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Technological Affordance and the Realities of Citizen Science Projects Developed in Challenging Territories

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Abstract: Citizen science has established itself as an important approach to the co-production of knowledge and public participation in scientific research. Combined with digital technologies and online tools, the approach has been celebrated as a path toward the democratization of science. However, only a few studies have investigated the role digital technologies play in shaping interactions between people and nature. Additionally, the role of context in shaping online and face-to-face participation in citizen science projects has yet to receive much attention. This article takes a citizen science initiative in the Brazilian Atlantic Forest in the state of São Paulo as an illustrative case of the emergence of unanticipated consequences of digital technologies. The emergence of a socio-material practice of animal identification through a popular instant-messaging app is described, allowing a better understanding of the role of digital technologies and the context framing citizen participation in challenging environments.

Keywords: citizen science; digital technologies; materialities; affordances; participation; digital communities

Citation: Grigoletto, F.; de Oliveira, F.A.; Momesso, C.C.; Nehemy, I.K.R.; Junior, J.E.d.A.; São Pedro, V.d.A.; Greco, R.; Alves, M.A.; Edwards, T. Technological Affordance and the Realities of Citizen Science Projects Developed in Challenging Territories. *Sustainability* **2023**, *15*, 6654. https://doi.org/10.3390/su15086654

Academic Editor: Antonio P. Gutierrez de Blume

Received: 3 February 2023
Revised: 20 March 2023
Accepted: 8 April 2023
Published: 14 April 2023

1. Introduction

Citizen science is a term used to denote empirical research projects that benefit from the involvement of laypeople in advancing scientific understanding [1–3]. Whilst this approach can take many different forms [4–9], citizen science is particularly valued for mobilizing local efforts to respond to real-world problems such as climate change [10,11]. Laypeople can take part in different ways, which includes contributory, collaborative and co-created modes of participation [12]. In basic terms, contributory modes highlight how volunteers collect data providing scientists with information to assess geographic conditions and generate time related outcomes [13]. Collaborative projects are slightly different in that volunteer's support scientists by suggesting adjustments to research protocols, reconsidering findings, and indicating new directions for the project [12]. Co-created projects are in turn more resource intensive [14] with the volunteers being integral to not just data collection but also project design, redesign and dissemination [13]

According to Vayena and Tasioulas [6], the flourishing of citizen science can be put down to two important trends. These include the widespread adoption of "online tools and mobile devices that can record, store, process and transmit data" and a growing societal

expectation that ordinary people can and should have the right to science, which had been "regarded as the exclusive domain of specialists" [6]. Efforts to encourage collaborative and co-created citizen science presents a move to build a more inclusive approach to science [15–17] which emphasizes face-to-face interaction [18,19] that can influence the way volunteers understand environmental issues through their relationships with each other as well as the natural world. As West and Pateman [13] argue: "participation in a citizen science project can educate and inspire the participants, changing their attitudes and behaviors and even turning them into advocates or activists for a particular development challenge".

Whilst digitally enabled citizen science is largely viewed as beneficial, it is far from clear whether these benefits can be reproduced in different and, in particular, precarious social and environmental contexts. As scholars begin to reflect on the role and challenges of citizen science, the focus has tended toward consideration of the ethics of project arrangements, such as access to funding, oversight and regulation of projects and the rights of participants to intellectual property [6]. What is currently missing are studies of digitally enabled citizen science that couple an appreciation of the ethical use of digital tools with an understanding that such interventions can also reframe social relations in support of the right to science [20]. As citizen science projects ripple out into more remote rural locations, the potential for participation supported by digital technologies becomes increasingly plausible, but at the same time, much harder because such territories often offer few educational chances to volunteer, which is compounded by a natural environment that is inhospitable for data collection [21].

