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Deciphering the role of epistemic injustice in school-based citizen science: Sources, implications, and possible ways for mitigation

Osnat Atias[1] | **Ayelet Shavit**[2,3] | **Yael Kali**[1] | **Ayelet Baram-Tsabari**[2]

[1]Faculty of Education, University of Haifa, Haifa, Israel

[2]Faculty of Education in Science and Technology, Technion, Haifa, Israel

[3]Department of Multidisciplinary Studies, Tel-Hai Academic College, Upper Galilee, Israel

Correspondence
Osnat Atias, Faculty of Education, University of Haifa, Haifa, Israel.
Email: osnat_atias@yahoo.com

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Abstract

Participation in citizen science, a research approach in which nonscientists take part in performing research, is a growing practice in schools. A main premise in school-based citizen science is that through their participation, students and teachers make meaningful contributions to the advancement of science. However, such initiatives may encounter difficulties in drawing on students' and teachers' knowledge and incorporating their voice in research processes and outcomes, partly due to established knowledge hierarchies in both science and schools. This research theoretically examines misuses of students' and teachers' knowledge in school-based citizen science that can be defined as an epistemic injustice. This term describes wrongful evaluations and considerations of people's knowledge or perspectives. Based on existing theoretical work on epistemic injustice, we first map out epistemic justifications for public participation in science and discuss deficiencies in current forms of citizen science that lead to the

perseverance of epistemic injustice. Then, we identify and characterize four forms through which epistemic injustice may be manifested in school-based citizen science. Our theoretical analysis is complemented by illustrative examples from citizen science projects enacted in schools, demonstrating cases where epistemic injustice toward students and teachers was either instigated or mitigated. We discuss implications toward educational goals and the design of school-based citizen science, suggesting that epistemic injustice can be reduced or avoided by delegating authorities to schools, maximizing teacher and student agency, and leveraging schools' community connections. Overall, this research establishes theoretical grounds for examinations of epistemic injustice in school-based citizen science.

KEYWORDS

citizen science, epistemic injustice, justice-oriented science education, school-based citizen science

1 | INTRODUCTION

Citizen science is a research approach in which nonscientists participate in the practice of science. We here use the term "citizen science" to reference a broad range of models for public participation in research (Bonney et al., 2016; Senabre Hidalgo et al., 2021; Shirk et al., 2012). At one end are top-down models such as contributory citizen science, where scientists lead and perform a study while nonscientists take part in specific tasks like data collection. In bottom-up models such as community science, nonscientists take ownership and responsibility over a scientific inquiry that concerns them. In between are collaborative and co-creative models, in which nonscientists participate more extensively in scientist-led studies or partner with scientists in directing research (Table 1). A common denominator of citizen science initiatives is the goal of advancing scientific research and generating new knowledge (Robinson et al., 2018). Other objectives may also be sought, such as educating the public in scientific matters, increasing public awareness or public engagement with a scientific issue, or incorporating the public's voice into research and related decision-making processes (Haywood & Besley, 2014; Kennedy, 2016; Roche et al., 2020; Sagy et al., 2019; Smallman, 2018). Citizen science allows people to engage with scientific issues that interest them and possibly act upon scientific problems that are relevant to their lives. It can help scientists advance or improve their research, for example, by collecting more data (McKinley et al., 2017) or by increasing the relevance, accuracy and representativeness of findings and conclusions (Albert et al., 2023; Dillon et al., 2016; Shavit & Silver, 2022). Thus, in general, citizen science efforts are driven by the presumption that public participation in research strengthens the capacity of science to address socio-scientific challenges (Soleri et al., 2016).

TABLE 1 Short definitions for citizen science and common participation models.

Term	Definition	Sources
Citizen Science	Scientific research in which nonscientists take part in performing research.	Bonney et al., 2009; Shirk et al., 2012
Contributory Citizen Science	Nonscientist participants take part mainly in data collection or processing, in a study designed, led, and operated by scientists.	Bonney et al., 2009; Shirk et al., 2012
Collaborative Citizen Science	Research is led by scientists, while nonscientists contribute data and assist in project design, data analysis, and/or dissemination of findings.	Bonney et al., 2009; Shirk et al., 2012
Co-Created Citizen Science	Scientists and nonscientists work together in identifying a research problem, and in designing and enacting a study to resolve it in line with the goals of all participants.	Bonney et al., 2009; Senabre Hidalgo et al., 2021; Shirk et al., 2012
Community Science	A study is initiated by community members to address problems that concern them. They develop and enact the research with or without the help of scientists, often seeking action-oriented outcomes.	Bonney et al., 2016

Participation in citizen science is a growing practice in schools, involving teachers and students in citizen science initiatives. The main motivations for such school-based citizen science are students' learning of science and other domains (Roche et al., 2020), and students' engagement with current scientific issues and questions (Kali et al., 2023). Common learning goals include hands-on experience with scientific practices, learning of science content, understanding of the nature of science, developing interest in science and a science identity, building awareness toward socio-scientific issues, and enticing behavioral changes or students' agency toward socio-scientific issues (Ballard et al., 2017; Jenkins, 2011; Lüsse et al., 2022; Phillips et al., 2018; Roche et al., 2020). Unlike most pedagogical approaches, when students participate in citizen science their work bears consequences outside of the school boundaries and may involve interactions with experts, officials, and other individuals (e.g., scientists, representatives of local authorities, community members). Thus, students learn as they engage with practice-oriented networks, interact with different types and levels of expertise, and contribute to the resolution of a real-world scientific problem.

Alongside the positive potential, the science-society interface embedded in citizen science is also a source for various tensions that are not easily resolved, both in and out of schools. While citizen science increases the diversity of people involved in science, most research and policymaking pathways rely on the expertise of scientists and other officials, on closed social networks, and on top-down directed funding (Bai, 2020; Strasser et al., 2019; Strasser & Haklay, 2018). Public participation efforts are not always attentive toward the public's needs and wishes, or otherwise do not go far enough in incorporating the public's voice (Chen, 2019; Dickel & Franzen, 2016; Gunnell et al., 2021; Land-Zandstra et al., 2021). One of the risks of such oversights is the development of non-dialogic relations, where nonscientists are akin to "laborers" in service of research, instead of being influential participants (Haklay, 2015). In school-based citizen science, additional factors may lead to a similar devaluing of students' participation. Students may be seen mainly as recipients of education rather than meaningful contributors to research, by both scientists and teachers (Atias, Kali, et al., 2023). Challenges

specific to the school-based context may arise, such as maintaining student motivation and positive attitude or ensuring that teachers are skilled and confident in facilitating student participation in a real-world research (Roche et al., 2020).

This article addresses one particular challenge for citizen science, centered around the (il) legitimacy ascribed to nonscientist participants, such as students and teachers, as contributors of knowledge and meaning making (Herzog & Lepenies, 2022). Such occurrences, where people are prevented from conveying knowledge in matters that concern them, may constitute an *epistemic injustice*, defined as "a wrong done to someone specifically in their capacity as a knower" (Fricker, 2007, p. 1). Generally put, the term "epistemic injustice" describes various conditions in which individuals are unjustly denied of the opportunity to exercise knowledge as a social power, including, for example, restrictions on applying one's knowledge or participating in collective meaning-making (Fricker, 2007). The epistemic nature of this injustice stems from the fact that a persons' knowledge is not truthfully evaluated or taken into consideration. Epistemic injustice was previously suggested to be an adverse factor in realizing a democratic vision of citizen science, where nonscientists take a meaningful role in the practice of science alongside scientists (Herzog & Lepenies, 2022). In this article, we lay out theoretical grounds for the applicability of epistemic injustice in citizen science, and particularly in school-based citizen science. Discussing causes and effects of undue restrictions put forth on integration of teachers' and students' knowledge into research processes, we characterize different forms of epistemic injustice relevant to school-based citizen science. Offering illustrative examples, we also derive initial design considerations for mitigating the effects of epistemic injustice.

2 | RESEARCH GOAL AND OUTLINE

In this research, we wish to deeply examine the potential for epistemic injustice in school-based citizen science, its possible causes, and its modes of operation. This is accomplished in a theoretical analysis based on literature of epistemic injustice and of citizen science. Our analysis shows how multiple forms of epistemic injustice may be induced in school-based citizen science due to systematic forces within science and education, and through their juxtaposition in school-based citizen science. The theoretical argumentation is complemented by illustrative examples of citizen science projects enacted in schools, identifying occurrences of epistemic injustice as well as its mitigation. These cases demonstrate how epistemic (in)justice may play out in real-world scenarios, and how current challenges in school-based citizen science may be seen through the lens of epistemic injustice.

The rest of the article is organized as follows. We first outline a theoretical framework for epistemic injustice, drawing on the initial depiction of the term in the philosophical work of Fricker (2007) as well as more recent interpretations. Then, we present our theoretical analysis on the manifestation of epistemic injustice in citizen science in general, and in school-based citizen science. Following a description of our methodology for empirical analysis, we present examples for occurrences of epistemic injustice in school-based citizen science projects and of its mitigation. Finally, we discuss the implications of both our theoretical and empirical exploration.

