Received: 23 October 2022 | Revised: 19 February 2023 | Accepted: 18 May 2023

DOI: 10.1002/sce.21800

RESEARCH ARTICLE

Science Education WILEY

Meaningful participation of schools in scientific research through contributory citizen science projects

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Abstract

School-based citizen science offers a way for students and teachers to collaborate with scientists and take part in multiple facets of research such as data collection and analysis, and sometimes research initiation, co-design, and reporting of findings. However, most citizen science projects offered to schools are of the contributory type, often regarded as a lesser form of participation since the role of nonscientific participants lies mostly in data collection. The current study set out to examine the potential of contributory projects to afford—despite their limitations—more equitable power relations between schools and scientists and a meaningful participation of schools in scientific research. We view meaningful participation as such that embodies students' and teachers' responsibility over scientific processes or outcomes. Nine pairs of teachers and scientists who collaborated in contributory-based projects were asked to think aloud as they answered a questionnaire regarding their experiences, resulting with rich commentary on how they perceived relationships between the schools and the scientists. Analysis of the think-aloud data, using a framework based on the notion of reciprocity in university-community partnerships, indicated that most teachers and scientists developed a sense of reciprocal relations where both sides are acknowledged contributors, some even deeply so. We discuss factors influencing the emergence of reciprocity and implications towards the premise of school-based citizen science to democratize science and change traditional power relations in school-based citizen science collaborations.

KEYWORDS

contributory citizen science, democratization of science, school-based citizen science, teacher-scientist partnerships

1 | INTRODUCTION

1.1 | Research motivation

Citizen science is often conceptualized as part of the movements toward open or democratized science (Dickel & Franzen, 2016; Peters & Besley, 2019; Smallman, 2018; Stilgoe et al., 2014; Strasser et al., 2019). These movements call for increased accessibility of research processes and inclusion of diverse publics in research efforts, building upon the premise that individuals who are not scientific experts can make tangible contributions to scientific research. This empowers citizens to act in scientific arenas relevant to their lives and aligns scientific research with citizens' needs and values (e.g., Butkevičienė et al., 2021; Hoover, 2016; Krings et al., 2019). A democratic vision of citizen science may be readily associated with co-created (Shirk et al., 2012) or community-based projects, where citizens participate in most or all of the research stages, such as study design, data analysis, dissemination of findings, and implementation of conclusions. In such projects citizens may take full responsibility over the research, or work with scientists in various of degrees of engagement. Yet, the democratic rhetoric is sometimes employed in cases where citizens have little control over the research (Cooper & Lewenstein, 2016; Del Savio et al., 2016; Strasser et al., 2019), for example, in contributory projects where scientists conceptualize and lead studies to which citizens contribute data without participating in other research stages (Shirk et al., 2012). Scientist-led citizen science projects can provide citizens with access to data or tools and establish dialogue between citizens and scientists, and thus may address, at least in part, the aspirations of open science (Ceccaroni et al., 2021; Chen, 2019; Del Savio et al., 2016; Kloetzer et al., 2016). Nonetheless, the premise of top-down citizen science to create collaborative relations between citizens and scientists remains contested, as citizens' have marginal authority over the research.

Democratization of science may be under even more scrutiny in school-based citizen science, where students and teachers participate in citizen science as part of their school activities (Roche et al., 2020). Educational impacts are especially sought after in these contexts (Kloetzer et al., 2021), which may require the adaptation of citizen science to an educational system that is essentially nondemocratic (Weinstein, 2012). Most citizen science projects available to schools are of the contributory type, as these are more abundant (Hecker et al., 2018; Turbé et al., 2019) and generally require less time and resources (Herodotou et al., 2022). Still, the empowerment of students in science and in their communities is often a stated goal of school-based citizen science (Ballard et al., 2017; Kaplan Mintz et al., 2021; Morales-Doyle & Frausto, 2021; Mueller & Tippins, 2015; Roche et al., 2020), a venture successfully achieved mostly on a case-by-case basis (e.g., Barton & Tan, 2010; Benavides Lahnstein et al., 2022; Binder et al., 2021; Harris et al., 2020; Herodotou et al., 2022). The participation of students and adult volunteers in citizen science endeavors can lead to various learning outcomes (Harris et al., 2020; Kloetzer et al., 2021; Koomen et al., 2018; Lüsse et al., 2022; Matuk et al., 2021; Phillips et al., 2018, 2019). Among these is the development of expansive framing, a term that describes how learners come to perceive their work as relevant and valuable in contexts that transcend the immediate learning environment (Harris et al., 2020). Citizen science has been suggested to serve as a pathway for schools to take part in scientific knowledge-building (Kali et al., n.d.; Mueller et al., 2012; Sagy et al., 2019), yet strategizing towards this broad objective requires further examination of the fundamental nature of school-science relationships in school-based citizen science.

This study is motivated by the central conundrum disclosed by these issues, namely, the extent to which school-based citizen science, specifically in its contributory mode, can realize aspirations for meaningful participation of schools in scientific research and fulfill, at least in part, a democratic vision for citizen science. This is a complex and rather abstract question, which we approach by first closely defining the shape and boundaries of our investigation.

1.2 | Definitions and overarching goal

1.2.1 | School-based citizen science collaborations

We focus our examination on collaborations established between schools and scientists around contributory citizen science projects. For this study's purposes, a collaboration is conceptualized in broad terms that overarch related notions such as coordination, cooperation, and partnership (Barnett et al., 2010). In the context of school-based citizen science, a collaboration generally involves teachers and scientists interacting to facilitate students' participation in scientific research, with the aim of achieving both educational and scientific goals (Gray et al., 2012; Sagy et al., 2019; Zoellick et al., 2012). The collaboration may be mediated by a third party such as educational or citizen science specialists.

1.2.2 | Meaningful participation

The study adopts two related typologies of citizen science. The first is based on Shirk et al. (2012), who define types of projects based on the participation of citizens in different research stages (contributory projects, co-created ones, and more). The second typology bases its definitions on levels of engagement (Haklay, 2013), where high levels of citizen engagement correspond to greater responsibility of citizens over scientific knowledge creation. This is contrasted with “regular” science, which is under the sole responsibility of scientific experts. A general correspondence exists between these two typologies, as enhanced participation in research stages is often associated with a greater influence over the research (Gunnell et al., 2021; Haklay, 2018; Ottinger, 2016; Senabre Hidalgo et al., 2021). We endorse Haklay's notion of participation as manifesting responsibility over knowledge production and inspect it in the context of contributory projects. We suggest that “meaningful participation” of schools in citizen science describes a condition in which schools hold a significant degree of responsibility over the scientific processes or outcomes of the project.

1.2.3 | Overarching goal

Considering these definitions, the overarching goal of the current study is to explore the potential for meaningful participation of schools in contributory citizen science projects. We investigate this by integrating perspectives from scholarships in the fields of the learning sciences with citizen science, science education, and science communication. Our analysis builds upon the perceptions of teachers and scientists that have worked together in such projects, focusing on these two groups of stakeholders who have a key role in driving school-based citizen science collaborations and determining the nature of the relationship. Their perceptions of the collaboration reveal underlying conceptions of who is responsible for what aspects of the project.