In this paper, we are interested in exploring the artful use of digital technologies in challenging social and natural environments. We examine the potential for digital technologies to enhance face-to-face approaches in an effort to de-naturalize co-created models of citizen science. This is to question the notion that such activities are functional, a question of simply matching and coordinating volunteers and scientists, supported by digital tools. Our exploratory study presents a different reality: an effort to co-create a citizen science project was the product of situated responses to build a communications network that created—in unexpected ways—the social context to empower and democratize participation. By situated responses, we mean the action options contained within particular socio-historical contexts and "the processes through which actors draw upon these" [22].

It is our contention that the work of the citizen scientists (mainly youth in our study) and researchers was opportunistic in that local responses to the practical challenges of collecting data in a rainforest created the context for finding a digital solution and this re-framed the project. By understanding the situated nature of co-creation, we suggest that participants overcame barriers to inclusion as a consequence of new ways of thinking about the limited resources that were available to community members. It is in this context that we draw attention to the way the affordances of an instant-messaging group, first conceived as a communicative space for organizing fieldwork and group meetings, was repurposed. Exploring the attempts to build this network, we reflect on the responses of the youth and researchers when they turned to create a messaging group with a popular instant-messaging app. We propose that data collection is not just a technical exercise but also forms the bonds for community and scientific inquiry seen as an iterative process of alternation between face-to-face and digital interactions. Here, digital tools afford an opportunity to take affirmative action, setting up a real-time interactional space, through which the group in this social media assumed a leading role in the science project and community life.

We offer two contributions to the study of digital citizen science: Our first contribution concerns the framing of co-created citizen science in rural São Paulo state, Brazil, which is to unpack the social relations around which a digital community emerged. We argue that current representations of co-creation based on functional accounts of data collection and coordination do not fully avail the variety and consequences of interactions shaping that coordination. Engaging with affordances [23], we illustrate how users enabled the emergence of a socio-material practice [24] that supported knowledge exchange, includ-

ing building a digital community using the materialities of the group created with the instant-messaging app. Our second contribution is reassessing digital technology as a technical tool that assists data collection. Instead, we consider digital technology as a socio-technical mechanism that can overcome barriers to co-operation, which in our case established a context for the participants to reimagine the possibilities and realities of citizen science. Our aim is to open the "black-box" of agency [25], which is to explain how specific contexts shape the actorhood of participants in ways that shed light on different forms of participation. We challenge the universalism of co-created models that tend to underplay the contexts in which projects emerge, while also seeking to normalize accounts of co-operation. In doing so, accounts will fail to address the asymmetry of citizenship rights and participation, especially for participants that live in deprived communities [3,26]. Beyond these asymmetries [27], such accounts fail to address the practical challenges of collaboration in inhospitable terrains.

In what follows, we begin by exploring the idea of citizen science as the means to support the right to science [6]. This provides an opportunity to rethink the role of digital tools in shaping participation in often-unintended ways. We then introduce our study and our research methods. This is followed by our findings and discussion section that presents an appraisal of digital citizen science based on the ideas of affordance [23] and materialities [24]. In the last section, we conclude and reflect on the conceptual and managerial implications of our study.

Citizen Science

Our interest in citizen science is in the exploration of the involvement of non-professionals in scientific projects aimed at responding to scientific problems [4,6], that address real-world problems [28]. More specifically, we are interested in the idea that a right to science forms part of an emancipatory process. Here, the various actors involved (e.g., scientists, teachers and civil servants) have positive obligations for this right to be materialized in effective practices, such as enabling and promoting scientific activities and equipping ordinary people with scientific knowledge (e.g., educational projects) [6].

However, not all citizen science projects have the same potential to emancipate and this reflects distinctions in how individuals engage in science [29], including the extent to which they contribute to the thinking, design and delivery of projects [9,12,30]. Debate about participation has been dominated by studies looking at the challenges of ensuring data quality and comparability [31]. However, few studies grapple with the relationship between participation and the context in which those activities unfold. Notable exceptions include studies that explore the representation of participation because it makes little sense to talk of citizen science when the science is conducted in places where there is a high citizenship deficit [32].