3 | THEORETICAL BACKGROUND

In this literature review, we foreground meanings and types of epistemic injustice, as conceptualized in the original depiction of the term (Fricker, 2007) and its subsequent development in

TABLE 2 Summary of terms related to epistemic injustice used in this article.

Term	Short definition	Sources
Epistemic Injustice	"A wrong done to someone specifically in their capacity as a knower"	Fricker, 2007, p.1
Epistemic Power	"One's ability to influence what comes to be regarded as knowledge and who qualifies as authoritative"	Geuskens, 2018, p. 147
Testimonial Injustice	A type of epistemic injustice in which a speaker is attributed with either less or more credibility than they deserve (with credibility-deficiency being the primary case)	Fricker, 2007
Hermeneutical Injustice	A type of epistemic injustice in which the collective epistemic resources used for social meaning-making do not represent of the experiences of a particular social group	Fricker, 2007
Ethical Order	"A set of values, virtues, norms, ethical demands and responsibilities associated with some role we might fulfill"	Tanswell & Rittberg, 2020, p. 1205
Epistemic Friction	Alternative ways of knowing and the viewpoints of marginalized communities are expressed, contesting established epistemic hegemonies	Medina, 2011
Participatory Injustice	A type of epistemic injustice in which an individual is restricted in their capacity to take part in collective epistemic activities due to systematic forces of oppression	Hookway, 2010; Grasswick, 2017
Formative Injustice	A type of epistemic injustice which entails "the unjustified control of one's self-formation or undue restriction of one's formative capacities," leading to restrained formative opportunities.	Nikolaidis, 2021, p. 383

both general contexts and in relation to the domains of science and education. Throughout the review, several key terms related to epistemic injustice emerge and are later used throughout the article. For reference and to aid in reading, these terms and their short descriptions are summarized in Table 2.

3.1 | Types and properties of epistemic injustice

Building upon the view that the capacity to convey knowledge is a form of social power, Fricker (2007) coined the term *epistemic injustice* to describe cases in which this power is denied from certain members of society. According to Fricker, an epistemic injustice occurs when a "speaker is wrongfully undermined in her capacity as a knower" (p. 28). The term "speaker" refers to any individual who wishes to communicate their knowledge in any one of possible mediums such as speech, writing, and more. A "hearer" is a recipient of such a message, whether it may be through interpersonal interaction or otherwise. Epistemic injustice describes occurrences that are both an epistemological and ethical failure. Epistemologically, the knowledge that individuals hold is not properly and accurately evaluated. Ethically, individuals may be denied a fair chance to express their knowledge and speak out on matters that concern them. The power to induce epistemic injustice, possibly inadvertently, falls within those holding *epistemic power* (Dotson, 2014; Geuskens, 2018; Wanderer, 2017), defined as "one's ability to influence what comes to be regarded as knowledge and who qualifies as authoritative" (Geuskens, 2018,

p. 147). Abuse of epistemic power may occur within a localized context or on singular occasions, yet epistemic injustice, as a phenomenon, is associated with broad-level and socially structured failures where the distribution of epistemic power is allocated unevenly without proper justification (Fricker, 2007; Geuskens, 2018). Two conditions are pertinent for defining a situation as epistemically unjust (Byskov, 2021). First, the speaker should be a stakeholder in the matter at hand, that is, impacted by the wrongful judgment of their testimony and placed in a state of disadvantage or unfair advantage. Second, the speaker should hold knowledge that is relevant to the situation. Otherwise, their testimony can most probably be legitimately dismissed, even if they are stakeholders.

Fricker (2007) defines two types of epistemic injustices. The first, *testimonial injustice*, occurs as a speaker delivers testimony (i.e., conveys a message) and their words are judged by the hearer. These exchanges are susceptible to stereotypical thinking, whether it be intentional or unintentional, and that may impact the hearer's evaluation of the speaker's credibility. This process would have unjust results if the speaker is attributed with either less or more credibility than they deserve, and the "truthfulness" of their knowledge is mis-evaluated. An example of this type of injustice, provided by Fricker, is a dismissal of women's testimonies as they are labeled "emotional" or "inapt" (Fricker, 2007). According to Fricker, the focal case of testimonial injustice is deficient attribution of credibility, yet other scholars view credibility excess—an unjustified readiness to attribute truthfulness to one's testimony—as another important origin of epistemic injustice (Bai, 2020; Medina, 2011; Medvecky, 2018).

The second type of epistemic injustice defined by Fricker (2007) is *hermeneutical injustice*, which occurs when the collective epistemic resources used for social meaning-making, such as concepts, theories and ideologies, fail to represent the experiences of a particular social group. This puts some individuals at a disadvantage as they try to either make sense of their own experiences or communicate them to others. The primary example given by Fricker to this type of injustice is that of women suffering from sexual harassment at times when this concept was not fully developed. The distinction between the two basic types of epistemic injustice, testimonial and hermeneutical, is not always clear-cut, as several factors may simultaneously impact a particular case of injustice (Anderson, 2012; Fricker, 2007; Pohlhaus, 2017).

Fricker's focus was on identity-based epistemic injustice, stemming from conceptions of one's identity such as those related to gender or race, yet epistemic injustice may also be derived from other forms of social exclusion. Thus, for example, when certain social groups are denied an equal chance for education, their members may potentially suffer from epistemic injustice not because of prejudice, but since education is an acceptable marker of credibility (Anderson, 2012). Some scholars view aspects of epistemic injustice as relating to distributive injustice, defined as an unfair allocation of goods among social groups (Cook & Hegtvedt, 1983). This point of view, based upon the moral tenet of an individual's right to know, holds that unequal access to epistemic resources and power may lead to an epistemic injustice (Coady, 2010, 2017). Epistemic injustice may also relate to cultural differences, or distinct ethical orders (Larvor, 2020). An *ethical order* is "a set of values, virtues, norms, ethical demands and responsibilities associated with some role we might fulfill" (Tanswell & Rittberg, 2020, p. 1205). When conflicting ethical orders are coupled with misuse of epistemic power, and dominating norms and values foreshadow those of disadvantaged groups, testimonial or hermeneutical capacities of disadvantaged individuals may be restricted (Tanswell & Rittberg, 2020).

3.2 | Remedies to epistemic injustice

Part of the responsibility to counteract the effects of epistemic injustice in dialogic interactions lies with the hearer, since the speaker is the one being wronged and is often positioned in a state of low epistemic power (Fricker, 2007). Individuals evaluating other people's words are encouraged to practice proactive listening that can correct erroneous judgments of credibility and is sensitive to gaps in interpretive capacities. This form of listening incorporates a critical awareness of power dynamics, social identities, issues of trust, and a general cautiousness in performing judgments. It involves not just a careful evaluation of the message, but also of one's interpretation of the message (Fricker, 2007).

Nevertheless, such individual and localized efforts for avoiding epistemic injustice would not usually provide a wholesome solution (Anderson, 2012). Proactive listening is often counterintuitive and hard to implement, since subtle and sometimes unconscious psychological biases are responsible for individual judgments of a speaker's testimony (Anderson, 2012; Fricker, 2007). Moreover, structural elements are associated with many cases of epistemic injustices. A complementary and more comprehensive approach would incorporate institutionalized principles, rules, and practices designed to reduce or eliminate epistemic injustice (Anderson, 2012). While no one such framework exists, a common denominator in multiple suggested approaches is the promotion of heterogeneity in viewpoints and forms of knowledge (Shavit & Ellison, 2021), based on principles of inclusiveness and equity (Anderson, 2012; Bai, 2020; Geuskens, 2018). Such solutions follow one of three main themes (Medina, 2011), the first of which is creation of a shared reality where meanings, perspectives, and judgments converge (Anderson, 2012; Geuskens, 2018). This approach is sometimes criticized as leading to unification, where the desirable effects of a pluralistic culture are neutralized (Medina, 2011). The second theme is that of cooperation, including strategies such as integration of resources and knowledge, increased accessibility, and practices for negotiating different ethical orders (Anderson, 2012; Bohensky & Maru, 2011; Danielsen et al., 2014; Fischer, 2000b; Geuskens, 2018; Huntington, 1998; Tanswell & Rittberg, 2020; Turnbull, 1997). The main goal of this approach is to reach mutual understandings and promote, through consideration of different perspectives, a more objective and "truthful" state of mind (Medina, 2011). The third theme is that of resistance, mainly conceived as a way to handle strong cases of discrimination and marginalization (Medina, 2011, 2013, 2017). This approach holds that epistemic injustice should be opposed by counteracting hegemonies of power. The main mechanism for such resistance is *epistemic friction*, where alternative ways of knowing and the viewpoints of marginalized communities are expressed in ways that challenge or contest established knowledge structures (Medina, 2011).