2 | THEORETICAL BACKGROUND

2.1 | Teachers' and scientists' perspectives on citizen science

Teachers seek various educational outcomes when they engage their students with citizen science activities. Alongside learning of science content and practices, teachers often underscore additional beneficial effects of students' engagement with authentic science investigations. Teachers typically believe that helping to solve a real-world scientific problem has an important role in: (a) motivating students (Aristeidou et al., 2022; Doyle et al., 2018, 2019; Kaplan Mintz et al., 2021), (b) enriching students' perspectives about their own identity and work (Bracey, 2018; Rushton & Reiss, 2019), (c) building students' science identity (Bracey, 2018; Doyle et al., 2019; Kaplan Mintz et al., 2021; Rushton & Reiss, 2019), and (d) enhancing students' capacity for agency and action (Atias et al., 2023; Bracey, 2018; Kaplan Mintz et al., 2021). The studies demonstrating these findings were conducted mostly in the context of contributory projects, illustrating that teachers expect and encounter such outcomes even as students participate in limited roles within the scientific research. Nevertheless, teachers stress that exposure of students to the overarching scientific process is important for realizing such impacts (Bracey, 2018; Doyle et al., 2018, 2019). As teachers plan and enact citizen science activities, possibly in collaboration with scientists or other specialists, they may undergo transformational changes themselves. These can include enhanced pedagogical capabilities, developed science identity, and expanded framing of their own work as contributing to science or other out-of-school contexts (Benichou, Kali, et al., 2022; Doyle et al., 2019; Rushton & Reiss, 2019).

Our knowledge on scientists' perspectives on citizen science in schools is limited, yet studies performed in the context of general citizen science reveal mixed attitudes towards nonscientists' participation in science. Scientists with little or no experience with citizen science can be skeptical of its use as a research methodology, sometimes objecting to the very idea that non-scientists are able to contribute to scientific research (Burgess et al., 2017; Golumbic et al., 2017). But even among those who support citizen science as a legitimate genre of research, concerns regarding the quality of data collected by citizens or acceptance of such data by the scientific community are prevalent (Burgess et al., 2017; Riesch & Potter, 2014). Scientists typically believe that citizen science raises public awareness to scientific issues and increases the public's understanding of science (Burgess et al., 2017; Golumbic et al., 2017; Riesch & Potter, 2014), yet they are not always willing to develop dialogue with the public and receive public feedback (Golumbic et al., 2017). Nonetheless, a growing awareness among scientists towards the importance of public engagement (Besley et al., 2018; Rose et al., 2020) continues to drive citizen science efforts, including scientists' recognition that citizen science needs to provide added value and a meaningful experience to participating citizens (Esch et al., 2020; Riesch & Potter, 2014). Within this realm, a small but growing number of scientists is motivated to invest time and effort in school-based citizen science and support students' learning of science and scientific agency (Atias et al., 2023; Esch et al., 2020).

2.2 | Power relations in teacher-scientist partnerships

Partnerships between teachers and scientists have a long tradition of supporting science education in schools. Such partnerships include, for example, teachers visiting an academic institution as scientific apprentices, teachers and scientists co-designing curriculum materials, or teachers, students and scientists interacting around scientific research.

Often framed as a professional development opportunity for teachers, these partnerships have been shown to promote teachers' scientific knowledge and skills as well as their confidence and positive feelings towards science and its instruction (Brown et al., 2014; Caton et al., 2000; Dresner & Worley, 2006; Morrison & Estes, 2007; Morrison, 2014; Ufnar & Shepherd, 2019). In such partnerships, scientists are often considered as experts and providers of resources and research opportunities (Drayton & Falk, 2006). Thus, teacher-scientist partnerships are often shaped under pre-existing power relations that imply a mostly unilateral flow of knowledge from scientists to teachers (Carlone & Webb, 2006).

Some teacher-scientist partnerships seek to consciously establish a mutual learning relationship in which both sides are contributors (Tanner et al., 2003). Such relationships can cultivate mutual respect towards partners' disciplinary expertise and reflections about one's practices, especially when scientists remain open to teachers' ideas (Bissaker, 2014; Caton et al., 2000; Drayton & Falk, 2006). Nonetheless, tensions often accompany such efforts, as uncommon grounds between teachers and scientists arise from cultural and linguistic differences (Benichou, Kali, et al., 2022; Tanner et al., 2003). Unbalanced perceptions of scientific and pedagogical expertise can introduce barriers for mutual learning, as teachers may find that their own expertise is disregarded by scientists, at least during the beginning stages of the partnership (Bissaker, 2014; Shanahan & Bechtel, 2019). The teachers themselves, especially less-experienced ones, may emphasize scientists' contributions and be hesitant to portray their own pedagogical expertise as superior to that of scientists (Shanahan & Bechtel, 2019). Finally, teachers' and scientists' institutional identities may direct and constrain discourse in the partnership, leading to replication of hierarchical power relations despite good intentions (Carlone & Webb, 2006).

To summarize, teacher-scientist partnerships are often built to accomplish educational goals and follow a hierarchy model that places scientists as knowledge providers and teachers as knowledge consumers. Even when partnerships are established under a vision of equal grounds, traditional social and cultural stances, distinct discourses and ways of thinking, institutional identities, and perceptions of expertise often affect their dynamics. In light of teachers' positive attitudes towards implementing citizen science in classrooms, and their contrast to scientists' hesitancy, unbalanced power relations in school-based citizen science collaborations may seem imminent. Considering this, we now turn to describe an alternative framework taken from studies of university-community partnerships. This body of literature focuses on building sustainable collaborations between academic institutions and various community players, examining ways to overcome differences between partners.

2.3 | Perceptions of reciprocity in university-community partnerships

University-community partnerships are institutionalized constructs whereby universities and other academic organizations establish relationships with nonacademic partners, following a key belief that the "engaged university" can better benefit society (Fitzgerald et al., 2012). Engagement may be realized in different forms, such as staff volunteering, knowledge exchange and integration, and community-based research (Harney & Wills, 2017), and is based on dialogic communication (Cherrington et al., 2019). Such communication strategies require negotiation of power structures, including an infusion of epistemologies that value knowledge that originates from outside the boundaries of academia (Davis et al., 2017; Saltmarsh et al., 2009).

Two major principles guide relationships in university-community partnerships: mutual benefits and reciprocity (Fitzgerald et al., 2012). The concept of mutual benefits describes the attainment of benefits for all involved partners. Reciprocity, however, is a more nuanced term, sometimes conceptualized along a continuum that ranges between "thin reciprocity", which implies an exchange of transactions, and "thick reciprocity" that emerges from equity in power relations and joint ownership of processes (Jameson et al., 2011). Janke (2013) explained that "in fully reciprocal partnerships, the power is balanced in such a way that the community and academic partners become true collaborators… each contributing in meaningful ways" (p. 5). The differing terminology between this scholarship and that of citizen science is noteworthy. In Shirk's et al. (2012) typology, contributory projects are described as a low-engagement form of citizen science, while literature based on university-community partnerships highly regard mutual contributions.

Dostilio et al. (2012) conducted an extensive literature review that summarized common conceptions of reciprocity, acknowledging the different uses of the term. They provide an overarching definition of reciprocity as "an epistemological position in which authority and responsibility for knowledge creation are shared" (p. 18) and proclaim that the term represents a recognition of all partners as contributors to partnerships' processes or outcomes. They describe the following three forms of reciprocity, referred to as "orientations", that differ in the ways in which partners appreciate each other's roles as contributors:

2.3.1 | Exchange-oriented reciprocity

Close in meaning to thin reciprocity (Jameson et al., 2011), this orientation centers around a mutual exchange of benefits or resources. Individual goals and gains are sought after based on the assumption that collective action would serve all sides. Other times, collective action is maintained by a status-quo, such as social order, or an external authority.

2.3.2 | Influence-oriented reciprocity

This orientation focuses on the interactions between partners and how they iteratively affect participating individuals. Partners' ways of thinking and being are manifested in these interactions, as well as personal, social, and environmental contexts. Thus, the orientation of influence-oriented reciprocity relates to theories of social justice and indigenous knowledge (Denzin & Lincoln, 2008; Young, 1990).

2.3.3 | Generativity-oriented reciprocity

This orientation focuses on processes that lead to "co-construction of emergent systems" (Dostilio et al., 2012, p. 25), where collaboration creates something that would not have existed otherwise. Considering that such systems have transformative power, the collaboration may affect partners' identities.

