Understanding the Nature of Science

Students need to develop the ability to differentiate between facts, hypotheses, theories and evidence, and to understand how data can gain meaning as it is used to evaluate potential explanations. Additional learning objectives involve understanding how research designs, sampling and measurement methodologies provide theoretical interpretative frameworks through which research questions and hypotheses are related to data, and how these methodologies can enable or limit the strength of inferences that can be drawn from the data. Closely related to these skills is the process of scientific argumentation, whereby evidence-based claims to knowledge are constructed, alternative claims are considered and critiqued, and claims are revised. There is consensus that the development of scientific reasoning, argumentation and discourse skills requires opportunities for active engagement in scientific research practices (National Research Council, 2007, 2009, 2012).

Knowledge and reflection on science as an empirical way of knowing the world, which uses transparent methods to make evidence-based claims, implies an understanding of the nature of science (McComas & Olson, 2002; Osborne et al., 2003). This understanding also requires an awareness of the values implicit in scientific endeavors that shape the products of science, as well as an awareness of the ways in which science is not neutral and subject to constant review. It also includes an understanding of how scientific knowledge is constructed and the notion that there is a community of scientists who work together to construct knowledge by using a range of scientific methods and practices.

It is equally important to understand that scientific knowledge is based, in part, on human inference, imagination and creativity, as well as on surrounding social and cultural contexts. It has been argued that involving students in authentic

scientific research contributes to their understanding of the nature of science (Schwartz et al., 2004), but evidence suggests it is important to explicitly teach students about the nature of science (Abd-El-Khalick & Lederman, 2000). As citizen science is directly engaged in scientific activity, it has the potential—though largely unrealized—to provide opportunities to learn about the nature of science (NASEM, 2018).

A small number of research and assessment studies of citizen science projects have attempted to examine whether participants show gains in their understanding of the nature of science and in their ability to engage in various aspects of scientific reasoning. Reasoning and critical thinking are often difficult to measure reliably (National Research Council, 2011, 2014). Giving students who participate in citizen science projects the opportunity to understand the reasoning involved in decision-making at different stages and aspects of a citizen science project has proven to help them engage in more scientific thinking throughout their participation (NASEM, 2018). These opportunities are available in some citizen science projects, particularly those in which students have meaningful collaborative roles and have participated in decision-making associated with the creation or implementation of the projects and their activities (Bonney, Ballard, et al., 2009).

Citizen science investigative activities, according to the inquiry-based science education (IBSE) perspective, increase engagement, motivation, content learning, and understanding of the nature of science (Jenkins, 2011). A comparative study by Hiller and Kitsantas (2014) reported positive effects of participation in citizen science projects, compared to classroom-based science education, on content knowledge and perceived self-efficacy in scientific observation.

In university education, as reported by He et al. (2018), the nature of feedback to participants in citizen science projects had an effect on their motivation and efforts. Participation in citizen science stimulates the ability to question the mechanisms involved in the transfer of scientific knowledge between the scientific community and society, the articulation of expert and lay knowledge in science, and the ways in which public understanding of science is understood by science teachers and others (Jenkins, 1999). According to Williams et al. (2021), although some evaluations focus on content knowledge, few have explored other postulated outcomes, such as understanding attitudes towards science.

6.5 Development of Motivation, Interest and Positive Attitudes

Motivation, interest, and positive attitudes towards science are considered potential and important outcomes of participation in citizen science (Ballard, Dixon, et al., 2017; Bonney, Ballard, et al., 2009; NASEM, 2018). Vitone et al. (2016) conducted a study on the educational effects of activities from two citizen science projects (*School of Ants* and *Backyard Bark*) incorporated into an entomology course at the University of Florida. The authors used pre- and post-tests to assess students'

knowledge of insects and attitudes towards science. The authors reported an improvement in conceptual knowledge and revealed that student participation in scientific research positively changed attitudes towards science. The greatest positive attitude changes were recorded in students' interest in entomology and participation in citizen science projects.

Araújo et al. (2021b) conducted a study that aimed to identify students' attitudes towards science and whether their participation in the PVC citizen science project contributed to positive attitudinal changes. Thus, an attitudinal scale was developed, validated, and applied (as a pre- and post-test) to 574 students between the ages of 12 and 14, who were attending middle school in Portugal. Positive attitudes towards science were recorded from the outset among students in the control and experimental groups. The students in the experimental group demonstrated significant positive attitudinal changes in terms of critical analysis, related to the perceived development of skills, such as questioning and critical thinking. Furthermore, positive shifts in attitudes were observed, particularly in terms of affinity, perceived self-efficacy, and appreciation of both science classes and science as a whole.

In the context of a study on the integration of a citizen science project into the high school curriculum in Spain, Queiruga-Dios et al. (2020) reported a significant improvement in attitudes towards science and technology among participating students, as well as a better understanding of scientific processes. The results also reflected how the implementation of the citizen science project contributed to the United Nations Sustainable Development Goals. This study showed changes in the perception of science and technology among participating students, in line with the results of other studies on the impact of citizen science, both in formal education (RecerCaixa, 2016; Vitone et al., 2016) and in non-formal education (Bonney, Ballard, et al., 2009; Land-Zandstra, Devilee, et al., 2016; Ruiz-Mallén et al., 2016), as well as in pilot experiments for the co-creation of citizen science projects with high school students (Ruiz-Mallén et al., 2016; Senabre et al., 2018).

Other studies, such as Kelemen-Finan et al. (2018), examined students' interest and motivation in citizen science projects on biodiversity, integrated into formal education. The results showed that the students' interest and motivation, as well as their perceived self-efficacy, increased during the project. They also found that attitudes towards wild animals, natural gardens and biodiversity increased significantly.

Aivelo and Huovelin (2020) examined high school students' interest in a citizen science project on urban rats. The results suggested that students' interest was stimulated by their perceived contribution to a real research project. In addition, the authors noted that student participation in a project in which they can investigate an environment close to them proved to be significant for the students. The authors also noted that autonomy and freedom in choosing study locations increased students' interest in participating in the project.

Moreover, Silva et al. (2016) reported on how a citizen science project in cell biology, the *Cell Spotting* project, was implemented in high school classrooms in Spain and Portugal. The aim of the project was to search for new cancer treatments by asking volunteers to review a large number of images of cancer cells. Schools

were invited to participate, with teachers attending training workshops throughout the project. The project was well integrated with the biology curriculum and provided teachers with the necessary tools (e.g., a data analysis computer application developed by the project) and other support resources for implementing the project in a formal educational context. Teachers and students followed the project protocol to analyze the data using the *Cell Spotting* application and had opportunities to communicate directly with the scientist, the project's principal investigator. The duration of the project's implementation in classrooms ranged from a few lessons to months or an entire school year. The evaluation of the project's implementation reported gains in terms of knowledge acquisition and motivation among participants. On the other hand, teachers shared their concerns about implementation, citing lack of time, tight curricula, and the need to prepare students for national exams.