3.3 | Epistemic injustice in science

The practice of science can inaugurate epistemic injustices when research efforts dismiss or fail to consider the knowledge and perspectives of certain groups (Grasswick, 2017). For example, gender biases sometimes arise in health care as women's testimonies and experiences are not appropriately incorporated in medical research (Hamberg, 2008; Samulowitz et al., 2018; Verdonk et al., 2009). Such occurrences may represent cases of testimonial or hermeneutical injustice, caused by identity-based prejudice and systematic forces of social exclusion. However, science in its current form of practice and as a knowledge building enterprise entails further

challenges for controlling epistemic injustice. First, the practice of science follows a specific set of norms, values and beliefs that constitute what we have previously referred to as an ethical order, dictating acceptable ways of constructing and evaluating knowledge (Nadasdy, 1999). This ethical order is arguably essential for withholding truthful scientific processes. Second, science, and especially certain domains of science, are sometimes seen as privileged considering the amount of funding, research efforts and science communication pathways invested (Bai, 2020; Medvecky, 2018). Overall, these privileges combined with an adherence to a strong ethical order may lead to a credibility excess where scientific knowledge is ascribed with such credibility that it overshadows other forms of knowledge and ways of knowing (Fischer, 2000c; Medvecky, 2018). For example, indigenous people may hold different ideas of what knowledge is and how it is created, following holistic views that combine the scientific school of thought with those governed by different ethical orders, such as ethics and religion (Aikenhead & Ogawa, 2007; Tsosie, 2012). The challenge of integrating such knowledge within the acceptable ways of doing science has led to indigenous knowledge being dismissed or overlooked in scientific research (Bohensky & Maru, 2011; Brook & McLachlan, 2008; Huntington, 1998; Nadasdy, 1999; Tengö et al., 2012; Tsosie, 2012; Turnbull, 1997).

One form of epistemic injustice, termed *participatory injustice*, builds and expands upon the two basic types of testimonial and hermeneutical injustices. It occurs when an individual's capacity to take part in collective epistemic activities is oppressed (Hookway, 2010). As with other forms of epistemic injustice, this undermines people's identity as knowers and may put them at a disadvantage. Participatory injustice is highly related to the practice of science, considering the centrality science holds in contemporary society as a device for building society-level beliefs and setting agendas (Grasswick, 2017). Thus, exclusion from participation in the practices and enterprises of science can be highly disadvantageous (Bai, 2020; Grasswick, 2017).

3.4 | Epistemic injustice in education

Educational systems are occupied with questions such as what knowledge is, what comprises knowledge worth having, and how is such knowledge acquired (Stroupe, 2022). Resolution of these questions largely relies upon the social-embeddedness of these systems, reflecting the underlying distribution of epistemic power and leaving space for cases of epistemic injustice (Gorur et al., 2019; Kotzee, 2017; Stroupe, 2022). Thus, for example, testimonial injustice may occur as policies affect schools' curricula, accentuating the viewpoints of certain societal groups or unfairly treating those of others (Kotzee, 2017; Stroupe, 2022). This may, in turn, lead to hermeneutical injustice, as the set of truths and values students are exposed to represents only some of them, placing others at a disadvantage (Kotzee, 2017). Distributive patterns of epistemic injustice occur when accessibility to education is unjustly limited, or as the means, resources and quality of education vary in different locations and communities (Kotzee, 2017). The epistemic nature of such occurrences of injustice is marked by the restrictions this exclusion places on an individual's identity as a knower.

Children are sometimes wrongfully ascribed with low levels of credibility or placed in a position of low epistemic power (Burroughs & Tollefsen, 2016; Kotzee, 2017). This can occur in noneducational settings such as children bearing witness in crime investigations and court hearings (Burroughs & Tollefsen, 2016; Danby et al., 2022), but also in classrooms (Kotzee, 2017). Students are encouraged to develop autonomous epistemic capabilities yet are also required to follow epistemic authorities such as teachers and other external sources

(Barzilai & Chinn, 2018). While teachers and other experts are, on a general level, rightfully entitled to hold epistemic power, tensions in the allocation of epistemic authority are integral to the acts of teaching and learning. This opens a possible arena for unjust judgment of students' knowledge (Kotzee, 2017), negatively affecting students' epistemic development (Burroughs & Tollefsen, 2016) and possibly violating the educational goal of promoting "learners' agency as knowers" (Barzilai & Chinn, 2018, p. 362). Such restrictions on students' self-formation constitute another form of epistemic injustice labeled *formative injustice* (Nikolaidis, 2021), which occurs as epistemic marginalization constrains opportunities for development in ways that may conflict with one's current or future interests.

4 | THEORETICAL ANALYSIS OF EPISTEMIC INJUSTICE IN SCHOOL-BASED CITIZEN SCIENCE

Our theoretical analysis is divided into three main parts. First, we discuss epistemic injustice in the context of general citizen science, grounding a moral and epistemic justification for public participation in scientific research. Second, we reflect on possible causes for epistemic injustice in citizen science despite its participatory nature. Finally, we focus on school-based citizen science, examining the potential manifestation of different forms of epistemic injustice and theorizing possible causes for their instigation.

4.1 | Conditions for epistemic injustice in science

In the theoretical background, we discussed the relevancy of participatory injustice to the practice of science, considering cases where individuals are denied the opportunity to participate in scientific research as a possible epistemic injustice. We posit that the previously described conditions for testimonial injustice are key for understanding occurrences of epistemic injustice in science: (1) that members of the public have a stake in its practice, and (2) that they hold relevant knowledge. Regarding the first condition, we note that a large proportion of scientific research aims to impact different aspects of living, such as health, economics, education, and other social structures. Hence, the implementation of scientific knowledge in various forms affects people's well-being (Irzik & Kurtulmus, 2021). One may argue that epistemic injustice is not a risk factor in research that has little implications on people's lives, such as research of faraway galaxies. Indeed, we acknowledge that the potential for epistemic injustice escalates as the affinity between research and public interests increases. However, members of the public are known to have made significant contributions to astronomical research (Cardamone et al., 2009; Lintott et al., 2009; Straub, 2016). Such citizen science initiatives may hold indirect stakes toward participants, such as enjoying the benefits of access to scientific knowledge and science-related social networks (Herzog & Lepenies, 2022). Thus, instigation of epistemic injustice should be seriously considered in various domains of science, acknowledging different ways in which members of the public are affected by scientific research and take interest in it.

The second condition, of people holding relevant knowledge for scientific research, perhaps requires further examination. It can be argued that in many scientific studies, the public would have little knowledge to contribute and that the general lack in knowledge and skill may lead to errors and inaccuracies in the research process. We acknowledge the importance of scientific expertise in directing and supporting research that builds upon and adds to established

scientific knowledge. However, we contend that acting solely based on deficit views of the public increases the risk of epistemic injustice and can stimulate a vicious cycle, where exclusion preserves or deepens the gap between science and excluded publics (Pearce, 2004). Communities and social groups would often hold knowledge that is relevant to issues that concern them (Colfer et al., 2005; Dillon et al., 2016; Fischer, 2000a), such as practical know-hows and a "nuanced understanding of the environment of study" (Grasswick, 2017, p. 318). Integration of such local knowledge within scientific research processes can help solve complex socio-scientific problems and inform official policies (Balazs & Morello-Frosch, 2013; Danielsen et al., 2014; Dillon et al., 2016; Fischer, 2000a; Kolawole, 2015; Schade et al., 2021). Thus, a research process that fails to make use of this knowledge may result with deficiencies in the validity of produced findings, or lead to conclusions and policies that are not adequately applicable (Irzik & Kurtulmus, 2021; Jaeger et al., 2023). When this happens, it may also lead to a secondary form of epistemic injustice that is distributive in nature, as people are denied the opportunity to acquire knowledge important to their interests (Irzik & Kurtulmus, 2021).

4.2 | Citizen science is not a silver bullet solution to epistemic injustice

In principle, the practice of citizen science is directed toward remedying cases of participatory injustice by including more people in the scientific processes. Citizen science is often envisioned as an interface for establishing dialog between scientists and members of the public and incorporating the public's voice into research and related decision-making processes (Haywood & Besley, 2014; Kennedy, 2016; Sagy et al., 2019; Smallman, 2018). This has the dual effect of (a) empowering people to engage and potentially act upon scientific matters that interest them and might be relevant to their lives, (b) integrating knowledge and voices of various stakeholders from diverse sources into the scientific knowledge generation process. A commitment to include diverse publics can increase the accuracy and representativeness of findings and conclusions since multiple insights and perspectives are taken into consideration. This may lead to better and more robust science (Albert et al., 2023; Dillon et al., 2016; Jaeger et al., 2023; Shavit & Silver, 2022). Thus, citizen science efforts are driven by the premise that public participation in research strengthens the capacity of science to address socio-scientific challenges (Soleri et al., 2016).