A more contextualized approach to explaining citizen science helps to uncover how and why projects often evolve as participants and researchers identify opportunities to work differently together. Implicit in this work is the view that projects "unfold" and this is more likely if the participants are deeply involved in co-creating the science. The current understanding has tended to explain involvement in citizen science through the lens of motivation, which is based on a functionalist understanding of action, "according to which people display similar attitudes in response to psychological functions that serve individuals' needs" [30]. Whilst this offers helpful insights, such an approach fails to account for the ways in which different contexts shape and mold those personal interests. In other words, individualized accounts of motivation provide little insight into the scope of agency. If scholarship is to adequately explain the emancipatory potential of citizen science, we need to explore the possibilities of action, and this means unlocking the black box of agency [25].

2. Context, Material and Methods

This work is a qualitative case study [33] that originates from the analysis of data accumulated over a long-lasting research process in the rural community of Guapiruvu [21,34]. The Guapiruvu neighborhood is a rural site in Sete Barras in the Ribeira Valley of the State of São Paulo. It is one of the most distant rural communities from the urban center, from which it is separated by more than 30 km. The citizen science project follows from the lead author's work, as he completed his PhD on rural reform in that territory. Research collaborations based on this initial work included Brazilian and UK experts in biology, science education, responsible innovation and computer science. In the period between 2018 and 2021, an interdisciplinary project was developed in the community, encompassing three major aims: (1) the experimentation and construction of a citizen science project with the community's youth, (2) the provision of decentralized network servers for internet access in the Atlantic Forest biome and (3) the creation of an environmental monitoring app based on the observation of frog species, carried out by the community. Here, we classify the three objectives as procedural in building a digital research community. It was deemed important because the inhabitants of Guapiruvu are not only distanced from resources available in urban areas but also dislocated in terms of educational opportunities to address the climate emergency.

Our analysis consists of messages and files exchanged in a messaging group between the citizen science team members engaged in the project. The long collaboration established by the research team and the community ensured adequate access conditions, allowing the case to be delimited. Additionally, this is a case with significant distinctiveness, as it is associated with an innovative project carried out in a global hotspot. Therefore, we understand this is a case of intrinsic interest [33]. The analysis was guided by the interest aroused by the emergence of unforeseen interactions between residents and researchers in an instant-message group created for other purposes. Although the analysis does not offer possibilities of generalization, it raises relevant implications for practitioners of citizen science.

Initially, a cross-sectional analysis of the virtual interactions that occurred since the creation of the group (June 2018) was performed in order to identify those directly related to species identification. Then, the photos, videos and textual messages exchanged for this purpose were analyzed to identify the moment of the exchanges, the senders and the identified species. The identified interactions of interest were printed and associated with shared photos and videos. These interactions were categorized based on their objectives. When interactions were oriented toward recognizing a species through sharing, the category "Identification" was used; when interactions focused on solving curiosities raised by encountering already-known animals, the category "Curiosity" was used.

These interactions are listed in Table 1, including the dates on which they occurred, a classification of the sender (adult, young and researcher) and the name of the species, in addition to the classification of the motivation as either "Identification" or "Curiosity". Senders were anonymized. We classified them as youth, adults and researchers and numbered them following the chronological order of interactions. Thus, it is possible to identify recurring senders. Additionally, we listed the popular and scientific names of the identified species.

It is possible to note the prevalence of submissions by young citizen scientists, as well as the recurring participation of those numbered 1 and 3.

Table 1. Table summarizing virtual interactions aimed at identifying species and sharing curiosities about animals already known.