Schneiderhan-Opel and Bogner (2020) studied fascination with biology in a citizen science project on biodiversity. The authors conceptualized fascination as to include concepts of curiosity, interest, and identification with scientific research. High school students collected soil samples in forests near their homes and recorded the GPS location, composition, and condition of their respective forests. The authors found no change in fascination with biology from pre- to post-test.

Dohn (2021) examined high school students' interest in a citizen science program involving the genetic monitoring of freshwater fauna through the analysis of environmental DNA extracted from local pond water. The results indicated that students were enthusiastic about the highly sophisticated laboratory procedure. However, the most important finding was that the students' own contributions in terms of sample collection and analysis had only a small predictive effect on their interest. The authors hypothesized that this was because students participating in citizen science projects as part of their science classes were guided by curricular requirements and extrinsic goals (i.e., "compulsory volunteering"). Thus, they may not have been aware they were actually contributing to research, and may have felt they were "only" participating in a curricular learning experience.

Tsivitanidou and Ioannou (2020) acknowledged that the body of empirical work at the intersection of citizen science and formal and non-formal education is not very extensive. According to Phillips et al. (2018), several factors may explain the lack of more significant and measurable learning outcomes. First, the field of citizen science is still young, and those responsible for citizen science projects may not have clear concepts of what kind of learning they are trying to foster. Furthermore, the assessment of learning demands time, resources, and experience in science education research (Fig. 6.2).

Thus, although progress has been made in enhancing learning in citizen science projects and facilitating the integration of citizen science into formal and non-formal educational contexts, as shown by the increase of educational research on citizen science, there are still many challenges to overcome. Although such challenges can become barriers to the integration of citizen science into education systems, they can also be seen as relevant points for outlining possible synergies and opportunities (Roche et al., 2020). The National Academies of Sciences, Engineering, and Medicine, in their publication *Learning through citizen science: Enhancing*

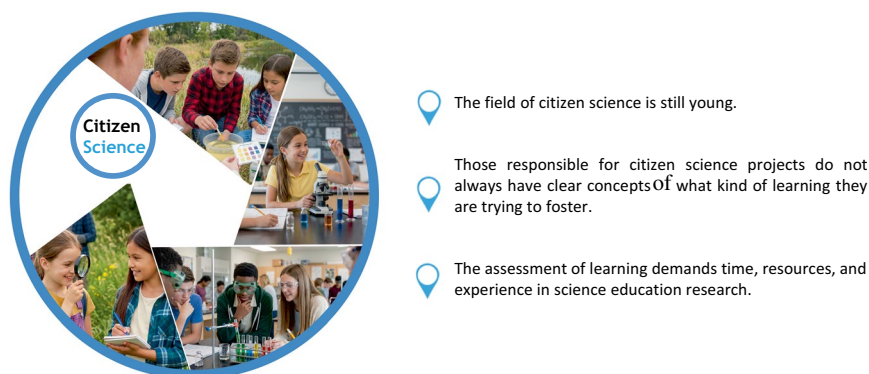


Fig. 6.2 Several factors may explain the lack of more significant and measurable learning outcomes at the intersection of citizen science with formal and non-formal education

opportunities by design (2018), set out to discuss the potential of citizen science to support science learning, identifying citizen science projects that exemplify promising practices and establishing a research agenda that could fill the gaps in the current understanding of how citizen science can support science learning and improve science education.

Citizen science can be integrated into education, in both formal and informal contexts. Formal learning usually takes place in school and university settings with clear learning objectives, while non-formal education can take place outside the classroom or after school, often in public engagement spaces such as museums, science centers, botanical gardens or aquariums (Eshach, 2007; National Research Council, 2009). Each environment poses unique challenges, which result from the different needs of scientists, students, teachers, educators, researchers, and other key agents (Roche et al., 2020). We will now seek to address specifically the educational potential and challenges of citizen science in both formal and non-formal educational contexts.

6.6 Citizen Science in Formal Education

The integration of citizen science into formal education is a unique opportunity to reach all sectors of society, thus embodying the democratic, inclusive and transformative potential of citizen science (Kloetzer et al., 2021), so that science is indeed for everyone and with everyone (Ruiz-Mallén et al., 2016). As Harlin et al. (2018) point out, citizen science brings advantages for all the actors involved: teachers and students have authentic access to science in action, including scientists, scientific research questions, processes, data and data analysis, which promote engagement with science and learning opportunities. Scientists, in turn, can collaborate with many volunteers (students) alongside “team leaders” (teachers), while expanding

public awareness of their topics and findings. A careful reading of the emerging scientific literature, which focuses on the integration of citizen science projects in schools, supports this hypothesis, but also highlights some critical challenges, as will be reported below. Schools are seen as having great multiplier and outreach potential, with teachers playing a key role as participants, facilitators, and motivators in citizen science projects (Weinstein, 2012). In the classroom, teachers often face the challenge of finding a balance between curriculum development and the desire to find new and interesting ways to engage and motivate students (Harlin et al., 2018). Participation in the collection and analysis of real-world data is engaging for both students and teachers (Trautmann et al., 2012). Because it has real-world value, citizen science can reinforce the meaning of learning (Paige et al., 2015).

6.6.1 *Factors that Promote the Integration of Citizen Science into Formal Education*

Support from school and university management bodies, as well as peer support, are factors that encourage teachers to participate in citizen science (Harlin et al., 2018). As Hayes et al. (2020) point out, having a network of teachers who jointly implement citizen science projects has many benefits, including opportunities to solve problems and encourage each other, to structure projects vertically, allowing interaction on different topics and school years, as well as share data and analysis processes. The support and approval of management bodies is also essential to help teachers maintain implementation. Administrative support helps make citizen science a pillar of science integration in schools and helps eliminate barriers (e.g., lack of financial resources) that might otherwise constrain project implementation.

Another essential factor that promotes the integration of citizen science projects into formal education is related to the availability of relevant teaching materials to facilitate teachers' work in connecting them with the school curriculum (Bonney, Phillips, et al., 2014; Harlin et al., 2018; Jenkins, 2011; Kloetzer et al., 2021) (Fig. 6.3).