3 | RESEARCH GOAL AND QUESTION

Current research shows that teacher-scientist partnerships are affected by traditional power relations. Reciprocal collaborations disrupt these traditional perceptions by valuing the knowledge of all participants and acknowledging their role as active contributors. We view the notion of reciprocity as conveying a meaningful participation by all sides of the collaboration. Hence, our main goal in this study was to characterize teachers' and scientists' experience-derived perceptions of reciprocity in contributory school-based citizen science collaborations. Our research question was: What perceptions of reciprocity do teachers and scientists hold within such collaborations?

4 | METHODS

4.1 | Context

The study was conducted as part of the TCSS research center which supports participation of Israeli schools in citizen science projects and studies projects' design, implementation, and outcomes (Kali et al., 2020; Sagy et al., 2020). Nine cases of school-scientist collaborations were examined, each revolving around a different citizen science project (Table 1). The projects were of the contributory type, where scientists lead a study while the school's main contribution is through collecting or processing data. In each collaboration, one or more teachers from the same school, and one or more scientists leading the citizen science project, worked together on planning and implementing the enactment of the project in classrooms. In most cases, TCSS educational researchers or other specialists acted as facilitators, introducing parties and supporting their ongoing collaboration. At the time of data collection for this study, the collaborations were operating for 1 or 2 school-years with a considerable time invested by all stakeholders each year.

The notions of “meaningful participation” or “reciprocity,” as they are presented in this article, were not discussed in any of the collaborations. However, a common stated goal was achievement of mutual benefits, mainly pertaining to educational outcomes for participating students and collected or processed data that may advance the scientists' research. In all cases but one (project 4), students' participation was accompanied by a learning program typically co-designed by the educational researchers and the teachers, sometimes with input from scientists in various degrees of involvement. Programs generally exposed students to the research subject and motivation, and to related concepts. In most cases, students engaged in scientific practices beyond data collection and processing, such as asking research questions or analyzing data. Nevertheless, participation in such activities fulfilled educational goals and did not have bearings on the scientists' research. In some cases, scientists took part in classroom activities, meeting with students for one or more lessons in which they introduced their research, explained background material, or instructed students on how to perform data collection tasks.

The “Mammals” and “Radon” projects are typical examples of the collaborations presented in this study (Benichou, Atias, et al., 2022; Golumbic et al., 2023; Tsapalov et al., 2020). The former was led by ecologists wishing to examine distribution of mammalian species in places with varying ecological features (such as urban, agricultural, and natural areas). The latter was led by civil engineering scientists who developed new kits for measuring levels of the Radon gas, which has toxic effects at high concentrations and may accumulate in buildings. The scientists intended to use the kits for a survey of Radon levels in residential homes. In both cases, students collected data for the scientists' research following a provided protocol. The data was accumulated in a central database that was managed by the scientists and contained observations from other schools or citizen science volunteers. Participating schools received processed copies of the database, so that students could browse and analyze the results. In the “Mammals” project, the accompanying learning program focused on nature conservation challenges and students' investigation of factors that affect the distribution of mammals in areas near their school. In the “Radon” project, the program raised awareness to the hazards of Radon and included statistical analysis of the data.

4.2 | Participants

From each of the nine school-scientist collaborations included in this study, we recruited one teacher and one scientist who were highly active in the collaboration (a total of 18 study participants). In most cases, study participants were either team leaders (of the respective educational or scientific team) or worked as single teachers or scientists. In one case, a junior scientist was recruited as a participant, based on the advice of the project's chief scientist. Of participating scientists, seven identified as males and two as females. Four were university faculty members, two worked in private research centers, two were graduate students, and one a postdoctoral fellow. Of participating teachers, eight identified as females and one as male. Seven were science teachers, one a math teacher, and one a geography teacher. To protect the privacy of study participants, especially as some collaborations may still be ongoing while participants maintain working relationships, we do not identify the collaborators and the projects they took part in. However, more details about the same group of projects and participants are available in a previously published article (Atias et al., 2023).

TABLE 1 Description of projects participating in the study.

Project no.	Mediation by a third party	Main domain of citizen science research	Students' main contribution to the research	Other student activities included in a designed learning program
1	Yes, educational researchers	Engineering/Public health	Data collection	• Design personal investigations (unrelated to scientists' research) • Data analysis (own data, separately from scientists) • Derive and present conclusions (own data, separately from scientists)
2	Yes, public outreach specialists in a private research center	Ecology	Data collection	• Learning background material and related topics • Meeting with the scientists
3	No	Ecology	Data collection	• Research design[a] • Data analysis • Derive and present conclusions
4	No	Engineering/Ecology	Data processing	• Protocol instruction (by a scientist)
5	Yes, educational researchers	Ecology	Data collection	• Learning background material and related topics • Meeting with the scientists • Data analysis (own and public data, separately from scientists) • Presenting learning products
6	Yes, educational researchers	Ecology	Data collection	• Learning background material and related topics • Meeting with the scientists • Data analysis (own data, separately from scientists) • Presenting learning products
7	Yes, educational researchers	Engineering/Public health	Data collection	• Learning background material and related topics • Meeting with the scientists

TABLE 1 (Continued)

Project no.	Mediation by a third party	Main domain of citizen science research	Students' main contribution to the research	Other student activities included in a designed learning program
8	Yes, educational researchers	Engineering/Public health	Data collection	• Learning background material and related topics • Data analysis (own and public data, separately from scientists)
9	Yes, educational researchers	Public health	Data collection	• Learning background material and related topics • Meeting with the scientists • Data analysis (own and public data, separately from scientists)

[a]This project was initially conceived as a co-created project. Yet, students' work was closely guided by the scientists and through their testimony, it can be understood that students provided little input other than collecting data. Thus, the project effectively followed the contributory model.

4.3 | Data collection

A researcher (the first author of this article) met with each study participant in a 1-h one-on-one video call that began with a short interview to gather basic background information and an overview of the participant's impressions from their experiences in the collaboration. Then, participants shared their screen with the researcher and answered an extensive online questionnaire that contained Likert-type and ranking questions about motivations to participate in citizen science, costs and benefits derived from participation, perceptions of relationships, and perceptions of expertise (findings regarding motivations, costs, and benefits are published in Atias et al., 2023). Participants were asked to think aloud while answering the questionnaire, providing oral data that was used in this study. Similar think-aloud methods, in which participants are asked to speak their thoughts while engaging a task, were developed to assess thought processes (Charters, 2003; Ericsson & Simon, 1980). Such methods are also used for evaluating questionnaires as participants verbalize thoughts while answering, thus demonstrating how they interpret the questions and respond to them (Beatty & Willis, 2007). The technique is used in this study not for validation, but to receive additional information alongside the questionnaire data (e.g., French & Hevey, 2008; McGavock & Traeharne, 2011; Ryan et al., 2009; Zhang et al., 2017). Study participants were instructed to voice thoughts that came to mind as they were answering the questionnaire, often providing explanations to their responses. The rich commentary revealed participants' perceptions of the school-based citizen science collaborations they took part in. To avoid bias, the researcher did not prompt for verbal statements, yet asked for clarifications as seen fit when statements were initiated by participants. The interviews were transcribed and think-aloud statements were used for qualitative analysis as described in the following section.

4.4 | Data analysis

Based on the work of Dostilio and her colleagues (2012), we constructed an analytical rubric that summarizes basic markers of reciprocity (Figure 1), as well as definitions and indicators for the three orientations of reciprocity (Table 2). Each of the 18 think-aloud transcripts (for each participant) was scrutinized for excerpts (a sentence or several of them talking about the same subject) when participants talked about relationships within the collaboration. Three different interpreters, two of which are the first and second author of this article and the third a doctoral researcher, individually analyzed excerpts for seven participants, evaluating them against the rubric and deciding whether each described a reciprocal point of view, and if so, through which orientation. Comparison of the separate analyses showed 82%–96% (average of 90%) agreement between interpreters. Excerpts for the rest of the participants were analyzed by one researcher, with the work later corroborated by the other two. Sample excerpts and their classification to orientations of reciprocity are provided in Table 3. A summary was formulated for each

Marker #1: All partners are contributors
Each side of the partnership is both a teacher and a learner, a service provider and a service receiver, contributor and one who is contributed to.