Date	Citizen Scientist	Group	Species	English Names	Occasion
12 June 2019	Young 1	Amphibian	*Scinax* sp.	Snouted Treefrog	Identification
12 June 2019	Adult 1	Arachnid	*Phoneutria* sp.	Wandering Spider	Curiosity

Table 1. *Cont.*

Date	Citizen Scientist	Group	Species	English Names	Occasion
12 June 2019	Adult 2	Amphibian	*Rhinella* sp.	Common Toad	Identification
12 June 2019	Adult 2	Amphibian	*Leptodactylus latrans*	Spotted Grassfrog	Curiosity
13 June 2019	Young 2	Amphibian	*Rhinella* sp.	Common Toad	Identification
15 June 2019	Young 3	Amphibian	*Boana semilineata*	Map Treefrog	Identification
15 June 2019	Young 3	Amphibian	*Leptodactylus latrans*	Spotted Grassfrog	Identification
21 June 2019	Adult 2	Reptile	*Oxyrhopus clathratus*	False Coral Snake	Identification
22 June 2019	Young 4	Amphibian	*Rhinella* sp.	Common Toad	Identification
26 June 2019	Young 1	Amphibian	*Trachycephalus mesophaeus*	Golden-eyed Treefrog	Identification
28 June 2019	Young 5	Amphibian	Unidentified species	Green Treefrog	Identification
4 July 2019	Researcher 1	Amphibian	*Boana semilineata*	Map Treefrog	Identification
5 July 2019	Adult 3	Reptile	*Bothrops alternatus*	Urutu Pitviper	Curiosity
12 July 2019	Adult 2	Bird	*Tangara seledon*	Green-headed Tanager	Identification
26 July 2019	Young 5	Mammal	*Guerlinguetus ingrami*	Southeastern Squirrel	Curiosity
3 August 2019	Adult 2	Amphibian	*Boana raniceps*	Chaco Treefrog	Identification
27 August 2019	Adult 1	Amphibian	*Boana faber*	Smith Frog	Identification
21 September 2019	Adult 2	Amphibian	*Rhinella icterica*	Yellow Toad	Curiosity
26 September 2019	Adult 1	Reptile	Unidentified species	False Pitviper	Identification
19 October 2019	Young 1	Amphibian	*Proceratophrys boiei*	Smooth Horned Frog	Identification
24 October 2019	Young 6	Amphibian	*Leptodactylus notoaktites*	White-lipped Frog	Identification
25 October 2019	Young 2	Amphibian	*Rhinella* sp.	Common Toad	Curiosity
27 October 2019	Adult 4	Amphibian	*Trachycephalus mesophaeus*	Golden-eyed Treefrog	Identification
6 November 2019	Adult 2	Amphibian	*Trachycephalus mesophaeus*	Golden-eyed Treefrog	Identification
11 November 2019	Young 7	Amphibian	*Dendropsophus* sp.	Dwarf Treefrogs	Identification
24 November 2019	Young 8	Amphibian	*Boana albomarginata*	White-banded Tree Frog	Identification
25 November 2019	Adult 2	Amphibian	*Scinax fuscovarius*	Common Snouted Treefrog	Identification
27 November 2019	Young 9	Reptile	Unidentified species	Vine Snake	Identification
8 December 2019	Adult 2	Amphibian	*Brachycephalus* sp.	Three-toed Toadlets	Identification
11 December 2019	Young 10	Reptile	*Erythrolamprus miliaris*	Military Ground Snake	Curiosity
12 December 2019	Young 11	Reptile	*Spilotes pullatus*	Yellow Rat Snake	Identification
25 December 2019	Young 9	Amphibian	*Trachycephalus* sp.	Golden-eyed Treefrog	Identification
7 January 2020	Young 7	Bird	*Vanellus chilensis*	Southern Lapwing	Curiosity
11 January 2020	Young 12	Amphibian	*Proceratophrys* sp.	Smooth Horned Frog	Identification
15 January 2020	Adult 5	Bird	*Columbina talpacoti*	Ruddy Ground Dove	Identification
11 May 2020	Young 10	Arachnid	*Lycosa erythrognatha*	Wolf Spider	Identification
20 May 2020	Young 3	Amphibian	*Rhinella hoogmoedi*	Hoogmoed Leaf Toad	Identification
26 June 2020	Young 1	Reptile	*Placosoma glabellum*	Small Snouted Lizard	Identification
1 July 2020	Adult 6	Bird	*Hemithraupis ruficapilla*	Rufous-headed Tanager	Curiosity
7 August 2020	Adult 7	Reptile	*Spilotes pullatus*	Yellow Rat Snake	Identification
13 August 2020	Adult 3	Reptile	*Bothrops* sp.	Pitviper	Curiosity
23 February 2022	Adult 8	Reptile	*Tomodon dorsatus*	Pampa's Snake	Identification