However, citizen science is sometimes criticized as not going far enough in realizing this democratic vision of science. As a start, citizen science initiatives often lack in diversity of participants, drawing in mostly educated white people (Paleco et al., 2021). Thus, communities that suffer most strongly from participatory injustice may continue to be excluded. Bottom-up models of citizen science, such as co-created citizen science or community science, are sometimes seen as a rightful approach that maximizes incorporation of the public's voice. These models certainly provide nonscientists with more epistemic power than in other forms of participatory science. However, top-down models such as contributory citizen science are an important part of the citizen science landscape that can oppose epistemic injustice by broadening the reach of citizen science and providing approachable opportunities for participation. Thus, epistemic injustice should be addressed across the wide spectrum of participation models. However, experience shows that epistemic injustice continues to be an issue in various forms of

citizen science, mainly because traditionally established avenues for practicing science and enforcing scientific-based policies are not sufficiently attuned to public participation and incorporation of public voice. First, institutionalized science is governed by closed social networks and funding systems from which the public is excluded, and are sometimes inaccessible or lack transparency (Bai, 2020; Lacey et al., 2020; Palecho et al., 2021; Paleco et al., 2021). Second, these systems mostly lack incentives for scientists to engage with the public. While some funding schemes encourage use of participatory research methods, scientists' careers and professional status often depend on strong publication records, an objective that may not be consistent with taking the citizen science and public engagement route (Lacey et al., 2020; Schade et al., 2021). Third, scientists often hold deficit views of the public, considering nonscientists as lacking in knowledge and literacy, sometimes challenging the idea that the public can contribute to scientific research (Burgess et al., 2017; Golumbic, Orr, et al., 2016; Riesch & Potter, 2014). Thus, perpetuation of existing power relations and hierarches of knowledge may impose the agenda of the authoritative side in public participation endeavors (Chiaravalloti et al., 2022; Dressler et al., 2010). These barriers to participation of nonscientists reinforce scientists' authority in directing and conducting participatory research and potentially inhibit nonscientists' opportunity to contribute their own knowledge, possibly leading to an epistemic injustice.

4.3 | Forms of epistemic injustice relevant to school-based citizen science

Based on the literature review and our theoretical analysis, we view four forms of epistemic injustice as relevant for school-based citizen science: testimonial injustice, hermeneutical injustice, participatory injustice, and formative injustice. We provide a short characterization of each of these forms in the context of school-based citizen science (Table 3), focusing on students and teachers as the main target of these injustices. Next, we explain how each of these forms may manifest in school-based citizen science.

TABLE 3 Forms of epistemic injustice relevant to school-based citizen science and characterization of their manifestation.

Form of epistemic injustice	Manifestation in school-based citizen science
Testimonial Injustice	Students or teachers are attributed with less credibility than they deserve. Their knowledge is not regarded as valuable enough to be expressed or heard.
Hermeneutical Injustice	Students' or teachers' perceptions and experiences are unjustifiably disregarded when considering research questions, practices, or interpretation of findings, leading to students' or teachers' reduced capacity for meaning-making or meaning-sharing of their own lived experiences.
Participatory Injustice	Students or teachers are restricted in their capacity to impactfully participate in scientific knowledge building, in cases where they are able to make significant contributions.
Formative Injustice	Students or teachers are unduly restricted in pursuing pathways to develop as knowers, or their capacity as knowers is restricted in a way that prevents personal growth.

4.3.1 | Testimonial injustice

Students that participate in citizen science initiatives may hold knowledge relevant to the scientific research, primarily as members of the public and of their respective communities (e.g., Magnussen & Hod, 2023). Their unique position as representatives of their age group may be advantageous for research, especially in cases where an accurate description of children's lives and experiences is a target of the research question or if they are affected by the research topic or its findings in substantial ways. Disregarding students' knowledge when it is relevant and useful constitutes a case of testimonial injustice. While this is true for citizen science in general, the school-based context introduces unique dynamics that may contribute to the devaluing of this knowledge. Educational benefits for students are a primary goal of school-based citizen science (Roche et al., 2020). We suggest that a focus on students as knowledge recipients may coalesce with the general view of children as possessing less knowledge and holding reduced epistemic capabilities (Burroughs & Tollefsen, 2016; Kotzee, 2017), and with the deficit-based approach that scientists often assume when communicating with the public (Besley & Nisbet, 2013; Rose et al., 2020), resulting in unwarranted dismissal of students' knowledge and reduced opportunities to put this knowledge to use (also relating to occurrences of participatory injustice).

Teachers in school-based citizen science would generally take the role of facilitators and enablers of students' participation and learning. Other than the general knowledge they hold as individuals, they also hold knowledge derived from their professional expertise. However, this knowledge is not always properly evaluated, particularly in cases where teachers work alongside scientists and other professionals. Teacher–scientist partnerships are common in various settings, such as in co-development of learning materials and activities as well as facilitation of students' participation in science. Evidence shows how teachers' expertise in such partnerships is sometimes devalued in relation to that of scientists' expertise, resulting with an underlying hierarchy of scientists as knowledge providers and teachers as knowledge receivers (Bissaker, 2014; Carlone & Webb, 2006; Drayton & Falk, 2006; Shanahan & Bechtel, 2019). Thus, teachers too may be victims of testimonial injustice in school-based citizen science.

4.3.2 | Hermeneutical injustice

Most scientific research holds some degree of impact on people's lives, especially when it produces knowledge made available for personal decision-making or applied in public policies. From an epistemic injustice standpoint, such research should take care to reduce hermeneutical gaps between individuals' perceptions of their own lives and experiences and those derived from the research processes, findings, conclusions, and applications. When such hermeneutical gaps persist, research may become "misaligned with local realities" (Dressler et al., 2010, p. 12), rendering it inapplicable or irrelevant to misrepresented communities and thus obstructing their own meaning-making, leading to a hermeneutical injustice (Miller et al., 2018). We suggest that in school-based citizen science, students may suffer from additional risk of hermeneutical injustice as their perceptions and experiences are not fully reflected through their participation. First, students are often mandated to participate as part of their school activities and so, they are not willing volunteers as other citizen science participants. Second, in school-based citizen science students will sometimes not fully grasp their role as participants in research and contributors to science (Harris et al., 2020). For example, they may center their participation

around class-related achievements. Decreased motivation to participate and school-centered goals may compromise students' participation and make it less authentic. As such, misalignments between the research and students' realities may perpetuate, possibly leading to a hermeneutical injustice.

Hermeneutical gaps may be partially responsible for the unbalanced power relations present in teacher–scientist partnerships and school-based citizen science collaborations. Teachers and scientists come from different ethical orders, that is, they comply with different sets of norms and values. Differences in professional cultures can lead to communication difficulties (Carlone & Webb, 2006; Tanner et al., 2003). Epistemic goals of science and education are not entirely compatible, as scientists aim to create and evaluate new knowledge while teachers often concentrate on transmission and reconstruction of existing knowledge. This may lead to communication and interpretive discrepancies in how teachers and scientists perceive project goals and their roles within it. Given scientists' position of power, teachers' perspectives may be given less consideration and have less impact over the project and its outcomes.

4.3.3 | Participatory injustice

With public participation in research, epistemic injustice is potentially reduced twofold: the research becomes more accurate and "truthful," and better knowledge and policies are made available to the public. Justice-oriented participation implies that people can exercise voice where it matters, that is, their knowledge is given an opportunity to make an impact (Kidron et al., 2019; Schejter & Tirosh, 2014). In citizen science this should occur, at least to some extent, in all forms and participation models, yet as discussed earlier that is not always fully realized. However, while learning through participation is an established pedagogical approach (Lave & Wenger, 1991; Sfard, 1998), participation "where it matters" is not common in school settings since learning is not usually directed toward societal impact or knowledge products that are of actual use (Miller et al., 2018). Moreover, democratic practices such as those manifested in citizen science are not easily adopted in formal education systems, which traditionally support hierarchies of knowledge and expertise in somewhat similar manners to institutions of science (Weinstein, 2012). For a true mitigation of participatory injustice to occur in school-based citizen science, learning should coalesce with a clear intention to impact scientific research in ways that promote students' and teachers' agency as knowers (Ballard et al., 2021; Kali et al., 2023; Magnussen & Hod, 2023; Miller et al., 2018; Sjöström & Eilks, 2018).

4.3.4 | Formative injustice

School-based citizen science initiatives are normally committed to educational goals such as gaining of scientific knowledge and skills, motivation and interest in science, altered attitudes or increased awareness toward scientific issues, and behavioral changes (Phillips et al., 2018, 2019). These are all important learning outcomes that may promote students' epistemic competencies, including their ability to express their knowledge and put it to use in current and future settings. Some of our claims outlined above set the educational focus as a possible instigator of epistemic injustice, yet we stress that learning is an important part of school-based citizen science. From an epistemic injustice standpoint, obstruction in achieving educational goals or fully realizing the educational potential of students' participation may constitute a formative

injustice, where students' formative capacities are restricted. We note that for teachers as well, participation in citizen science can lead to considerable personal and professional development (Benichou et al., 2022; Scheuch et al., 2018). Thus, affordances for formative capacities of students and teachers should be encouraged in school-based citizen science.

Balancing scientific and educational goals in school-based citizen science projects is sometimes difficult because they may be driven by different considerations (Gray et al., 2012; Penuel et al., 2006; Radinsky et al., 2001; Roche et al., 2020; Zoellick et al., 2012). In a similar fashion, fulfilling of formative justice while managing other forms of epistemic injustice may be challenging. When considering the focus of students' activities in citizen science and the purposes they serve, formative injustice dictates a mindful approach toward creating nurturing learning environments. That may come in expense of scientific objectives and student participation in research-oriented activities.

5 | ILLUSTRATIVE EXAMPLES

To substantiate our theoretical claims regarding the potential for epistemic injustice in school-based citizen science, we present an analysis of multiple citizen science projects and their enactment in schools, showing several occurrences of epistemic injustice as well as cases where epistemic injustice was reduced or avoided. This analysis serves three objectives: (1) exemplifying how occurrences of epistemic injustice may look like "in action," (2) providing initial examples of how design elements of school-based citizen science can support mitigation of epistemic injustice, and (3) initiating precursory discussions on the role of epistemic injustice in common tensions arising in school-based citizen science. Since our approach is limited to mostly secondary analysis of readily available data sources, we do not consider this to be a thorough examination but rather a demonstration of the applicability of our theoretical claims. Next, we describe the process for gathering empirical evidence, followed by a case-by-case presentation of the examples.