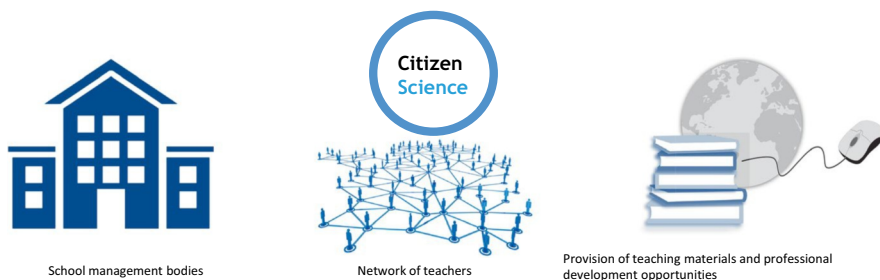


Fig. 6.3 Factors that enhance the integration of citizen science projects into formal education

Citizen science projects can be linked to the school curriculum through their research topic, but also through the processes selected for data collection and analysis. Providing explicit tools and information enables students to engage in the scientific research process without losing sight of the school curriculum. This is essential, especially if students are involved in data collection without prior experience of the research process (Jenkins et al., 2015). Providing these resources reduces the risk that teachers will fail to meet the educational objectives of the school curriculum (Gray et al., 2012). However, as highlighted by Bonney, Cooper, et al. (2009), simply offering project support materials to groups of teachers rarely leads to taking on projects. More importantly, opportunities for professional development for teachers must also be offered (Harlin et al., 2018).

6.6.2 Ways of Integrating Citizen Science into Formal Education

Harlin et al. (2018) organize three ways of integrating citizen science into schools, which are in line with those mentioned by the National Academies of Sciences, Engineering, and Medicine (2018).

The first way relates to adopting and adapting *existing citizen science projects, even if the project did not initially have clear educational purposes*. These are citizen science projects that were originally designed without explicit learning objectives and were later used to promote learning. This option of pedagogically leveraging the hundreds of citizen science projects available around the world opens up great possibilities, but it can also make it difficult to know which projects are suitable for the region or school curriculum. For example, the *CITI-SENSE* project, completed in 2016, involved high school students (from nine European cities) in research on urban air quality, the environmental quality of urban public spaces, and indoor air quality in schools. The results indicated that students and teachers were motivated to participate in environmental research and were able to carry out high-quality studies.

However, additional efforts were required to integrate research into narrow time windows during which the curriculum requirements matched the needs of scientific research. Schools also expressed concerns about privacy, misuse of data, and how to deal with school policies on access to technology and the internet. Thus, although school recruitment has been successful, it requires significant time and effort.

Rather than actively recruiting schools, it is more common for citizen science projects to make themselves available online for teachers to learn about them. Some projects have developed support resources, ranging from teaching guides to specific protocols and individual lesson plans.

According to records, the oldest and most widely used citizen science project for schools is the *GLOBE Program (Global Learning and Observations to Benefit the Environment)*. This is an international citizen science project, sponsored by NASA

since 1995, with support from the National Oceanic and Atmospheric Administration and the National Science Foundation. It involves teachers and students from various levels of education in collecting a wide variety of environmental data. It is present in more than 100 countries and has more than 100 million entries in its internal database. Developed explicitly for schools, its initiatives and teacher support resources are extensive.

The second way relates to the *development of a local citizen science project that includes scientific citizenship practices used for learning*. These are suitable for particularly motivated teachers who want to develop their own citizen science projects in their local environments. The main aspects to consider in this context include, first, the choice of a research question, together with the development of a connection with the scientific community. This is followed by professional training for teachers, if possible, in groups, where they can discuss how to guide students, as well as the ethical, scientific and practical issues of research.

Finally, there are practical issues, including the choice of data collection and analysis tools. Often, practices or elements of citizen science are used to promote learning, but some essential features of citizen science are missing; for example, a teacher may teach their students to use a citizen science protocol to analyze water quality in a local stream, which presents a variety of opportunities for different types of learning, but is not necessarily citizen science in itself. However, more often than not, teachers and students take their participation to the next level by contributing to citizen science projects where they not only collect data according to a prescribed protocol, but also share their data with a database accessible to the wider community or use it in local decision-making.

The third way is the *development of local partnerships between scientists and teachers to create citizen science projects for educational purposes*. These are projects that are intentionally designed to support science learning from the outset (along with other objectives). In this example, scientists, teachers, and often community leaders work together to design a project with learning objectives that integrate with other project objectives, such as collecting high-quality scientific data. This type of project has been tested by the Cornell Lab of Ornithology, in Cornell University, over the past twenty years, where it has been very productive, but it requires careful planning and significant effort from both teachers and researchers. It also requires interdisciplinary collaboration between experts in education, biology, information science, computational statistics, and evaluation. The co-construction of citizen science projects facilitates links to the curriculum, as in the *BirdSleuth* project, which was developed over three years, with extensive input from more than 100 high school teachers across North America. Teachers collaborated in the development of the project and in conducting pilot experiments on the school grounds (Bonney, Cooper, et al., 2009). These partnerships are time-intensive for teachers and scientists in order to achieve a productive balance between scientific and educational goals.

Perelló et al. (2017) presented empirical results on the implementation of citizen science projects in formal education (each involving more than 500 high school students between the ages of 12 and 15) and proposed an assessment rubric model

that considers four categories: scientific attitudes, communication, use of information technologies, and participation and motivation. The results of the study revealed that, by requiring a very comprehensive cognitive and organizational effort, students developed good scientific skills to think and act like researchers. They also improved their communication and technology skills.

Despite the positive results, some differences were observed between the projects, with the open inquiry design facilitating the development of different skills and attitudes. By pursuing context-based learning and shifting research to students' everyday lives, schools can produce real research and help strengthen the links between citizen science, citizenship and democracy, thus helping to address major social challenges.

6.6.3 Challenges for Integrating Citizen Science into Formal Education

There are some challenges related to the participation of teachers, students and academic institutions in citizen science projects, such as (Fig. 6.4):

- (i) *Motivation and interest of young students*: the initial commitment for youth participation is usually made by adults, for example, in their role as teachers or parents (Kelemen-Finan et al., 2018). In the case of teachers, if they participate in or initiate citizen science projects in which students are automatically involved, this may lead to constraints related to students' motivation and interest in participating (Kloetzer et al., 2021). As Aivelo and Huovelin (2020) point out, participation is usually driven by the curriculum and teachers' decisions on how to implement that curriculum. Therefore, it is important to