Marker #2: A collaboration with, not for
Partners see the partnership as a collaboration *with* someone, not *for* someone.

Marker #3: All types of knowledge are valued
Local and contextual knowledge, that is not of expert sources, is valued.

FIGURE 1 Markers of reciprocity in university-community partnerships, based on Dostilio et al. (2012)

TABLE 2 Summary of definitions and properties for reciprocity and its orientations, based on Dostilio et al. (2012).

Orientation	Definition	Properties of partnerships
Exchange (partners benefit)	An exchange of benefits, resources, or actions.	• Promotes collective action alongside personal benefits. • Sustained by individual gains, social norms, external authority, and sometimes by expectations for future benefits.
Influence (partners impact)	The partners, their ways of thinking and acting, iteratively impact the partnership's processes and/or outcomes.	• Based on the relational influence embedded in social interaction. • Personal, social and environmental factors iteratively and interactively influence one another, as well as partnerships' processes and outcomes.
Generativity (partners create)	Partners co-construct new value or systemic change. May induce transformations in identities and ways of being, either of individuals or of systems.	• Rejects reductionist worldviews in favor of ecological ones that highlight interconnectedness and synergy between beings and/or systems. • May affect not just what partners do but also what they are. • Partners honor multiple forms of meaning-making, opening pathways for new perspectives and understandings.

TABLE 3 Examples for classifications given to excerpts based on definitions for reciprocity and its orientations.

Excerpt	Participant type	Classification
"The project is more about the pedagogy than the science, To my understanding, it's something where we give to the schools, more than they give to us."	Scientist	Nonreciprocal
"There's a huge gap between the students and the scientific community. I'm therefore hesitant about students getting involved in the scientists' research."	Teacher	Nonreciprocal
"I provide teachers with professional training and agree to meet with students as part of the data collection for my research."	Scientist	Exchange-oriented reciprocity
"Students are responsible for providing reliable data. The scientists benefit from the enlarged database."	Teacher	Exchange-oriented reciprocity
"Students have an open mind and creative thinking. With good guidance they can ask interesting research questions and do good research."	Scientist	Influence-oriented reciprocity
"Interactions between the scientists and the students are important. They motivate students and expand scientists' point of view beyond their personal standpoint."	Teacher	Influence-oriented reciprocity
"Teachers [doing citizen science] transfer their work from the realm of schools to the realm of science."	Teacher	Generativity-oriented reciprocity

participant, recapping their point of view on the collaboration in light of our interpretation of their perceptions of reciprocity. All summaries were reviewed and refined by each of the three interpreters. This process resulted with summaries for 13 out of the 18 study participants (6 teachers, 7 scientists). For other participants, the transcripts did not provide enough substantial evidence to reach a conclusive interpretation of their perceptions. Quotations shown in Table 3 and in the Findings section were translated from Hebrew.

5 | FINDINGS

5.1 | Overview

Content analysis facilitated a characterization of participants' conceptions of reciprocity for 13 out of the 18 participants. Based on our analysis, the 13 participants are classified in one of four groups: nonreciprocal, exchange-oriented, influence-oriented, and inconsistent (Table 4). Inconsistent participants described reciprocity within the collaborations in different ways depending on context. We note that identification of these groups involved a carefully constructed process that considered the content of participants' statements and their context, and not just the number of excerpts that supported each viewpoint. We also used excerpts that did not support any particular point of view, when they were found to enlighten the meaning of other excerpts or of the participant's views.

In most cases, teachers and scientists that collaborated within the same project were not classified in the same group. However, in all cases but one this mismatch did not derive from contradicting points of view. Instead, the typical case was for one participant to have a coherent vision of the collaboration while the other one was hesitant about it. For example, one participant may have seen iterative influences within the collaboration (influence-oriented group), while the other was aware of such influences yet was focused on attaining educational impacts (inconsistent group). Such cases reflect the distinct individual worldviews of the collaborating parties without negating the contribution of both sides. In one striking counterexample, a teacher firmly viewed the collaboration as influence-oriented while her collaborating scientist fluctuated between nonreciprocal and exchange-oriented points of view. This case may represent a misevaluation of the relationship by at least one participant.

We now provide an in-depth description of the qualitative analysis performed for one participant in each of the four groups. These descriptions clarify what a typical viewpoint for each group looks like, while providing additional insights. Each representative case includes a summary of the analysis accompanied by illustrative quotes and a short comparison between this case and other participants classified in the same group. Participant numbers in the descriptions correspond to Table 4, and project numbers to Table 1.

5.2 | Representative cases

5.2.1 | Case A: Nonreciprocal, participant 1 (teacher, project 9)

This high school science teacher joined two different citizen science projects with her students. One of these projects was mediated by educational researchers and included two scientists. The teacher believed that both students and scientists benefited from the collaboration, referring to collected data as the scientists' main benefit. The teacher reported students' enthusiasm and affirmed that she had reached her main educational goals.

The teacher's acknowledgment of mutual benefits potentially laid grounds for a perception of reciprocal relationships. However, further statements made by the teacher strongly showed that her perceptions of the collaboration did not comply with the basic markers of reciprocity (Figure 1). Her statements did not indicate that she saw students as contributors or service providers (lacking marker #1—all partners are contributors), but focused on the students being serviced, and on the collaboration being *for* students and not *with* students (lacking marker

TABLE 4 Classification of participants according to their statements about relationships in the collaborations.

Group	Participant number	Role in collaboration[a]	Total number of analyzed excerpts	Number of excerpts supporting[b]: Nonreciprocal views	Exchange-oriented views	Influence-oriented views	Generativity-oriented views
Nonreciprocal	1	Teacher (case A)	30	14	3	2	0
	2	Scientist	8	7	1	3	0
	3	Scientist	13	9	0	0	0
Exchange-oriented reciprocity	4	Teacher (case B)	33	0	17	1	0
	5	Scientist	14	1	7	3	0
Influence-oriented reciprocity	6	Teacher	8	0	0	5	0
	7	Teacher	26	1	0	14	3
	8	Scientist (case C)	32	0	3	14	1
Inconsistent	9	Teacher	34	8	4	7	0
	10	Teacher	11	0	3	4	0
	11	Scientist (case D)	21	8	2	5	0
	12	Scientist	13	7	1	3	0
	13	Scientist	33	7	4	3	0

[a]Four participants are marked as representative cases whose analysis is shown later in detail.

[b]A few excerpts are counted more than once, as they exhibited more than one point of view on reciprocity.

#2—a collaboration *with*, not *for*). She repeatedly pointed out that neither her knowledge nor her students' was relevant to the scientists' goals (lacking marker #3—all types of knowledge are valued). This demonstrates that a participant's sense of mutualism within the collaboration is not necessarily related to their sense of reciprocity.

The teacher repeatedly emphasized the positive contribution of scientists to the students. For example, regarding students' data analysis activities, she said:

> The students didn't really understand how to approach so much data, how to take the large dataset and ask something about it. The scientist showed them different [types of] graphs… that [they can use to] answer various research questions. This focused students on how to choose a research question.

In contrast, apart from mentioning that collected data benefits scientists, she had not once referred to students as contributors, even in contexts that potentially draw up such references (therefore, lacking markers #1 and #2). In the following excerpt, for example, she was asked about the importance of establishing dialogue between students and scientists, and provided a comment that positioned students as the sole recipients in such an interaction:

> I think there should be a dialogue between future scientists [the students] and current scientists, in order to raise future scientists who will have the values we want them to have.