5.1 | Data collection

5.1.1 | Context and examined projects

Our examination focuses on eight citizen science projects related to the Taking Citizen Science to School (TCSS) center which supports the design and enactment of school-based learning activities centered around citizen science projects in Israel (Table 4). The center operates several citizen science projects, most of them follow the contributory model of citizen science in which scientists lead a study while citizen scientists participate mainly in data collection. Normally, an educational researcher affiliated with the center acts as project manager, leading the pedagogical design sometimes in tandem with teachers. When teachers are not part of the initial design process, they are often provided with opportunities and support for adapting an existing curriculum. Enactment of learning activities and facilitation of students' participation in the research is the main role of participating teachers. The project manager also acts as a focal point in linking teachers and scientists and ensuring a fruitful cooperation. Scientists, which are not affiliated with the center but with their own academic units, sometimes participate in the educational design and often take part in educational activities, such as meetings with the students.

TABLE 4 School-based citizen science projects featured in illustrative examples.

Project title Participation model Years of operation	Number of participants	The scientific research	Scientists' involvement	Teachers' involvement	Students' involvement	Case study reference used as data source
Air quality Contributory 2015–2017	8 schools 8 teachers ∼250 students	Testing the use of micro air quality sensors, comparison to standard measurements, pilot for extended distribution.	Conceived and led the research, provided schools with sensors, installed sensors in schools, met with students in a few lessons.	Designed classrooms activities, determined locations for sensor installment, guided students' work.	Learned about topics related to the research, handled the sensors (which automatically uploaded data to a central database), engaged in data analysis activities, produced a report of their inquiry and presented it in a regional school event (in some schools).	Golumbic (2019); Golumbic, Baram-Tsabari, and Fishbain (2016)
Irises Community Science 2019–2020	1 school 1 teacher 25 students	Investigating discrepancies in fertilization status among Iris plants near the school.	Acted as expert advisors when contacted by the teacher, helped the teacher in selecting the research topic and advised the students when taking action to protect the Irises population.	Initiated the project, selected research topic by consulting a scientist, guided students' work. managed student interaction with community members and an additional scientist.	Collected and analyzed data, engaged in community action when the Irises population was put in danger, produced a report of their inquiry and presented it to the community.	Tal et al. (2023)
Jellyfish Contributory 2016–2017	1 school 8 teachers ∼90 students	Investigating distribution patterns of Jellyfish along shores.	Conceived and led the research, met with students in a few lessons, discussed research findings with students.	Co-designed a learning program with educational researchers, guided students' work.	Learned about topics related to the research, collected data and reported it to a central database, engaged in data analysis activities, presented learning products in a local school event.	Kali et al. (2019)

(Continues)

TABLE 4 (Continued)

Project title Participation model Years of operation	Number of participants	The scientific research	Scientists' involvement	Teachers' involvement	Students' involvement	Case study reference used as data source
Mammals Contributory 2019–2022	8+ schools 15+ teachers 500+ students	Investigating distribution patterns of small mammalian species in areas with different ecological features.	Conceived and led the research, met with students in a few lessons (in two schools), discussed research findings with students (in three schools).	Co-designed a learning program with educational researchers, guided students' work.	Learned about topics related to the research, collected data and reported it to a central database, engaged in data analysis activities (in some schools), produced a report of their inquiry (in some schools), presented learning products in a school event (in some schools).	N/A
Mapping Contributory 2020–2022	12 schools 18 teachers ~650 students (1 additional school enacted the project as a school-wide event with the participation of ~1000 students)	Calculating optimal walking paths for the visually impaired in urban areas.	Conceived and led the research, met with students in a few lessons, hosted students' visit to an academical institution (for some schools).	Adapted an existing learning program to their classrooms, designed additional student activities (in some schools), guided students' work, interacted with other third parties such as municipal authorities (in some schools).	Learned about topics related to the research, mapped sidewalk features on urban streets, engaged in geographical data analysis activities (in some schools), produced a report of their inquiry (in some schools), presented findings to municipal authorities (in some schools).	Lan et al. (2022)

TABLE 4 (Continued)

Project title Participation model Years of operation	Number of participants	The scientific research	Scientists' involvement	Teachers' involvement	Students' involvement	Case study reference used as data source
Radon Contributory 2019–2020	7 schools 8 teachers ∼450 students	Surveying levels of Radon gas in residential homes.	Conceived and led the research, provided schools with measurement kits, interacted with participants around a few cases of aberrant measurements.	Adapted an existing learning program to their classrooms, guided students' work, organized a public awareness community event (in some schools).	Learned about topics related to the research, performed measurements and sent them back to the scientists, engaged in data analysis activities, presented learning products to the community (in some schools).	Golumbic et al. (2023)
Rare species Co-created 2020–2021	1 school 1 teacher 81 students	Monitoring rare plant species in a forest near the school.	Suggested the research topic, acted as expert partners in designing and enacting the research while interacting with the teacher.	Initiated the project, interacted with scientists to determine, design, and maintain the research, guided students' work.	Took ecology lessons in the forest, collected data that was reported back to the scientists.	Oren et al. (2022)
Sleep Contributory 2020–2023	45 schools ∼60 teachers ∼3370 students	Investigating sleeping patterns among youth.	Conceived and led the research, met with students in a few lessons, produced videos for students, hosted students' visit to an academical institution (for some schools).	Adapted an existing learning program to their classrooms, guided students' work.	Learned about topics related to the research, recorded their own sleep logs and sent them back to the scientists, engaged in data analysis activities, produced a report of their inquiry (in some schools).	N/A

We note that none of the examined projects were designed and operated with epistemic injustice in mind.

5.1.2 | Choice of projects and authors' affiliation with the projects

The eight projects were chosen for analysis because we had access to multiple data sources for each of them, enabling in-close examination and triangulation of evidence. However, for the Mammals and Rare Species projects, information was available from only two of the four data sources (Table 5). Three of the authors are affiliated with the TCSS center and all of them were, between them, involved in some way with operating six of the projects. The first author was the project manager in the Jellyfish and Mammals projects. The second author was an advisor of the scientist leading the Mammals project. The third author was an advisor of the first author and of the researcher managing the Sleep project. The fourth author was an advisor of the first author and of the researchers managing the Air Quality, Mapping, and Radon projects.

5.1.3 | Data sources

Four data sources were used to gather evidence on occurrences and participant perspectives in each of the eight projects (Table 5). The first data source consisted of published case studies about the projects. These publications provided descriptions and analyses of the projects' enactment, each in one or more schools. The second data source included data previously collected from teachers and scientists that participated in the projects as part of another study (Atias, Baram-Tsabari, et al., 2023; Atias, Kali, et al., 2023). The collected data pertained to teachers' and scientists' motivations to participate, their views on the distribution of roles and expertise between teachers, scientists and students, and perceived relationships between the students, teachers, and scientists. The third data source was a story platform named Insights, developed by the TCSS center for the purpose of sharing implementation stories and collectively building a database of design principles for enactment of citizen science in schools. Stories are contributed to the platform by project participants of all kinds, including educational researchers, teachers, scientists, and students, and they typically include descriptions of one or more occurrences that happened during project enactment. For our analysis we identified 19 stories shared by various participants in the eight projects. The fourth data source consisted of one-on-one interviews with project managers and was the only data source produced specifically for this research. Since epistemic injustice was not a discussed or researched theme in any of the projects, these interviews were conducted to focus examination of the projects through the specific lens of epistemic injustice. Each interview began with an explanation of the notion of epistemic injustice. Then, project managers were asked to recount occurrences in their projects where they believe epistemic injustice was ensued or avoided. Occurrences extracted from other data sources were also discussed.

5.1.4 | Extraction of illustrative examples

The data sources were used to extract illustrative examples for instigation or mitigation of epistemic injustice in the examined projects. As a first step, data for each project was aggregated

TABLE 5 Data sources used for empirical analysis.

No.	Data source	Presented projects							
		Air quality	Jellyfish	Mammals	Mapping	Radon	Sleep	Rare species	Irises
1	Existing publications describing the projects, mostly in the form of case studies (see Table 4 for references)	X	X		X	X		X	X
2	Collected data from teachers and scientists participating in the projects (Atias et al., 2022; Atias, Baram-Tsabari, et al., 2023; Atias, Kali, et al., 2023)	X	X	X	X	X	X		
3	Insights (Kali et al., 2020), a platform established and maintained by the TCSS center, holding personal accounts of students, teachers and researchers participating in the projects		X	X	X	X	X		X
4	Original interviews with TCSS researchers acting as project managers	X			X	X	X	X	X

from the four sources. Such data would typically include one or more of the following: descriptions of events as given by a participant (project manager, scientist, teacher, or student), quotes of verbal statements made by such participants, observations provided by project managers or other educational researchers, and findings and conclusions included in published cases. This data was used to construct a fragmented timeline of events that occurred in each project, with associated opinions, insights, and reports by different participants. Second, the timelines were scrutinized by the first author for events or utterances that may constitute a case of epistemic injustice or of its mitigation. This process was guided by our own characterization of forms of epistemic injustice in school-based citizen science (Table 3), as detected events were evaluated against each of the four forms of epistemic injustice. A written account was constructed for each identified occurrence, describing events and other relevant data, and explaining how epistemic injustice was ensued or avoided. For further validation of our interpretations, the project managers that were interviewed for the fourth data source participated in a second informal interview, examining these accounts and providing feedback. Finally, accounts were collectively examined by all authors in a series of talks and meetings, jointly discussing whether each represents an occurrence of epistemic injustice or its mitigation, and if so, what was the nature of the injustice and its significance to the school-based context. In this process, some of the accounts were discarded due to a reevaluation of the events. We here present the remaining accounts, containing detected examples for occurrences of epistemic injustice or its mitigation.