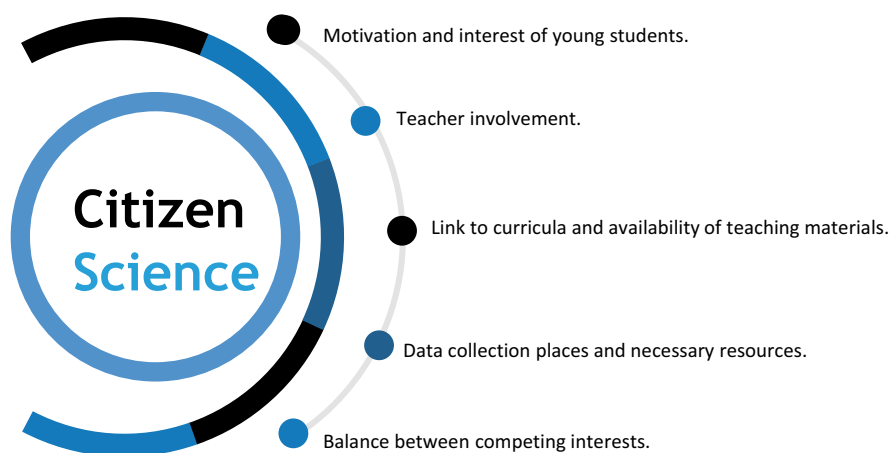


Fig. 6.4 Challenges for the integration of citizen science into formal education

consider how participation that occurs in a non-voluntary context (as in the case of formal education, where a grade may depend on participation) can influence learning outcomes. The resources and structure available in a formal education setting can foster motivation and interest, but the negative consequences associated with non-participation or “incorrect” participation can also have destructive impacts on participants’ motivation (NASEM, 2018). Freedom of choice is an important mechanism for developing interest in science. As Dohn (2021) points out, this “compulsory volunteering” can make students unaware they are actually contributing to scientific research, believing they are “only” participating in a curricular learning experience. Therefore, it is important to understand the impact of the absence of “free-choice learning”, in which interest and intention to learn do not originate from the student, but are imposed by external elements (Falk & Dierking, 2012). Another aspect of freedom of choice is informed choice. In this regard, the article “Engaging students through citizen science, by the National Science Teaching Association” (NSTA, 2018), revealed that students can contribute significantly to citizen science projects. However, as Hayes et al. (2020) suggest, when they do not understand why they are collecting data, why they are collecting data in a certain way, or what the data may mean when properly analysed, the educational potential of citizen science projects may be compromised.

- (ii) *Teacher involvement*: as mentioned above, teachers taking on citizen science projects is important, but difficulties may arise. The way teachers view their role in teaching, coupled with their perceived academic authority over their students, may conflict with the reality of their involvement in citizen science projects (Fazio & Karrow, 2015). Their multiple tasks as participants and facilitators make school participation in citizen science challenging, especially if teachers lack confidence in their content knowledge, scientific literacy (Jenkins et al., 2015), or ability to manage student participation in projects that take place outside the school environment. Overcoming these difficulties may require systematic and structured training and support (Jeanpierre et al., 2005; Zoellick et al., 2012).
- (iii) *Link to curricula*: the relationship between learning and the learning of institutionally defined content and skills, through national and subject curricula, programs, exams, assessments, etc., is a determining factor. The participation of teachers and, consequently, the participation of students in citizen science depends on the specificities of the school and curriculum (Jenkins, 1999), which need to enable, value and stimulate learning in real contexts through participation in scientific research projects. Flexible curricula facilitate the involvement of teachers and their students.
- (iv) *Data collection sites and necessary resources*: operating within the “boundaries” of a school environment also presents logistical challenges that can compromise data collection. For example, field observations that are necessary outside of school hours, or outside of the school grounds, require an extra level of organization (Soanes et al., 2020). School participation may also be constrained by timetables or logistical issues. For teachers and schools interested

in participating in citizen science projects, it can be difficult to navigate the number of initiatives available to them, especially if these involve frequent data collection outside the school grounds, which may require funding for transportation and a time allocation that is not always feasible. Therefore, students cannot collect data as often or will have to do so only outside of school hours, which understandably presents its own constraints (Hayes et al., 2020). Additionally, it is important to consider projects that do not require specialized equipment or that need to take into account the availability of such equipment. If data collection is not feasible for all students based on their location, it will be important to develop tasks that allow students to contribute to the project in other ways, such as organizing classes for the observation of data collected from various sites and sharing results with classmates. It is also possible for students to analyse data collected by citizens in other locations, and compare this data with their own, in order to expand their understanding and draw broader and more generalizable conclusions about the scientific information revealed in the data (Hayes et al., 2020). Research in the field of citizen science recognizes that science teachers and students (and other members of the community) are participating members of a wider scientific community. Scientific data is increasingly being made available on the World Wide Web, from sea turtle and bird migrations to real-time earthquake, water and air quality monitoring, as well as volcano activity records. These data sets can be analysed by science teachers and students and then compared with scientific work taking place around the world (Mueller & Tippins, 2012).

- (v) *Balancing competing interests*: although student-teacher-scientist partnerships offer many benefits, such as high levels of student engagement (McLaughlin et al., 2016), it is also a challenge to implement these partnerships. For example, scientists are concerned about the validity of scientific research involving data collected by students, and teachers are concerned about time demands and aligning objectives and activities with curriculum standards. It is therefore necessary to ensure the quality of fieldwork and data is maintained to achieve important scientific benefits, while focusing on the learning objectives to be achieved (Shah & Martinez, 2016). Moreover, it is difficult to gather meaningful scientific results in short periods of time, but the lack of results risks diminishing student interest. Thus, while the data collected by students can contribute to long-term datasets, it is difficult for students to see clear patterns in the short term (Bopardikar et al., 2021). Teachers and scientists need to balance educational and scientific outcomes to ensure fruitful cooperation. The different objectives of students, teachers, and scientists influence how educational experiences can be planned, implemented, and experienced at the respective points of engagement between these actors (Scheuch et al., 2018). Concerns about data quality and publication are also perceived barriers to student involvement in citizen science projects, particularly for younger age groups (Pitt & Schultz, 2018; Soanes et al., 2020; Trautmann et al., 2012). As Soanes et al. (2020) point out, quality data collection can take place if students have age-appropriate prior training, so that they understand what they are collecting and for what

purpose. In addition, it is important to regularly validate protocols, allowing the data collected by students to be comparable with other studies. Achieving the right balance between independent data collection and scientific supervision is key to ensuring that the collected data meets the project's objectives and that students are benefiting from meaningful engagement in scientific research work alongside scientists (Zoellick et al., 2012). When deciding how much time to invest, it is worth remembering that students' interactions with scientists are often some of the most popular and important aspects of the experience (Trautmann et al., 2012; Zoellick et al., 2012). Consequently, educational institutions, such as schools and universities, can become mediators between scientists and educators to ensure that both research and educational objectives are achieved (Zoellick et al., 2012). Moreover, citizen science projects adapted to the school context should be disseminated so that teachers can easily identify them. Thus, as corroborated by Roche et al. (2020), one of the main emerging challenges is to align educational learning outcomes with the objectives of citizen science projects in the project planning phase, using co-creation approaches, to ensure that accessibility and inclusivity issues are paramount throughout the project, from its design to its implementation. Only then can citizen science achieve its true potential to empower citizens to take ownership of their own science education and learning.