Below, when asked about the importance of advancing science and the scientific research, she pictured this as a goal unrelated to the students:

> [Advancing scientific knowledge] is not a stated goal [in the project]. It happens as a side effect of the process and of students filling in reports.

These and other statements suggested that the teacher saw the project mainly as an educational endeavor, rather than a citizen science collaboration.

Regarding the third marker of reciprocity—that all types of knowledge are valued—the teacher's statements disregarded her own and her students' knowledge as valuable to the scientific study. While she saw herself as having relevant expertise, she believed that her knowledge was not contextualized and tuned-in to the research goals. For example, when talking about the possibility of co-designing the research with the scientists, she said:

> I don't think teachers should get involved in that because we don't have that general point of view on the research and I'm not sure that what the teacher brings would match the scientists' intentions.

She was hesitant about students' involvement in the scientific research beyond data collection, mainly on grounds of insufficient expertise:

> They can do that, but I have some reservations. Students sometimes don't have enough experience for that, so I don't know how practical that is. Ideally, they should be involved but in practice, I'm not sure they can totally do it.

To conclude, we classified this teachers' point of view on the collaboration as *nonreciprocal*, as her statements did not exhibit any of the three basic markers of reciprocity. It seems that for her, school-based citizen science is a collaboration where scientists are the main contributors to a project that is educational in nature, and that schools have little to offer to the scientific research.

Of the two scientists classified in the nonreciprocal group, participant 2 expressed a strong emphasis on educational (rather than reciprocal) goals. This scientist was aware of the possibility of developing exchange-oriented relations, yet specifically pointed out that educational impacts should be prioritized even at the expense of potential mutual benefits. Regarding her role as a scientist in the project, she said:

> [The scientists] can occasionally use the students' data, but for me that's not the main point. For me, the [scientists'] main contribution is in teacher training, helping with development of learning resources, and occasionally, giving lessons to students.

Views expressed by participant 3, which indicated a nonreciprocal perspective, were unlike any other participant. This scientist found himself, almost unintentionally, involved in citizen science as part of the conditions for a research grant. He saw citizen science as an outreach activity that produces educational value, but explicitly and strongly negated the possibility of reciprocal relationships. A lack of scientific expertise contradicts, in his opinion, the legitimacy of non-scientists to take part in scientific research, as expressed in the following excerpt:

> I don't think a school student has anything to contribute to me as a researcher. It's like saying a child can delineate the treatment to the doctor. No, the doctor is the one who had studied for many years and he should delineate the treatment.

5.2.2 | Case B: Exchange-oriented reciprocity, participant 4 (teacher, project 4)

This teacher was a middle-school science teacher who also served as a teacher instructor. She worked in a democratic school at the time of data collection for this study, and thus to align with the school's democratic agenda, gave students the freedom to decide if they want to participate in the project. Since she held a doctoral degree in education, research was an activity that she viewed as an integral part of her capacities. She testified that the project benefited her students very much. Her main goal in the collaboration was to open possibilities for students to engage in real-world research. She believed this goal was accomplished, alongside other benefits:

> It's not about learning how to do research, it's the fact that we are part of a project that is bigger than us and isn't a part of everyday schooling. This signals [the students] that there are horizons, possibilities, and they can make use of that in all sorts of ways. Even if they don't take advantage of the opportunity, the opportunity is there, and that's very important. Very, very important.

She also acknowledged students' contribution to the research:

> [Students did] a considerable amount of data collection that would have taken the scientists hundreds of hours to complete, and it was us [the teacher and students] who put in these hundreds of hours.

We classified this teacher's viewpoint as reciprocal based on repeated descriptions of herself and the scientists as sharing equal responsibilities for navigating the project, and of students as active agentic contributors. For example:

> I told the scientists what I need, they trust me. They made an effort to address my requests. I and [a particular scientist] were responsible for most of the project's design. I said, “I want this and that”, and he said, “I can do this and that”. That's how the project was developed.

And:

> The fact that my students participated with duty and a personal responsibility, that they worked and collected the data seriously - that's good education for citizenship and for science.

These and other statements led us to the conclusion that this teacher saw all sides in this collaboration as contributors whose knowledge was valued. We classified her perception of reciprocity as exchange-oriented based on several observations. First, her standpoint reflected a major property of exchange-oriented reciprocity—collective action that is sustained by individual gains and social norms, as in:

> The research does not interest me, the research serves my interests. Here I'm a teacher, not a researcher. The scientists will take care of their own research.

As well as:

> I do what the scientists ask and of course, I try to be cooperative because it's in my interests that they keep working with me. I want the project to benefit them so that this collaboration will continue.

Second, she seemed to set clear boundaries on her own role, her students' role, and the scientists' role, relying upon her perceptions of expertise, i.e., what she thinks each of the collaborators can or cannot do. For example:

> [The students] have no skill [for determining research subject and questions]. There is no serious input they can provide here, which I can seriously take into consideration without damaging the research. The scientists determine the research topic and questions, not me and not them [the students]. Definitely not them.

And:

> [The scientists] don't have the skill to teach my students. They communicate respectfully and pleasantly, they understand how the school works and they fit in nicely. But none of them can come into my classroom and run a lesson.

However, the boundaries drawn by the teacher stretch beyond considerations of expertise. Her statements explicitly rejected the establishment of interactional influences. For example, when specifically asked about impacts she and her students had on the scientists, she said:

> It's not my job [to impact the scientists]. It seems presumptuous to me, like, who am I to educate people who are not my students? Who am I to influence their point of view? It doesn't seem serious to me.

Similarly, she insisted that scientists should be disengaged from educational processes:

> I don't want the scientists in my classroom. My classroom is my classroom, it's my job. I know there are projects where scientists come in and lead the project [in the classrooms], but I never chose to participate in such projects.

Thus, this teacher's approach towards the collaboration purposefully took the exchange-oriented perspective, without the intention of shifting over to other kinds of reciprocity.

The scientist classified in the exchange-oriented group (participant 5) similarly described the distribution of roles in his collaboration in decisive tones, drawing boundaries for the responsibilities of each side and dismissing influence- and generativity-oriented reciprocity. He was positive about students' potential to contribute to the research in various ways, e.g., favorably indicating their open-mindedness. Nevertheless, he seemed content with keeping relations within the exchange-oriented arena and avoid getting overly involved, in his opinion, while ensuring he received a satisfactory amount of collected data.

5.2.3 | Case C: Influence-oriented reciprocity, participant 8 (scientist, project 8)

This scientist was a graduate student at the time of data collection for this study. He became involved in a citizen science project led by a group of scientists in the faculty where he studied. His responsibilities within the scientific team were not tied directly to the scientific research process, but to logistical and administrative aspects of communicating with the schools. Yet, he was working integrally within the team and was fully on board with the project's scientific goals.

This scientist was critical about both the teachers' and scientists' capacity to engage in tasks outside of their disciplinary expertise:

> [Teachers] shouldn't affect [research design] at all… If you let someone that doesn't know much about the topic make decisions, it would get messy.

Or:

> A scientist wouldn't know how to design a lesson plan. He doesn't understand how things work in the classroom and how to talk with the students.

Despite these stands, we classified his position under the influence-oriented group. First, we established that his views conformed to markers of reciprocity. He clearly considered the collaboration to be such where both sides were contributors. Even though he would not accept teachers' and students' inputs in some aspects of the research (such as determining research design), he asserted that they did have knowledge that was relevant to the scientific process. For example, he mentioned how teachers' efficient work with their students provided more valuable data than an attempt made by the chief scientist to operate the project in his undergraduate classroom. He commented on the school's impact on research, acknowledging teachers' and students' contributions and the key roles they played in its success:

> We work with the schools all the time. They give us feedback. [Their impact on the research was] very high because they did all the measurements and without them there wouldn't be a project.