Crucially, in examination of the projects and evaluation of epistemic injustice, we opted to honor the projects' chosen participation model. Most projects (six of eight) followed the contributory model. Accordingly, we did not label the exclusion of students and teachers from research stages such as research planning and data analysis as an epistemic injustice.

5.2 | Examples for instigation of epistemic injustice

We begin by detailing examples for instigation of epistemic injustice, followed by those of its mitigation. For each example, a short overview of the citizen science project is provided as well as a summary of relevant events and participant perspectives. This is followed by our analysis of forms of epistemic injustice showcased by the occurrences.

5.2.1 | Air quality project

In the Air Quality, project scientists wished to test the feasibility of using low-cost air quality sensors for large scale monitoring of air quality, in opposed to standard methods that employ use of larger sensors installed in public places. Scientists provided participating schools with sensors that students could use to make measurements at homes and other locations. Participating teachers designed learning activities with the sensors for their students. For example, some have encouraged their students to make personal investigations of air quality in their houses and neighborhood environments. Other teachers guided their students in collective investigations such as measuring air quality in different locations in the school. In some of the schools, students engaged in data analysis of their own collected data, produced a report of their inquiry and presented it in regional school events.

The project was successful in engaging teachers and students in air quality research and teaching students about air quality (first data source). At least one teacher attributed the project

with a high educational value for participating students (second data source). On the other hand, although the leading scientist recognized the value of the project as an educating device (first and second data sources), he had found no value in the project for himself as a scientist and for his research (second data source). Thus, for example, he stated that "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" (second data source). Such stances can be regarded as a testimonial injustice where students' knowledge is credited as less valuable than it actually is, on the grounds of their lack of expertise and their young age. The scientist is providing an unjust evaluation of the circumstances, describing students as needing a solution to a problem and scientists alone as contributors of knowledge, when in fact, the students were contributing data they collected to the scientist' research. It is possible that these stances have led to a participatory injustice where students were denied opportunities to impact the scientific research, thus prompting the scientist's claim for no positive scientific influence. However, the wholesale conviction that students have nothing to contribute seems far reaching. In this project, for example, students came up with their own investigations of air quality issues in their local environment. Such local measurements are a required practice in air quality research, where determination of pollution sources is made on a case-by-case basis since environmental factors can vary greatly among different locations (Golumbic, 2019). Thus, a predisposition to dismiss students' testimonies can lead to a testimonial injustice.

5.2.2 | Radon project

Radon is a gas that can accumulate in buildings and has toxic effects in high concentrations. The scientists leading the Radon project were interested in running a survey of radon concentrations in residential areas. They provided schools with radon measurement kits so that students would collect data about radon concentration levels in their homes. Each kit could be used once, and its contents were sent back to the scientists for analysis and determination of the measurement result. The scientists devised a protocol for using the kits, directing participants to take measurements in bedrooms only. However, students, who formulated their own research questions for examining how radon levels are affected by different conditions as part of the learning program accompanying their studies, have sometimes taken measurements in various in-house locations and conditions. The scientists expressed annoyance at this, preferring to focus on a standardized database (first and fourth data sources).

It is important to ensure that scientific data collected in citizen science projects is valid and appropriate for drawing reliable conclusions. This includes a need to use standardized protocols for data acquisition, although technically data may be collected in multiple conditions if these are properly recorded. It can be asserted that scientists, as the owners and funders of the measurement kits, are entitled to prescribe how they are used. While this is a legitimate claim, it should be taken with care and awareness of possible instigation of epistemic injustice. When scientists dictate how a citizen science study is to be performed, they are exercising their power as experts and resource-owners, possibly overcoming the interests of nonscientists. In the case of the Radon project, taking measurements in diverse conditions was an interest of students in multiple ways. First, some of these measurements detected radon levels that were higher than allowed by national health regulations, potentially alerting students and their families of hazards in their homes. Second, students were asked to investigate their own research questions as

part of the learning program that accompanied the project and focused on data-driven inquiry practices. The data that students collected was used for personal analysis in a statistical program. Third, students were genuinely interested in learning what factors affect radon concentrations, so that they could apply this knowledge for their own benefit and that of their families. Thus, denial of the opportunity to obtain knowledge through autonomous use of the radon kits would constitute an epistemic injustice. It is a formative injustice because students are denied an opportunity to pursue their own knowledge building investigations. They and their families, as well as people who access the project's public database, are prevented from acquiring and utilizing knowledge that benefits them. It is also a participatory injustice because students are denied an opportunity to impact the research. While this was a contributory project and students' participation was limited to data collection only, even within this setting they were afforded with very little agency. This case exemplifies how competing interests of scientists and schools in school-based citizen science may lead to conflicts whose resolution depends on considerations of epistemic injustice.

5.2.3 | Jellyfish project

The Jellyfish project invited the general public to send in reports of jellyfish sightings, for a study that investigated distribution patterns of Jellyfish along shores. The leading scientists wished to pilot the operation of the project in schools and thus, with the support of the TCSS center, contact was made with a school located in a coastal town. However, difficulties encountered at the onset of the collaboration have almost revoked it, forestalling student participation in the citizen science project. Communication challenges were apparent from the start, as exemplified by scientists' frustration: "The first meeting with the teachers was a blow. I felt like we weren't speaking the same language" (second data source). Here, the scientist attests to hermeneutical gaps between scientists and teachers that led to a mutual feeling of incomprehensibility. These discrepancies and communication challenges may be attributed to opposing ethical orders that scientists and teachers may hold, as different attitudes, norms, and habits of thought affect how these participants communicate. As discussed before, differences in ethical orders and the perceived superiority of the scientific ethical order may lead to testimonial and hermeneutical injustice.

In this case, collaboration continued despite initial difficulties largely due to the support of TCSS researchers and encouragement given by the school's headmaster. Yet, further evidence suggesting epistemic injustice emerged from the second data source, which included teachers' and scientists' evaluations of their own and each other's capacities to participate in various roles in the projects. This data shows that scientists evaluated teachers' capacities significantly lower than teachers' own evaluations, in both scientific roles and in some roles requiring pedagogical expertise, such as guiding students in performing research. This occurred not in one specific project but as a general trend across nine different projects included in this data source, and despite most teachers being experienced science teachers. This finding poses another red flag for possible occurrences of epistemic injustice toward teachers. In contrast, data for the Jellyfish project as well as several other projects showed that both teachers and scientists evaluated scientists' pedagogical capacities rather highly. Similar findings were obtained in other studies as well, where teachers and scientists devalued teachers' expertise by considering scientists as equally capable (Bissaker, 2014; Shanahan & Bechtel, 2019). These stances may reflect social messages that depict scientists as knowledgeable in domains that exceed their professional

scientific expertise. We interpret this as a case of hermeneutical injustice since teachers' own sense of their professional expertise is thus compromised.

The case of the Jellyfish project and other projects included in the second data source demonstrates that epistemic injustice is a risk factor not just toward students but also toward teachers. Teachers can assume various roles within school-based citizen science initiatives, such as logistical facilitators, pedagogical designers, educators, and participants in citizen science themselves. Thus, mitigation of epistemic injustice toward teachers requires consideration of teachers' knowledge across multiple domains.

5.3 | Examples for mitigation of epistemic injustice

5.3.1 | Rare Species and Irises projects

We jointly describe the two cases in our dataset that do not follow the contributory model of citizen science, as a demonstration of how epistemic injustice is mitigated when teachers and students take ownership of multiple aspects of the scientific research.

In the Rare Species project, a middle school science teacher initiated a citizen science project by contacting ecologists from the Israel Nature and Parks Authority (INPA), with the help of TCSS researchers. The teacher and the ecologists jointly decided to start a monitoring program that examines an unusually rich collection of rare plant species that resided in a forest near the school. The INPA was happy to find a community partner that would help in monitoring these plants, while the teacher used this opportunity to hold ecology lessons in the forest environment and engage students in citizen science activities. At the time of writing this article, the project has ended yet interactions between the school's educational staff and INPA representatives continue. INPA asks for intermittent updates of the status in the forest, and in response, either teachers or students take note and report back.