For citizen science to reach its potential within formal education, significant teamwork between scientists, teachers, and students will be necessary. Another challenge is working within the difficult constraints faced by teachers, including time, training, and curriculum. These challenges can be overcome with adequate training, the aid and development of technologies, and a support structure built around the integration of citizen science into the curriculum that includes recognition of its value to young people and to science.

6.7 Citizen Science in Non-formal Education

Non-formal education settings, such as science centres and museums, are crucial for science education (Burke & Navas Iannini, 2021). Citizen science projects find a "natural home" in these contexts due to their strong commitment to public engagement (Ballard, Robinson, et al., 2017), as well as their role in working simultaneously with the public, scientists, and formal education systems (Kloetzer et al., 2021; Sforzi et al., 2018). Thus, they are ideally positioned at the intersection of science, education, and public engagement with socio-scientific issues of both local and global relevance (Kloetzer et al., 2021). One of the common challenges faced in these contexts relates to the time and resources required to make activities engaging, and the efforts needed to serve the scientific and educational objectives of the project (National Research Council, 2009).

Learning that takes place in non-formal environments, through citizen science projects, can be difficult to capture. Nevertheless, efforts have been made to find ways to assess the intended learning outcomes for participants in these projects.

In this regard, Phillips et al. (2018) propose a framework for articulating and measuring individual learning outcomes resulting from participation in citizen science projects, which includes: interest in science and the environment (Phillips et al., 2019), self-efficacy, motivation, understanding of the nature of science, scientific inquiry skills, and behaviour and management. Edwards (2014) highlighted that the specific impact that citizen science can have on lifelong learning for individuals outside the classroom has not yet been widely explored. Similarly, although understanding social and cultural capital is fundamental to interpreting how people engage with non-formal science education institutions (Dawson, 2014), the way in which this capital affects participation in citizen science projects and the equity issues that may arise has not yet been sufficiently investigated (Birmingham, 2016).

Citizen science faces the same issues of inequality that are endemic throughout society, with inherent barriers to the participation of minorities and disadvantaged communities (Fiske et al., 2019; Soleri et al., 2016). Scientific capital (Bourdieu, 2001)—a concept that explores how a person’s environment and social class can affect their engagement with science—could make it easier to identify “inequalities in scientific participation”, which in turn could be used to promote “social justice within science education” (Archer et al., 2015, p. 943). If citizen science is to fulfil its potential in improving equity of access and participation in science education within informal learning environments, then “the extent to which citizen science can build science capital and enable greater engagement with science-related issues [...] warrants further investigation” (Edwards et al., 2018, p. 390).

6.8 Criticisms of the Contributive (Top-Down) Approach

Despite the potential benefits of strengthening science education through citizen science (Fazio & Karrow, 2015), some criticisms arise regarding the contributory (top-down) approach, which is frequently used, where a team of scientists and educators determines the research questions, the research protocol, and who will be included in the project (Mueller & Tippins, 2012). Although a scientist-led approach is an effective way to cover a wide area, in this case students/citizens are limited to data collection, while professionals design and test the protocols, analyse the data collected by volunteers, and publish the results. This approach also restricts the amount of time scientists spend within the community collaborating with citizens. Furthermore, a purely contributory model of citizen science may reinforce the silencing and lack of agency of teachers and students. According to Mueller and Tippins (2012, 2015), if citizen science is to be recognised for the relevant and meaningful questions it seeks to generate and the types of research it aims to conduct, in response to improving the living conditions of communities, it is important to strike a balance between scientist-led agendas and community-driven agendas.

When science teachers and students are acknowledged as active participants in the authentic research process, they are better positioned to take part in community decision-making about which problems should be addressed, which equipment can be designed locally, and which methods and protocols may guide scientific investigation.

6.9 Some Examples of Citizen Science Projects

Currently, there are numerous international platforms that host citizen science projects, with platforms such as *Zooniverse*, *EU-Citizen. Science*, and *SciStarter* probably hosting the largest and most diverse range of projects from various countries and fields of knowledge. Users can search for projects by activity, location, whether the projects are linked to schools, and whether they offer teaching materials.

Some of the oldest examples of citizen science projects that continue to this day date back to the late nineteenth century. These include the *Cooperative Observer Program* of the National Weather Service (USA, since 1890) and the *Audubon Christmas Bird Count* (since 1900) (Luís, 2021). A notable example of the integration of citizen science projects—primarily related to large-scale bird monitoring—into science education comes from the Cornell Lab of Ornithology, where ornithologists have been dedicated to promoting scientific research through the involvement of primary and secondary school students and adult volunteers, the development of citizen science curriculum materials, the design of guides, observation protocols, and scientific databases for bird monitoring, among other initiatives.

The *Classroom FeederWatch* (Bonney & Dhondt, 1997) and *Monarch Larva Monitoring* (Kountoupes & Oberhauser, 2008) projects are examples of citizen science initiatives in which the tasks were linked to the curricula of the respective age groups, enhancing local school engagement while generating valuable data for the projects as a whole (Bonney, Cooper, et al., 2009; Bonney et al., 2016).

More recent projects, such as *School of Ants* (Lucky et al., 2014), *LandSense* (Olteanu-Raimond et al., 2018), and *eMammal* (Schuttler et al., 2018), have highlighted the international success of these large-scale citizen science projects involving schools. Another example is the citizen science project *LiMPETS* (*Long-term Monitoring Program and Experiential Training for Students*). This is a coastal monitoring project for students, teachers, and volunteer groups from community organisations, which takes place in formal education settings with groups of students from various educational levels, as well as in non-formal contexts involving the Pacific Grove Museum of Natural History. The project coordinators train the teachers, provide a range of supporting materials, and contribute to the training of students in field data collection methods and the development of research questions (Ballard, Dixon, et al., 2017).

Luís (2021) provides a brief overview of citizen science in Portugal, where the number of citizen science projects has increased substantially in recent years,

following the global trend; that is, they are predominantly in the fields of environment, biodiversity, health, and astronomy. Within the scope of this work, particular emphasis is placed on projects implemented at the national level in both formal and non-formal education contexts (Table 6.1).