Our key consideration in classifying this scientist under the influence-oriented group was his repeated recognition of the interactional nature of the collaboration and of the mutual influences enabled by it. This was manifested through multiple frames of reference. First, he outlined students' participation in the project in light of possible social impacts, rather than their direct contribution in collecting data. In the following excerpt, for example, he talked about potential health benefits associated with the research:

> Most people don't know about [the research topic]. We want, through science, to provide people with an opportunity to get to know this topic and check for potential hazards themselves.

And also:

> We have a survey, whose goal is both to give us information, and also get the students to be interested in their environment. The more that people will understand and ask themselves questions about where they live, the more they will think about it and seek to change their own and others' environment.

The scientist's statements suggested that he saw the collaboration as an integrated system, rather than a collection of individuals and actions:

> I can't put [the advancement of the scientific research] at the center [of the project]. I should make sure that the project as a whole provides value. The research will advance as a part of it.

In addition, he was very mindful of the audience he was working with. He described cases in which the scientists engaged in dialogue with participating schools and reacted to needs and situations that arose as the collaboration developed:

> [When I think about the students], it affects me, it provides me with tools. You can call it feedback. When I think about the authenticity of the learning environment, how the person or the student would use our instruments.

Or:

> The schools, they keep calling us, we are talking with them all the time. And if, for example, we got an irregular measurement, we asked to add a different kind of instrument and they would agree… they are available all the time, cooperating all the time.

Thus, this scientist perceived the very interaction between the teachers, students, and scientists as one that carries iterative and mutual influences with it—an interaction that evolved around students' participation in data collection.

Of the two teachers classified in the influence-oriented group, participant 6 recognized the contributory nature of the project, yet, within the contributory model she focused on the interactive nature of the collaboration, similarly to the scientist. Participant 7 was part of a collaboration that was initially conceived as a co-created project. Her influence-oriented perception stemmed from collaborating with the scientists and from the scientists' and students' joint work. Notedly, the main scientist involved did not perceive the project as co-created, claiming that the scientific team closely oversaw most of the research processes.

5.2.4 | Case D: Inconsistent, participant 11 (scientist, project 5)

We classified a participant as inconsistent when they exhibited different viewpoints of the collaboration when referring to different questions in the questionnaire. This scientist alternated mostly between influence-oriented and nonreciprocal perceptions, as explained in the following analysis.

The scientist was open towards co-designing the research with the teachers, a stand he reached following his experiences in the collaboration:

Teachers should be more involved in choosing research goals and questions, we saw that.

He also expressed a wish to work closely with a "dedicated group" of students, picturing a condition in which data collection for the research relied on citizens that became "specialists" in providing high quality data. He noted that he had previously experienced this kind of relationship with some adult volunteers in the citizen science research he was leading. In addition, he was looking forward towards students' potential contributions, as in:

> [Drawing on students' knowledge] is important to me. It's something that… I don't know if we failed but we still haven't exhausted that potential. I really enjoyed it when children said something original. On a few occasions they said things I didn't think about before. It was important to me.

He attested that the collaboration has been a strong experience for him and his team, and that this experience had left an impression:

> Adding this layer to the project [of working with schools], it changed something in our research and in our approach.

Such influence-oriented thinking came up especially when the scientist talked about the distribution of roles within the collaboration, however, it was not representative of his entire approach towards the relationships. A different tone was evident in other statements, especially in response to questions about the project's goals and its scientific value.

The scientist stated two main motivations for collaborating with schools—educational outreach and enlarging the number of reports for their citizen science research, which had been open for public participation for several years before the scientists' first engagement with schools. Regarding the former goal, he stated:

> The educational aspect, [namely] the issue of nature conservation… that's very very important to me. To show people that what might be seen as problems that nature poses, should be viewed as challenges, and we have tools to deal with them.

Together with other statements, we observed that this scientist's spotlight on educational impacts was accompanied by a disregard of schools as potential collaborators. In the following elaboration on his goals for the collaboration, he referred to students as potential "data collectors" and was otherwise highly focused on scientist-centered objectives:

> Working with children was a way [for us] to make a statement - that we are doing something multidisciplinary that is bigger than the research itself. Cooperating with students in a similar way that we do with citizens - [i.e.] as data collectors - this may happen in the future. But connecting students to science and nature, sure, and getting more data and research grants, definitely.

When asked about the schools' contribution to the scientific research, he downplayed their potential role:

> We have low expectations about that. I don't doubt students' ability to make good reports. But I doubt we will succeed in getting to a point within the process where students' reports will advance scientific knowledge.

Notedly, the scientist stated that they did not get the amount of data they had wished for, yet he was pleased with attaining educational impacts and for that reason considered the collaboration to be a success. Thus, on one hand this scientist seemed to appreciate influence-oriented elements within the collaboration and was open to such relationships. On the other hand, he concentrated on benefits to the scientists that were not derived from students' contributions, or otherwise disregarded students as contributors. The general impression arising from our analysis of his statements was that he hoped for a more influence-oriented collaboration but found it to be mostly nonreciprocal. The only explanation he provided to this gap was a perceived lack of initiative among the school staff and students. He seems to lack criticism about the scientists' educational and scientist-centered approach.

Other participants classified in the inconsistent group conveyed an aspiration for reciprocal relations that did not abide with what they perceived as feasible. The two teachers in this group held their own and their students' scientific capacities in low regard. This seemed to limit the ways through which they thought schools could contribute to the research and the collaboration. A second scientist (participant 13) had very similar views to the scientist described in the representative case, except for alternating between nonreciprocal and exchange-oriented points of view. He too was highly focused on educational goals. The last scientist in this group (participant 12) was unique in her positions. She was very interested in attaining educational impacts through students' participation in the research, but was insecure about her own pedagogical abilities. In her opinion, this constituted a barrier for establishing a productive relationship with the students. Notably, this scientist and the two teachers classified in this group did not fully reject a reciprocal outcome for the collaborations they were involved in, but rather expressed uncertainty in its achievement.

To conclude, participants in the inconsistent group talked about the collaboration in both reciprocal and nonreciprocal terms. This inconsistency seemed to derive from a perceived gap between a vision of ideal relationships and the actual or expected outcomes. In some cases, expectations seemed to be restrained from the onset of the collaboration. For some participants this uncertainty was directed, at least in part, by their perceptions of expertise and of their own or their collaborators' capacities. Several participants with a strong emphasis on educational goals were classified in this group, similarly to participants in the nonreciprocal group.

6 | DISCUSSION

This study was motivated by the question of meaningful participation of schools in scientific research through contributory citizen science projects. Based on our theoretical review of university-community partnerships, we reformulated this question to that of reciprocal relations in contributory school-based citizen science collaborations. Analysis of participants' perceptions of reciprocity and capacities in such collaborations provides, in our opinion, an answer.

6.1 | Meaningful participation of schools in scientific research can be accomplished in contributory projects

A significant proportion (8 of 13) of study participants fully or partially believed the collaborations were reciprocal (all participants classified as holding exchange-oriented or influence-oriented views, and some classified as inconsistent). This is an important observation because reciprocity implies a balance of power that may not be equitable yet is far less biased than that suggested by nonreciprocal relations. In this study, nonreciprocal perceptions were associated with a heavy emphasis on educational goals, as evident in two of the three participants in the nonreciprocal group and in some participants in the inconsistent group. Nonreciprocal views were also associated, in some participants, with perceptions of expertise and a belief that teachers and students have low capacities for scientific practices. Thus, a nonreciprocal point of view places schools as recipients of benefits in a largely educational collaboration, leaving the responsibility for the scientific research solely within the hands of the scientists. As demonstrated by case A, this can occur even as mutual benefits are acknowledged.