The Irises project was initiated by a middle school science teacher who was also a graduate student at the TCSS center. She contacted an ecology expert that helped identify a research subject that students can investigate near their school, eventually deciding to study fertilization patterns in a local population of Iris plants. The teacher planned the research and guided her students in its execution. Students' involvement with the Iris plants extended beyond the research project. During their work, they learned that a construction plan was threatening to destroy the plants, and they joined community efforts for addressing this imminent danger and campaigning against it. When it became clear that construction would complete as planned, the teacher contacted a plant biologist who instructed the students on how to physically relocate the plants, and together with other community members they successfully relocated the plant population.

Mitigation of epistemic injustice occurred at multiple levels in these projects. The teachers opted to work with scientists that would help them carry out research that fitted their interests and educational needs, and they acted as partners or leaders in research design. This constitutes a mitigation of participatory injustice toward teachers. Teachers' involvement in the initial stages of the projects led to research subjects and objectives that closely related to teachers' and students' lives, as a primary goal for the two projects was, or turned out to be, nature conservation in the schools' surrounding environment. This may contribute to the mitigation of testimonial injustice, as teachers' and students' knowledge becomes relevant to the research and its intended impacts. Hermeneutical injustice may also be reduced, as the research may illuminate

aspects of teachers' and students' lived experiences. Finally, in both cases, the project led to continued engagement of students or teachers, at least to some extent, with scientists and scientific matters in their local environment. This constitutes a mitigation of participatory injustice, as they continue to make impactful contributions, and formative injustice, as teachers and students gain knowledge and capacities of current and potential future use to themselves and their communities.

5.3.2 | Radon project

The Radon project was featured in given examples for instigation of epistemic injustice where scientists wished to control how students used the measurements kits, leading to participatory and formative injustice. However, despite tensions around the data collection protocol the project was well received by participating teachers and students who found the issue of radon in homes to be an engaging and relevant research subject. Students gained knowledge relevant to their lives which was translated to some behavioral changes such as students making sure that residential rooms and school classes are properly ventilated and free of radon gas (fourth data source). Several schools that participated in the project, all from the same municipality, decided to organize a joint community event aimed at raising public awareness to the health hazards of radon (third and fourth data sources). In this event students shared knowledge and resources about radon and presented findings from their own measurements.

This case shows how schools can draw on community connections to increase public awareness to the research and the issues it investigates, redistributing knowledge gained as students and teachers participate in the project. We view this as a reduction and mitigation of formative injustice in three ways. First, the students and teachers become knowledge providers for the benefit of the community. Second, more people in the community gain knowledge relevant to their interests. Third, increased awareness potentially makes the community more receptive to research outcomes, increasing the impact of its findings and conclusions.

5.3.3 | Mapping project

In the Mapping project, students mapped street-level objects that either hinder or support street navigation by visually impaired people. The leading scientists wished to use this data for automatic calculation of optimal walking paths for the visually impaired. It took a long, multiyear process of identifying efficient ways for collecting the data by students in-sync with public mapping databases. The culmination of this process was the development of a designated smartphone application for use by mapping volunteers. Since the app was developed following scientists' collaboration with the schools, it incorporated solutions and insights that the scientists learned as they were getting feedback from students' mapping activities. Thus, the app was tailored both to research requirements as well as to the needs of volunteers. For example, a teacher from one of the participating schools, in coordination with representatives from the school's municipal authority, wished to collect additional data relevant for people in wheelchairs and other mobility restrictions. The scientists supported this request and the option to map such street features was included in the smartphone application developed by the scientists for data collection. This automatically makes such data available in the public maps of the platform used for the study (fourth data source).

Schools' input for the data collection app was made possible because schools were not presented with a predetermined protocol and tool for collecting the data, but rather, best practices were developed as the project progressed. However, this process entailed challenges. The first schools that participated in the project experienced difficulties, at times causing data collected by the students to be unsuitable or unavailable for the scientists' research. One of the teachers participating in these first experiences had stated her understanding that her class is part of a pilot study, and their contribution is in establishing the research rather than advancing scientific knowledge per se (second data source). Many contributory projects are thoroughly designed before reaching the public participation stage, an approach that makes sense since clear and tested protocols, accompanied by instructional materials, can support participants in contributing valuable data. Nevertheless, the Mapping project exemplifies how working with schools in the early stages of the project, for example, when data collection procedures are not fully finalized, supports the incorporation of participants' experiences and needs in the design process. This case presents a decrease in participatory injustice since schools took part in some of the research design processes and a potential reduction in testimonial injustice, as teachers' and students' contributions are given space to be heard.

5.3.4 | Mammals project

In the Mammals project data about the presence of small mammals was collected using hand-built devices that record the footprints of animals that walk into them. These devices are built using easily obtainable materials such as wooden plates and craft supplies. Participating schools, as other volunteer communities that participated in the project, were requested to fund these materials and build the devices themselves. The knowledge needed for assembly and use of the devices was made commonly available (short instructional videos were publicly published on YouTube). Thus, communities and individuals that wish to use the method for their own purposes may do so, choosing whether to contribute their data to a nationwide database managed by the leading scientists. This design contrasts that of the Radon project, where scientists distributed the data collection kits and wished to control how they were used. Here, schools funded the devices and were fully entitled to use them as they wished. As long as placement of the devices followed a few simple guidelines, scientists were happy to receive reported data from any location.

We view this design as supporting the mitigation of epistemic injustice in two major ways. First, knowledge about data collection methods is publicly dispersed, so that schools and other participants may use it for their own research activities. This represents a mitigation of formative injustice. Second, the schools manage their own research agendas and locations for data collection. Their choices largely determine what data is available to the scientists, and, indirectly, the findings and outcomes of the study. This represents a mitigation of participatory injustice. Although this approach may lead to a biased dataset, the scientists made an effort to compensate for this by working with diverse communities, both geographically and in terms of experience and research agendas (second data source and personal communication). Nevertheless, a possible caveat of this design is a participatory injustice caused by unequal distribution of goods, as some schools may have more difficulties in providing monetary resources for building the devices. Moreover, since the scientists' research is partly funded by the participating schools and volunteers, this design calls for added attention to possible occurrences of epistemic and other kinds of injustice.

Another pathway for mitigation of epistemic injustice was identified in the Mammals project. One of the participating schools invited students' parents to take part in the activities. Parents were invited for a meeting with the leading scientist and placement of the data collection devices in various places around the school's town was carried out as a family activity. Parents were invited again at the end of the project for a second meeting with the scientist and a showcasing of students' work (second and third data sources). While students participated in much more extensive learning and research activities, the inclusion of parents as active participants extended the reach of the project and thus supported mitigation of participatory injustice.

5.3.5 | Additional examples from the air quality and sleep projects

The option for schools and students to select personalized research projects was available not just in the Mammals project. The Air Quality project is notable for providing teachers and students with flexible use permissions for the sensors provided by the scientists, leading to various personal investigations instigated by participants' interests. For example, in one school the teachers decided to test air quality at multiple school locations. At another school, students took the sensors to their homes and neighborhoods to examine their own research questions (second data source). In the Sleep project, scientists provided schools with predesigned sleep logs through which students reported their sleep habits over a period of several weeks. Even though, students were research subjects in this project, we also consider them to be citizen scientists, since they engaged in investigations of their own sleep habits. As part of the learning program that accompanied the project, students learned about the science of sleep, asked their own research questions, decided upon additional variables to collect in the sleep logs, and analyzed data collected from their own classrooms. The scientists did not make use of any variables that were not part of the original logs, yet students were able to combine data collected for the scientists' research with that added for their own investigations (fourth data source). In both these projects the data collected by students for personal investigations had no impact on the scientists' research. This contrasts the design of the Mammals project, where teachers' and students' choices had a direct impact on the data available to the scientists. Therefore, this design does not contribute to mitigation of participatory injustice. Nevertheless, it supports the mitigation of formative injustice since students could pursue research directions that were of interest to them through personal investigations.

6 | DISCUSSION

6.1 | Managing epistemic injustice in school-based citizen science

This research suggests multiple forms of epistemic injustice that may be potentially instigated in school-based citizen science, showing that no one definition or characterization of epistemic injustice is sufficient for capturing its varied manifestations. We believe that the identification of these forms can support detection of occurrences of epistemic injustice, and further investigations of tensions known to arise in school-based citizen science projects. Our analysis shows how the merging of two domains, that of science and that of schooling, brings forth different factors that influence the instigation of epistemic injustice. These intricacies suggest that examination of epistemic injustice in school-based citizen science and devising of possible remedies

should be applied at multiple levels and through mixed strategies. The wide variety of citizen science projects and participation models may add to the complexity of this issue, but can also be seen as an asset for broadening the reach of citizen science and providing adaptable solutions that fit the needs of various audiences. Specifically, our illustrative examples show various ways in which epistemic injustice can be managed within contributory citizen science projects, which constitute a majority of projects accessible to schools.