Table 6.1 Examples of citizen science projects in Portugal (Luís, 2021)

Project	Brief description
III atlas of breeding birds of Portugal	Arises from the need to carry out a new comprehensive survey of the distribution and abundance of breeding birds throughout the national territory.
The cotton bud plague	Project aimed at raising awareness about the situation on Portuguese beaches regarding the quantity of cotton buds, while also contributing to raising awareness and solving the problem.
BioDiversity4All	Online biodiversity platform, accessible to all, featuring records of plants, animals, and fungi submitted by citizens.
Asteroid hunters	An asteroid search project coordinated by the University of Texas, involving schools from around forty countries, including Portugal.
Ponds with life	Aims to encourage the inventory, adoption, construction and maintenance of ponds and small water bodies for the development of scientific and educational exploration activities and for the observation of biodiversity, as well as to raise awareness of the importance of these habitats and their conservation.
CoastwatchPortugal	European environmental education and citizen science project in which Portugal also participates, focused on the environmental monitoring of the Portuguese coastline.
EduMar	Project aimed at raising awareness among primary and lower secondary students about the preservation of the sea and its resources through citizen science activities.
Galaxy zoo	Pioneering online platform that seeks public involvement in the classification of millions of galaxies, thereby supporting astronomers' research into the evolution of the universe. Available in Portugal.
Gripenet	Monitoring of the seasonal influenza epidemic online, based on voluntary citizen participation.
Invasoras.Pt	To raise awareness of the issue of biological invasions, to inform about invasive plant species at the national level, and to encourage active public participation both in mapping these species and in control and outreach activities.
MEDEA	Project for measuring electromagnetic fields in the environment, carried out by students from various secondary, vocational, and higher education institutions, aiming to measure electric and magnetic fields in the environment.
Sun4All	Project developed within the framework of the European <i>Socientize</i> project, aiming to promote astronomy among students in non-higher education schools using a collection of images of the sun.
Under water watch	Monitoring of marine litter present in the Portuguese coastal zone, down to a depth of approximately 20 m, through sampling and scuba diving activities carried out by citizens, with the support of diving centres and schools.

6.10 The Case of the PVC and Coastro Citizen Science Projects

The following two citizen science projects (Araújo, 2020; Costa, 2020), developed as part of doctoral research in Science Education and Communication, were implemented in formal and non-formal contexts under the supervision of the author of this work.

6.10.1 *PVC Project—Perceiving the Value of Chemistry Behind Water and Microplastics*

Although citizen science has the potential to enhance chemistry education (Araújo et al., 2021a; Urválková & Janoušková, 2019), according to Hecker, Garbe, et al. (2018), as well as through a brief survey of citizen science project aggregator platforms, it is evident that chemistry is one of the least represented sciences. Typically, when citizen science projects involve chemistry, it appears merely as a useful tool (as in environmental projects focusing, for example, on soil or air quality monitoring) or as a bridge to foster the interdisciplinarity of the project. This scarcity of citizen science projects in chemistry, according to Motion (2019), may be due to the fact that the safe handling of chemicals outside specialised laboratories can be problematic, and the use of specialised software or equipment may be prohibitively expensive or simply too critical for institutions to lend for use in schools or communities. Despite these constraints, Nichols (2018) emphasises that citizen science is a way to demonstrate the relevance of chemistry to the community.

In this context, given the lack of citizen science projects in chemistry and taking into account a range of other factors—such as: i) Portugal is a country with a vast coastline and strong historical ties to the sea; ii) the guidelines of the United Nations 2030 Agenda for Sustainable Development, particularly Goal 14, which recommends the conservation and sustainable use of oceans, seas, and marine resources; iii) the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), which aims to promote scientific knowledge and innovation for the sustainable management of the oceans, was therefore considered relevant to develop and implement a citizen science project within the context of coastal water quality, particularly the contamination of water by plastics and microplastics. Additionally, this issue is also recognised by the scientific community. This served as the driving force for the development of the *PVC* project.

A quick search on the *SciStarter* platform returns several successful examples of citizen science projects with themes similar to the *PVC* project, such as the international projects *EarthEcho Water Challenge* and *The Big Microplastic Survey*. However, their main objectives are to involve participants in the scientific research process through data collection and analysis, with the educational potential of these projects often relegated to a secondary role. Nevertheless, in the *EarthEcho Water*

Challenge project, activities are directed towards raising environmental awareness among young people and communicating information to the community. The project provides participants with a low-cost, basic kit for analysing certain physicochemical parameters of water quality, such as temperature, pH, turbidity, and dissolved oxygen, containing all the materials, reagents, and experimental procedures required for citizens to independently monitor the quality of watercourses in their community.

In order to better understand the value and role of chemical science, to promote both conceptual and procedural knowledge in chemistry (Araújo et al., 2021a), and to foster positive attitudes towards science (Araújo et al., 2021b), it was decided to develop the *PVC* project partially aligned with the objectives of the *EarthEcho Water Challenge* project. Thus, an educational kit was also developed, enabling the expansion of the number of physicochemical parameters analysed in the water. In addition to temperature, pH, turbidity, and dissolved oxygen, the analysis of nitrate and nitrite concentrations and salinity were also included, in line with the reference parameters for water quality indicated by the Portuguese Environment Agency (APA, 2021), as well as the detection of the presence of microplastics in these waters (Araújo et al., 2020a). To further enhance the chemical dimension of the *PVC* project, certain concepts related to polymer chemistry were also explored, including, in the design of the educational activities, the detection of microplastics in coastal waters.

The *PVC* project has already actively involved around 500 lower secondary school students and their teachers in four main stages: 1) online tasks, carried out on the *Moodle* platform, to raise awareness about marine litter, particularly the presence of (micro)plastics in coastal waters and their consequences (Araújo et al., 2020b), and, at the same time, to highlight the importance of chemistry and its preventive role in addressing these environmental challenges; 2) sampling of coastal waters and collection of plastics on the beach (Fig. 6.5); 3) physicochemical analysis of the waters and identification of (micro)plastics to promote the development of scientific skills and the learning of chemistry curriculum content underlying the project; and 4) dissemination of the project results to mobilise acquired knowledge and develop communication skills.

The communication and dissemination phase of the *PVC* project had distinct objectives. Firstly, it took place within the schools of the participating students through awareness campaigns addressing the environmental issues explored, as well as the organisation of scientific outreach sessions open to the school community. Secondly, the results concerning the quality of coastal waters were shared with the entire international community via the *EarthEcho Water Challenge* project platform. This enabled the students involved in the *PVC* project to become part of the international *EarthEcho Water Challenge* community, which already includes over 340,000 participants from 80 countries, actively contributing to the knowledge of scientists, organisations, and citizens regarding water quality, thereby enabling them to take appropriate measures to protect aquatic resources that are vital for the sustainability of the planet and its communities. It is worth noting that teachers were supported throughout all stages of the project's implementation and that all educational resources were developed in collaboration with scientists, who often accompanied the data collection and analysis process. The scientists also collaborated in leading outreach initiatives for the school community.