This study defines the meaningful participation of schools in scientific research as a condition in which schools hold a significant degree of responsibility over the scientific processes or outcomes of the citizen science project. We contend that teachers' and scientists' reciprocal points of view uncovered by our empirical analysis count towards such meaningful participation. Both teachers and scientists in the exchange-oriented or influence-oriented groups were very mindful of the roles and impacts afforded by both sides. Despite misgivings expressed by some participants (e.g., restrictions associated with collaborators' capacities), these participants saw all sides of the collaboration as active contributors. The teachers in particular saw students' work as self-empowering (see also findings about teachers' perceptions of benefits derived from these projects in Atias et al., 2023), and perceived themselves as valuable collaborators that shared responsibility towards a successful accomplishment of mutual goals. This is illustrated in case B—the exchange-oriented teacher. She saw herself strongly in control of the collaboration's processes and firmly believed that the participation of her students was meaningful both for them and for the scientists' research. Scientists with reciprocal points of view saw within the collaborations numerous ways through which schools positively affect the research. In case C—exemplifying the influence-oriented group—the scientist pictured the schools' contributions as integral to the collaboration and indispensable.

Co-created and community-based citizen science is sometimes pictured as a “golden path” towards empowerment of citizens in science (Bonney et al., 2016; Gray et al., 2017; Gunnell et al., 2021; Mueller et al., 2012; Shirk et al., 2012), and indeed, these models can lead to considerable outcomes in this regard (e.g., Barton & Tan, 2010; English et al., 2018; Fernandez-Gimenez et al., 2008; Roth & Lee, 2004; van de Gevel et al., 2020). Yet, these projects are challenging to implement and scale-up (Gunnell et al., 2021) and are less available than contributory projects (Hecker et al., 2018). Findings from the current study support a view of contributory projects as providing opportunities towards inclusion of schools, and possibly the general public, as impactful collaborators in scientific research. Our analysis shows that in some of the examined cases, school-based citizen science collaborations not only resulted in mutual benefits, but also stimulated a perception of teachers and students as important contributors to the projects and to the scientific process. This very perception contradicts traditional views of the public as passive recipients of scientific knowledge, and importantly, places some of the responsibility to knowledge creation in the hands of the students and teachers in schools.

6.2 | Contributory-based collaborations can affect teacher-scientist power relations

The perception that schools are important contributors to the citizen science projects also constitutes a certain shift in teacher-scientist power dynamics in the collaboration. As discussed in the Theoretical Background of this article, teacher-scientist partnerships are often built on, or fall into, a hierarchy model that places scientists as the main knowledge-providers in the relationship. Reciprocal viewpoints among study participants were often accompanied by a view of teachers as important collaborators. This was evident among scientists that recognized either the pivotal educational role teachers have in the collaboration or considered teachers as possible collaborators in its scientific aspects (e.g., acknowledging that teachers should be involved in research design). It was also evident among teachers who saw themselves as active agents in the collaboration (e.g., case B of the exchange-oriented teacher). It has been previously shown that participation in citizen science collaborations can lead to a re-framing of teachers' professional positionality, as teachers develop expansive framing and come to see themselves as contributing and active actors in an endeavor that transcends school boundaries (Benichou, Kali, et al., 2022). However, our findings do not indicate a considerable change in participants' views of their own and each other's expertise. This aspect of participants' perceptions was not thoroughly examined in this study, yet, the general picture that arises from participants' statements matches traditional viewpoints previously known in the literature. These place scientists' expertise as superior to that of teachers' and more readily favor scientists' capacities to engage in educational roles, than teachers' capacities to engage in scientific roles (Bissaker, 2014; Drayton & Falk, 2006; Shanahan & Bechtel, 2019). Thus, while findings indicate that contributory citizen science can positively destabilize traditional power relations in teacher-scientist partnerships, they do not support the premise of such projects to effectively transform these relations.

6.3 | Contributory-based collaborations stimulate both exchange- and influence-oriented reciprocity

Generativity-oriented reciprocity is scarcely apparent among perceptions expressed by study participants. Statements that match this orientation were mentioned by only two participants in a small number of excerpts (Table 4). Since generativity-oriented reciprocity involves transformative processes it is likely to develop gradually over time, if at all. The cases included in this study were of collaborations in their early stages, most of them operating for only 1 school year and some for 2 years. Thus, it is not surprising that participants did not incorporate generativity-oriented points of view within this timeline. The contributory nature of the citizen science projects may also provide an explanation to this finding. It is possible that contributory projects are not fertile grounds for generativity-oriented reciprocity.

Influence-oriented reciprocity, in contrast to exchange-oriented, relates more easily to expanded roles in the collaboration (Dostilio et al., 2012) and therefore may be intuitively affiliated with higher levels of citizen participation in various research stages. Interestingly, some participants viewed the contributory-based collaborations as reflecting influence-oriented reciprocity. While co-created and community-based projects may hold a high potential to foster influence-oriented reciprocity, our findings suggest that, perhaps in contrast to expectations, contributory citizen science also has this capacity. As in case C of the influence-based scientist, the contributory projects fostered at times an acknowledgment of various mutual influences afforded by the interaction and dialogue established between scientists and schools. Personal worldviews and epistemologies seem to differentiate study participants holding exchange-oriented and influence-oriented perceptions. Participants with exchange-oriented points of view were very clear about what the distribution of roles in the collaboration should look like, emphasizing distinct areas of responsibility for different collaborators. In contrast, participants with influence-oriented points of view were particularly conscious of the ecological nature of the collaboration, seeing it as an interconnected system and focusing on interactions between collaborators, rather than their individual roles.

6.4 | Supporting reciprocal relations in contributory school-based citizen science

A crucial question that stands out is how contributory school-based citizen science collaborations can be built to support perceptions of reciprocity among stakeholders. Based on findings from this study, we offer several directions worthy of exploration.

6.4.1 | Highlighting the importance of scientific goals for relationship-building

While scientific outcomes are a cornerstone of citizen science initiatives, they can be overshadowed in schools and other environments that emphasize educational impacts (Penuel et al., 2006; Roche et al., 2020; Zoellick et al., 2012). Reciprocal relations are not likely to evolve when a school-based project is regarded by teachers and scientists mainly as an educational activity. Moreover, a disregard of scientists' motivations and of the ways through which schools' contributions are used within the scientific research hinders the development of expansive framing through which students and teachers come to see themselves as active contributors to the citizen science project (Benichou, Kali, et al., 2022; Harris et al., 2020). Most study participants recognized the significance of scientific goals in the projects, yet lessons can be learned from the few cases where they did not.

Two teachers whose cases represented the nonreciprocal and exchange-oriented groups remarked that the scientific research is not of their concern and out of scope for their positions as teachers. However, the teacher holding a nonreciprocal point of view talked about scientific outcomes as a side effect of students' work, without providing any indication that she attributed any importance to them. In contrast, the teacher holding an exchange-oriented point of view affirmed that the pursuit of scientific goals is something that the scientists deserved as part of their involvement, and that it was crucial for maintaining the collaboration. This position embodies a recognition of collaborators' needs and motivations that may be missing in the former case. In contrast, three scientists were highly attentive to the achievement of educational outcomes, to the point of fully or partially downplaying scientific goals. They willingly depicted scientists as servicing educational goals in the school-based project, and by that may have unwittingly undermined the premise for schools' meaningful participation. Our findings support the notion that reciprocal relations are encouraged when all collaborators recognize the importance of both educational and scientific goals. Thus, it is recommended to convey the meaning of reciprocal relations to all parties and help stakeholders negotiate the orientation of reciprocity they aim for, while highlighting the fundamental nature of the project as a collaboration and its reliance on mutual benefits.