One recurring theme in our analysis, as well as in other studies of school-based citizen science initiatives (Gray et al., 2012; Roche et al., 2020; Zoellick et al., 2012), is that of conflicting interests or perspectives of scientists vs. students and teachers. Indeed, citizen science subverts regular science by making it less of a "scientists' science" and requiring scientists to delegate at least some authority over research processes. In this regard, citizen science can promote epistemic friction, where knowledge and perspectives of excluded communities contest those of established hegemonies (Medina, 2011, see also Table 2). Epistemic friction is originally conceptualized as a possible remedy for strong cases of epistemic injustice, yet its application in mild forms in citizen science may lead to knowledge integration through heterogeneity of perspectives (Herzog & Lepenies, 2022). Our illustrative examples show how small pockets of epistemic friction were created and epistemic injustice was resolved when both sides (schools and scientists) found value in their joint work. For instance, in the Mammals project schools determined the location and scope of their data collection while scientists capitalized on increased opportunities to investigate local distribution patterns of mammals. A second example is found in the Mapping project, where scientists relied on students' mapping experiences to design a cellular application that became the central data collection tool for their project. Nonetheless, realization of such mutual benefits is not a trivial task due to delicate balances between constraints and affordances and a required willingness on all sides to work toward an overall better solution. Moreover, it may not always be clear when would joint work result with mutually favorable outcomes. In the Mapping project, development of the mapping application was not a predetermined goal when the scientists first started to work with schools. Rather, it emerged as a possible solution to challenges faced by students and teachers. This shows the power of epistemic friction in fostering creative solutions, yet also suggests risks when there are unresolved difficulties. Thus, managing epistemic injustice is a commitment that requires an open-minded approach from all involved parties in school-based citizen science.

6.2 | Implications of epistemic injustice toward science education goals

By its very nature citizen science aims to take a step forward in reducing epistemic injustice, offering opportunities for nonscientists to participate in research efforts and opening pathways for their testimonies and hermeneutical points of view to be integrated in research process. However, existing power relations between scientists and the public can lead to exclusion of knowledge held by members of the public and ultimately to failures in the epistemic integrity of the research process, where produced knowledge is incomplete or unrepresentative. Epistemic injustice undermines people's identity and capacity as knowers and places excluded audiences at a disadvantage. They are denied the opportunity to take part in knowledge building that may impact them, while research findings, conclusions, and implementation may not be relevant enough for their own lives or supportive of their interests. When epistemic injustice

prevails, participation may not adequately fulfill a vision of citizen science as inclusive and dialogic (Haywood & Besley, 2014; Paleco et al., 2021; Sagy et al., 2019).

In school-based citizen science, we believe that epistemic injustice holds further implications toward educational goals of student participation in scientific research. To meet the overarching goal of supporting the student in becoming "capable for a self-determined life in his/her socio-cultural environment, for participation in a democratic society, and for empathy and solidarity with others" (Sjöström & Eilks, 2018, pp. 66–67), science education is increasingly advised to cultivate education for citizenship and sociopolitical action in scientific contexts (Aikenhead, 2007; Bang & Medin, 2010; Hodson, 2003; Hurley et al., 2022; Sjöström & Eilks, 2018; Wickman et al., 2012). To accomplish this, learning of science is encouraged to interlace with a critical and justice-oriented inspection of socio-scientific issues (Arada et al., 2023; Ardoin et al., 2014; Ballard et al., 2021; Birmingham et al., 2017; Calabrese Barton & Tan, 2018; Morales-Doyle, 2017; Nazar et al., 2019). A similar trend is evident in other educational domains. For example, the OECD Future of Education guidelines (OECD, 2019) foreground the development of transformative competencies which support students' agency in advancing the well-being of themselves, their communities, and society. Participation of schools in citizen science is a promising pathway toward accomplishing such learning goals, yet instigation of epistemic injustice limits this potential. As school-based citizen science aims to critically engage students with socio-scientific challenges and build a capacity for active citizenship, it is important to reinforce students' and teachers' identity as knowers and contributors of perspectives and meanings to knowledge generation processes in society (Magnussen & Hod, 2023).

6.3 | Designing for mitigation of epistemic injustice

As discussed in the theoretical analysis and demonstrated by the illustrative examples, the co-created and community-based participation models of citizen science possibly embody a considerable potential to mitigate epistemic injustice (Charles et al., 2020; Dillon et al., 2016; Senabre Hidalgo et al., 2021; Thompson et al., 2020). Effective co-creation involves sharing of power, inclusion of diverse perspectives, and respect to different forms of knowledge (Albert et al., 2023). However, commitment to a participation model does not determine, in itself, the risk for epistemic injustice. Rather, choices regarding the research processes and participation opportunities influence its occurrences. Moreover, we hold that efforts to reduce epistemic injustice should be made across the entire citizen science landscape, including contributory projects which constitute a large majority of citizen science initiatives (Hecker et al., 2018; Turbé et al., 2019). Drawing on the presented examples for mitigation of epistemic injustice, we offer three strategies that may be used in design of school-based citizen science projects that wish to address occurrences of epistemic injustice: delegate authorities to schools, maximize teacher and student agency, and leverage schools' community connections. We next expand on each of those.

6.3.1 | Delegate authorities to schools

Even when operating within a specific participatory science model, such as contributory or co-created citizen science, boundaries between roles assigned to stakeholders need not stay rigid, and schools may take over different functions of the project (Magnussen & Hod, 2023). For

example, in the Mapping project, schools took part in piloting the data collection methods. In other cases, schools may be entrusted with more control over roles already assigned to them. For example, in the Mammals project, schools owned data collection devices and formulated data collection agendas that suited them.

6.3.2 | Maximize teacher and student agency

Promoting teacher and student agency holds multiple benefits toward mitigation of epistemic injustice. It supports their knowledge contributions, affords authentic learning opportunities, and encourages their own sense of being epistemic agents (Miller et al., 2018). Agency may be manifested in several forms. It can occur in parallel to the scientists' research, as in the Air Quality and Sleep projects, where students devised personal research investigations. It may complement research objectives, as in projects where teachers organized public outreach activities or advocated their own research agendas. It may drive co-created and community-based projects, such as the Rare Species and Irises projects. These two cases demonstrate how pursuing local impact goals, such as nature conservation in the schools' surrounding environment, promotes use of students' knowledge.

6.3.3 | Leverage schools' community connections

Schools are community-embedded institutions that can reach out to families, community members, local organizations, and municipal authorities. This opens up unique opportunities for mitigation of epistemic injustice, as shown in multiple cases of our illustrative examples. In the Mammals project, one school turned participation in the citizen science project into a familial activity. In the Radon project three schools joined forces to raise a community-wide outreach event. In the Mapping project, a teacher consulted municipal authorities and initiated a community project for mapping objects that impair the mobility of people in wheelchairs. Thus, finding ways for leveraging schools' community connections can increase participation in citizen science and provide students and teachers with additional options for assuming various roles, such as becoming educators and agents of change for the benefit of their communities. Ultimately, this can expand the reach and impact of the scientific research.

We realize that these strategies would not be suitable for implementation in all projects and settings. However, they constitute only a sample of possible methods for mitigating epistemic injustice, and we encourage project managers and designers to think of strategies that fit their specific circumstances. It may be helpful to think of possible affordances provided by the school environment that support schools' contribution to research or its applications in local settings. Teachers can play an important role in designing and implementing such strategies and become valuable partners in effective and justice-oriented school-based citizen science.

6.4 | Limitations of the study and future research

This study is based on theoretical reasoning and, in its empirical parts, mostly on reflective examination of data sources that were not produced specifically for this research.

Presented projects are limited to those for which we had easy access to data, and available data lacked input from students, which are the main participants affected by instigation of epistemic injustice. Thus, the study is limited in its capacity to provide a comprehensive analysis of how epistemic injustice was manifested or mitigated in these projects. Moreover, the illustrative examples may not be representative of school-based citizen science projects in other settings. One consequence of these limitations is that the four forms of epistemic injustice suggested as relevant for school-based citizen science may not represent an exhaustive typology. A more comprehensive examination of case studies may detect additional ways in which epistemic injustice is manifested.

Nevertheless, the conceptual framework developed in this study provides a lens through which epistemic and ethical foundations for citizen science in schools can be examined. Future research may continue to investigate manifestations of epistemic injustice in school-based citizen science and develop strategies for its mitigation. Such work requires further operationalization of the framework for applications in practical settings and empirical research. Models of epistemically just citizen science in schools can be developed, examining the various forms in which they could operate and their affordances toward students, teachers, scientists, science, and society. In addition, we find that teachers' role in school-based citizen science, and benefits derived out of teachers' participation, are interesting research subjects that have not been fully explored.

7 | CONCLUSION

This research provides a theoretical basis for conceptualizing epistemic injustice in citizen science, and particularly in school-based citizen science. Building upon literature of epistemic injustice and research of citizen science in schools we identified multiple forms of epistemic injustice and explained what makes them relevant to the specific context of school-based citizen science. This characterization can be helpful in examining further cases of epistemic injustice and causes for their instigation. We described illustrative examples that demonstrate occurrences of these forms in practice and of their mitigation. Based on the latter, we suggested three strategies for controlling epistemic injustice through design of school-based citizen science initiatives: delegate authorities to schools, maximize teacher and student agency, and leverage schools' community connections. Such strategies and others can and should be employed across the entire citizen science landscape, providing students and teachers with opportunities to make tangible contributions to science and situating schools as more impactful players in citizen science initiatives and in society.

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ORCID

Osnat Atias https://orcid.org/0000-0001-5798-4766
Ayelet Shavit https://orcid.org/0000-0002-4683-0857
Yael Kali https://orcid.org/0000-0003-0930-6244
Ayelet Baram-Tsabari https://orcid.org/0000-0002-8123-5519

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