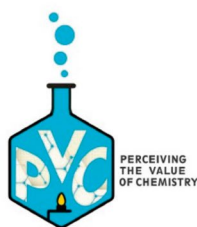


Fig. 6.5 PVC citizen science project: kits developed for the collection and analysis of certain physico-chemical water quality parameters

6.10.2 *CoAstro Project: An Astronomy Condominium*

The citizen science project *CoAstro: An Astronomy Condominium* brought into direct interaction five astronomers, nine primary school teachers, four science communicators, and one facilitator (Fig. 6.6). Throughout one academic year, within the *CoAstro* project, scientific content and processes were appropriated and integrated by the teachers into initiatives involving school communities, the Porto Planetarium—Centro Ciência Viva (PP-CCV), and the Institute of Astrophysics and Space Sciences (IA), directly reaching 980 people. *CoAstro* was one of the first Portuguese citizen science projects in astronomy that: i) had scientific objectives, but also aimed at science communication; ii) was implemented through primary school teachers and their schools, with a strong emphasis on teachers' professional development; iii) focused on public engagement with science and technology, but also in raising its audience's awareness of science and enhancing their understanding; iv) it was developed through both virtual and in-person interactions; v) it was designed according to the interests of its participants.

Primary school teachers are among the groups who exhibit the greatest gaps in both conceptual and procedural knowledge of astronomy, compared to others required to teach astronomy content (Maurício et al., 2018). On the other hand, it is known that interest in astronomy is shaped at an early age (Dang & Russo, 2015). The citizen science project *CoAstro* was organised in two main stages: engaging teachers with research in astronomy and promoting teaching and outreach activities in astronomy. To involve teachers in astronomical research, *CoAstro* developed two subprojects: “Stars” (aimed at the analysis of spectra from standard stars which would allow the qualitative

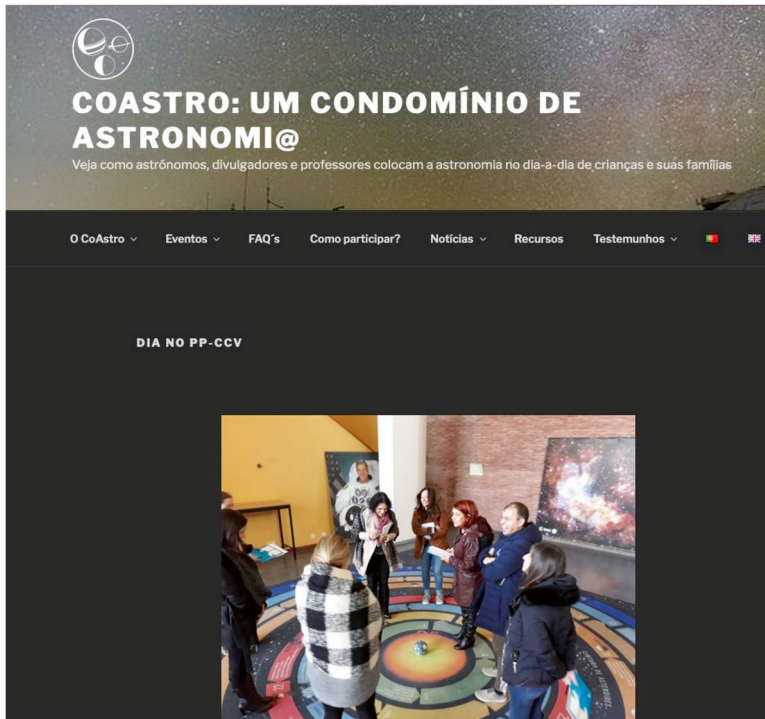


Fig. 6.6 Citizen science project: CoAstro

and quantitative determination of the composition of 57,000 stars and the determination of their luminosity using data from the *Data Release 2* of the *GAIA* mission) and “Planets” (aimed at producing a video of a planetary transit using the *Python* programme, and the analysis of light curves to identify potential exoplanets). The results of the first edition showed gains in both conceptual and procedural knowledge of astronomy among teachers, as well as a change in their attitudes towards astronomy and in the quality of astronomy outreach practices (Price & Lee, 2013). Astronomers and science communicators, in turn, acknowledge that the *CoAstro* project had an impact on their research and astronomy outreach practices (Costa et al., 2021).

6.11 Recommendations for the Integration of Citizen Science into Science Education

Several authors (Aivelo & Huovelin, 2020; NASEM, 2018; Perelló et al., 2021; Roche et al., 2020; Soanes et al., 2020) have put forward recommendations to maximise the synergies between citizen science and science education, seeking to create meaningful opportunities for citizen science in education and learning.

One of the recommendations concerns the *development of training and professional development initiatives* such as workshops, courses, and training sessions (Jeanpierre et al., 2005), in order to facilitate the integration of citizen science into classrooms and to overcome some of the barriers faced by schools, teachers, and students when participating in citizen science projects (Scheuch et al., 2018). Support for teachers is crucial, as otherwise it may be difficult for them—already overburdened and constrained by extensive curricula—to engage themselves and their students in new and complex activities (Harlin et al., 2018; Paige et al., 2015; Zoellick et al., 2012). According to Aivelo and Huovelin (2020), teachers cannot be passive participants in citizen science projects, but rather must act as active agents in integrating and making sense of the experiences and outcomes of their students' participation. The authors suggest that teachers should discuss with their students in the classroom about the objectives, related issues and, where applicable, experiences during participation in citizen science projects. Although some students may have meaningful learning experiences simply by taking part, the opportunity to reflect on the project in a classroom setting would provide many more learning opportunities. Additionally, data analysis would offer further learning opportunities; a collaborative or co-created citizen science project can be even more valuable from an educational perspective.

Another recommendation involves *ensuring alignment between the ontological and epistemological positions of citizen science, education, and learning*. The achievement of the educational objectives of citizen science projects depends on the goals established during the project planning phase (Bonney, Shirk, et al., 2014). Allowing students to participate in the process by contributing ideas and research questions helps to enhance learning and fosters a sense of ownership and investment in the project (Trautmann et al., 2012; Zoellick et al., 2012). Therefore, it is important for researchers to try to involve students, ensuring that data are returned to the classroom and providing students with the opportunity to analyse and present the data themselves. Furthermore, given that most citizen science projects remain contributory, incorporating a co-creation component into citizen science projects would significantly increase the likelihood of achieving the educational and scientific objectives of the project (Soanes et al., 2020). Such co-creation approaches should be considered a priority (Gray et al., 2012; Kelemen-Finan et al., 2018).