6.4.2 | Decoupling perceptions of expertise from perceptions of reciprocity

All study participants made either a mild or strong connection between perceptions of their own or their collaborators' capacities, and expectations of what practices each side of the collaboration should participate in. Some participants whom we classified as having nonreciprocal or inconsistent points of view perceived expertise gaps, and specifically teachers' and students' scientific capacities, as limiting the potential for reciprocal relations (notably, these were both teachers and scientists). That is, they connected between formal expertise and reciprocity, despite the premise of citizen science to build upon lay expertise as a valuable resource in scientific efforts.

Participants who saw the collaboration as reciprocal focused on scientific contributions made by teachers and students not as scientific experts, but through their engagements with scientific activities. For example, data collection performed by students was seen by some teachers and scientists as a crucial step in the success of the scientific research, while others regarded it merely as a technical procedure. In other cases, teachers and students were acknowledged for providing valuable inputs that exceeded the schools' responsibility over the data collection process. The contrast between perceptions of expertise and reciprocity is mostly evident in case C of the influence-oriented scientist. This scientist provided several examples for contributions made by teachers and students that were valuable to the scientific team, while at the same time firmly describing these teachers and students as having low scientific capacities.

The role of expertise in scientific processes and decision-making stands in the center of an ongoing debate in literature that discusses scientific expertise. The Studies of Expertise and Experience framework (Collins & Evans, 2002, 2007) draws distinctive lines between experts and nonexperts, reserving the highest form of expertise to those that are formally trained and consequently, are especially suited for making contributions to the practice of the domain in question. Critics of Collins and Evans oppose this highly normative view on expertise, claiming that it fails to recognize that evaluations of expertise are embedded within cultural contexts (Jasanoff, 2003; Wynne, 2003). Other critics hold that contribution is not a distinguishing characteristic of formal experts and that multiple pathways for contribution should be considered (Goddiksen, 2014; Plaisance & Kennedy, 2014).

This study by no means questions the importance of formal expertise in scientific endeavors. Nevertheless, it capitalizes on the citizen science approach that accentuates the contribution of students and teachers as non-experts and reinforces the benefits of highlighting this contribution to potential collaborators. The establishment of reciprocal relations can be supported by making clear that contributions are not limited to those afforded by formal scientific knowledge and by high performance in scientific practices.

6.4.3 | Establishing a unifying language for thinking and talking about relationships within contributory citizen science collaborations

The largest group of participants in this study were classified as inconsistent, as their perceptions of reciprocity were dominated by a general sense of incoherence. Possibly, inconsistency arises during a transition in perceptions, i.e., from a nonreciprocal point of view to a reciprocal one or vice-versa. It is also possible that this incoherence reflects the large body of opinions and sentiments that exists within the public and the scientific community in regard to the issues addressed in this study. Stakeholders who wish to establish citizen science collaborations, in and out of schools, would benefit from discourse that avoids mixed messages. The framework of reciprocity established in this study seems to be an appropriate starting point. Through its depiction of distinct orientations of reciprocity (exchange-, influence- and generativity-oriented) it offers conceptual scaffolding by which collaborators can navigate their relationships.

We emphasize that we do not see any one orientation of reciprocity as superior to another. An effective approach for building reciprocal collaborations would not take a one-size-fits-all solution. The three orientations of reciprocity are better seen as a range of possibilities to be matched to what stakeholders want, need and perceive as feasible, while providing space for negotiating and adjusting expectations.

6.5 | Limitations of the study

The study includes a rather small number of cases and only one teacher and one scientist from each collaboration. Examination of different cases, or even different collaborators within the same cases, might lead to different results. The choice of study participants stemmed from their willingness and availability to participate, without controlling for other confounding variables. For instance, most scientist participants identified as males (seven out of nine), while most teachers identified as females (eight out of nine). These gender discrepancies can affect participants' perceptions of expertise, power, and relations. We also reiterate the study's focus on participants' perceptions, with no objective measure of their actual capacities and expertise and of the actual outcomes of the collaborations. Study participants consisted solely of teachers and scientists and findings did not include the viewpoints of students. Yet, our goal is to examine the relational dynamics of the collaborations and for that matter, teachers' and scientists' perceptions as project leaders have a crucial role. Lastly, the collaborations discussed in this article do not represent all types of contributory projects. We focus on projects facilitated by at least some degree of interaction between teachers and scientists, sometimes also involving student-scientist communication. There are citizen science projects where such interactions are highly limited or do not exist, such as when participants follow a data collection protocol and submit results remotely or access an online interface to interact with data.

Taking these limitations into consideration, this study serves as an exploratory baseline of the presented issues. We believe it takes an important step forward, especially in light of lacking theoretical and empirical research that discusses these issues within the context of contributory school-based citizen science.

7 | CONCLUSIONS

The main question raised in this study is whether the contributory model of citizen science enables meaningful participation of schools in scientific research. This is a goal that may be more attainable in other citizen science models, such as the co-created and community-based models, in which schools participate in a larger range of scientific practices, including research design, data analysis and dissemination of findings. To answer this question, we made some assumptions, such as aligning the term “meaningful participation” with a position of responsibility over knowledge creation and with the notion of reciprocity.

Our findings indicate that contributory projects can lead to meaningful participation of schools in scientific research through the development of a sense of reciprocity among collaborating teachers and scientists. Namely, these projects can spark a perception of all parties as active contributors to the project processes or outcomes, including a view of schools as significant participants in scientific aspects of the project. Even though the extent of schools' contributions may be negotiable, the very perception of teachers and students as legitimate collaborators and active contributors in scientific research deviates from traditional views of the public as a passive recipient. A straightforward pathway towards reciprocal relations in contributory school-based citizen science may be the establishment of exchange-oriented reciprocity, in which collective action leads to mutual benefits alongside an awareness to the contributions of both sides. Interestingly, findings demonstrate that influence-oriented reciprocity can also develop in contributory projects. Here, collaborators recognize impacts embedded within the very interaction between parties, even as this interaction occurs around the participation of schools in limited research stages.

This study does not minimize the significance of citizen science models such as co-created or community-based projects. We endorse the potential that these models hold for inducing reciprocal relations and meaningful participation. However, the study suggests that a larger range of models, including contributory and other low engagement projects, also offer a pathway for schools to engage in scientific research while having their participation acknowledged as significant. This does not occur trivially, as traditional perceptions of expertise and power undermine a view of schools and students as active contributors to scientific research. Hence, contributory school-based projects would generally require attentive design that is aware of the dilemmas such collaborations bring to light. This study takes a step forward in this regard.

Future research should continue to explore the potential of contributory school-based projects to change perceptions of power relations among teachers, students or scientists, including the potential of contributory projects to change perceptions of expertise and valuing of different kinds of expertise and knowledge. The reciprocity framework can be applied to investigate other types of projects, to better understand the effect of different citizen science models on participant's perceptions and on the potential for democratization in citizen science. Investigating diverse ways through which schools and scientists can collaborate expands school participation in citizen science, ultimately amplifying its impact on education and schools' impact on science and society.

ACKNOWLEDGMENTS

The authors would like to thank Noam Malkinson for her important help in data analysis, and Dr. Yotam Hod for insightful feedback while drafting this manuscript. This study was supported by the The Israel Science Foundation under Grant 2678/17.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions. The data that support the findings of this study are not publicly available since they contain revealing information that may compromise the privacy of research participants. Requests for data can be sent to the corresponding author, and the authors will provide as much data as possible.

ETHICS STATEMENT

This study was approved by the ethics committee of the Faculty of Education at the University of Haifa. All study participants signed informed consent letters.

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How to cite this article: Atias, O., Kali, Y., Shavit, A., & Baram-Tsabari, A. (2023). Meaningful Participation of Schools in Scientific Research through Contributory Citizen Science Projects. *Science Education*, 1–30. https://doi.org/10.1002/sce.21800