It is also recommended that *engagement and educational outcomes should be explicitly measured*. Educational outcomes are a key component of school citizen science projects and, as such, the project's capacity to achieve these outcomes should be evaluated, rather than assumed (Soanes et al., 2020). Theoretical frameworks for measuring individual learning outcomes resulting from participation in citizen science—such as the model proposed by Phillips et al. (2018)—would facilitate the alignment of learning outcomes with the underlying epistemological positions.

Another recommendation concerns the *challenges surrounding communication, dissemination, and dialogue established within the scope of citizen science projects*. The need to increase training opportunities in science communication for scientists involved in citizen science, as well as for scientists in general, is emphasised.

Collaboration between scientists and citizens with public relations and communication professionals could lead to more open strategies for engaging with different audiences and could generate a clear alignment between dissemination and participatory modes of science communication (Bucchi & Trench, 2014, 2021).

Establishing curricular support and formal partnerships emerged as another recommendation to be considered. Formal partnerships can ensure that both schools and scientists have access to the necessary infrastructure and administrative support to develop meaningful and sustainable projects. This can be achieved by collaborating with organisations that already have established science education and science outreach programmes (Ballard, Robinson, et al., 2017; Zoellick et al., 2012) or by setting up initiatives within universities and research centres to support scientists working in schools (e.g., Matthews et al., 2014).

Another recommendation is to *investigate how the understanding of the nature of science is related to the implementation of scientific practices and participation in citizen science projects*. In fact, citizen science can provide a new context for researchers in the field of education to explore how citizens develop and refine their understanding of the nature of science (NASEM, 2018).

Since some scientific activities within citizen science projects can be productively sustained over long periods of time (which is important when the aims of science learning involve, for example, conceptual change), they can *enable the study of learning processes that require a broader temporal spectrum* (NASEM, 2018). It is therefore recommended that science educators take this opportunity into consideration (Table 6.2).

Table 6.2 Summary of recommendations for the integration of citizen science in science education

Recommendations for the integration of citizen science in science education
• Develop training and professional development initiatives; provide educational materials. • Ensure alignment between the onto-epistemological positions of citizen science, education, and learning. • Explicitly measure engagement and educational outcomes. • Strengthen communication, dissemination, and dialogue. • Establish curricular support and formal partnerships. • Investigate how the understanding of the nature of science is related to the implementation of scientific practices and participation in citizen science projects. • Enable the study of learning processes that require a broader temporal spectrum.

Chapter 7

Final Considerations



This work seeks to provide a characterisation of citizen science and to reflect on its potential and challenges for science education, in both formal and non-formal contexts. As emphasised throughout, participation in authentic scientific initiatives that take place in real-world settings is a key strength of citizen science, making it particularly relevant for science learning. Such learning may encompass not only a better understanding of content, but also of the nature, methods, and processes of science.

However, in order to harness the benefits of citizen science in educational contexts, it is necessary to address significant challenges, namely: i) the design and adoption of indicators to measure the outcomes resulting from the implementation of citizen science projects; ii) the development of infrastructures and platforms to support activities; iii) training and capacity building of participants; iv) international activities for mutual learning; and v) the promotion of career systems and incentives so that citizen science becomes a complementary part of the research and development landscape in Europe and worldwide (European Commission, 2020a).

The NASEM (2018) further emphasise that, to promote learning, those responsible for designing citizen science projects should make explicit the intended learning outcomes, identify the target audience (students, teachers, the wider community), integrate learning outcomes into the project objectives, and use evidence-based strategies to achieve these outcomes. To this end, it will be important to conduct long-term studies related to changes in the scientific knowledge, skills, attitudes, and behaviours of participants in citizen science projects, particularly in science education in both formal and non-formal contexts. The development of tools and platforms to support and share science learning will also be a goal to consider in the future. The institutionalisation of citizen science requires the development of competences in the design, implementation, and management of citizen science projects and activities.

In this regard, it will be necessary to train a new generation of academics and professionals equipped to meet the needs of the industry, the government, and the public and educational sectors, which are witnessing a fast increase in public interest and participation in scientific research, including from students and their teachers.

Throughout our academic and professional journey, we have witnessed the challenges involved in integrating citizen science into science education. In this context, we have sought to contribute to a transformative perspective on citizen science in education, which is seen as fundamental to fostering a more vital role for science in the public sphere, helping to develop responses to current and future socio-scientific issues and to achieve the United Nations Sustainable Development Goals.

Afterword

Citizen science is a rapidly growing field, both internationally and nationally, due to its potential to advance scientific research. Frequently conceptualised as part of movements towards a more open and democratised science, it calls for greater accessibility in research processes and for the inclusion and participation of diverse audiences in research efforts, based on the premise that participants are not specialists in the scientific field, yet can make tangible contributions to scientific research. This empowers participants to engage in scientific arenas relevant to their lives and aligns scientific research with the needs and values of society.

Regarding citizen science in educational contexts, we are witnessing a growing number of examples of students and teachers participating in citizen science as part of their school activities. In this context, educational impacts are naturally the most sought after, requiring a series of adaptations of citizen science to an educational setting, inevitably bringing a range of significant challenges. In the book *Citizen Science in Science Education*, several of these challenges are identified, along with ways to overcome them, making it a highly valuable source of reference and consultation for those wishing to work with citizen science in educational contexts.

However, the book *Citizen Science in Science Education* is more than a collection of ways to overcome challenges; it offers a comprehensive overview of the various facets of citizen science and, fundamentally, highlights its applicability in educational practices.

The integration of citizen science into education is addressed clearly in this book. From practical examples to guidelines for incorporating citizen science projects into the classroom, it offers perspectives that will undoubtedly benefit educators, students, and science enthusiasts across the country. The diversity of approaches presented reflects the richness and potential of citizen science as a powerful educational tool.

Its clear and concise structure makes it accessible to anyone interested in the subject, whether beginners or specialists in the field. The inclusion of simple and easy-to-understand diagrams enriches the reading experience, facilitating the

assimilation of the concepts. The book *Citizen Science in Science Education* will undoubtedly play a significant role in promoting citizen science in Portugal. It serves as a highly useful resource for those wishing to explore and implement citizen science in both formal and non-formal education contexts.

It is with great pleasure that I acknowledge the value of this work and congratulate the author, as well as her collaborators, for their contribution to the citizen science community in Portugal. May this book serve as both an inspiring and practical guide for those seeking to explore and promote citizen science as a transformative tool in various fields, including education.

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