3. Results: An Exploratory Study of Co-Creation

As part of the proposed citizen science project (aim No. 2), the team prototyped a communications system based on IoT and mobile technologies [34]. This initial work involved

the youth testing an IoT communications platform based on LoRa- enabled Raspberry Pis. It indicated that messages could be sent from up to 220 m into the densely wooded forest under humid conditions. This initial work demonstrated the severe restrictions for communications development in a dense, hot and humid. These problems have yet to be resolved and it is this technical impasse that created the context for the youth in the community to rethink how they engaged in the project.

The research project and team formed following discussions of how to empower the youth in Guapiruvu. The first author's work in the community confirmed that the youth had very little opportunity to engage in inquiry-led learning because the school curricula were based on an urban-centric syllabus. This meant there needed to be more content on the natural environment and climate change. Indeed, the students were largely unaware of the fact they lived in a biodiversity hotspot and that this territory was under threat because of industrial agricultural practices.

During this early time period, multiple training visits were conducted by the scientists (and not necessarily those that were experts in biology) to educate the youth about frogs and toads, focusing on the local species and eliciting the youths' lived experiences of cohabiting in the forest alongside these amphibians. Informal discussions in the community hall that serves as the project's home were followed by field trips into the Atlantic Forest. These mini-expeditions took place at night, with the use of flashlights, wet weather gear and training in sound identification, observation of physiological characteristics and the species' habitat. This methodology made it possible to engage the participants in the project, especially the youth, who had fun and were excited when they made a discovery or discussed specific species. On the part of the researchers who were not biologists, participation also made it possible to break the traditional researcher-community relationship, since they put themselves in the position of laymen. In combination, such face-to-face interaction inspired many of the youth to want to learn more about the fauna and flora as well as the technology used in these initial testing stages of the comms network.

In the absence of a bespoke communications network, a conversation group was created in June 2018 to facilitate a dialogue between residents and the science researchers who started the project. Initially, the group had two researchers and six residents as members. At the end of the same year, three new researchers and fourteen residents joined the founding members. Until that moment, all of the researchers were from the field of social sciences. In early 2019, the first fieldwork guided by biologists was carried out. Observation of animals, especially reptiles and amphibians, began during this period.

Virtual interactions aimed at identifying animals and plants species began in January 2019. At this moment, the group had five researchers and twenty-two residents as members. The only biologist on the team did not use the instant-messaging application, so he did not participate in the group. Queries were forwarded to him in person by one of the researchers who was already a member. Virtual interactions aimed at species identification intensified in June 2019, when two biology students were included in the group. At that time, the message group had 8 research members and 22 resident members, in addition to the manager of the environmental conservation unit that borders the neighborhood.

This was an unexpected development because work on the communications network had been started precisely because the community had very restricted access to telecommunications with the exception of the instant-messaging app. This was also limited because the mobile 3G signal in the community was very poor due to a lack of antennas, although there was access in the community hall and a few households were able to pay for internet in their home. These restrictions were alleviated with the installation of Wi-Fi internet in the community hall in November 2018.

Messages with photos of animals and questions about species identification began spontaneously days after the first visit of the biologists to the community, when the first 'frog watching' session was conducted with the children, which motivated inclusion in the group. In just over two years, there were 42 interactions in the group involving photos and videos for species identification (31) or questions about animals (11). These interactions

were triggered by 23 different people and included the recording of at least 33 species, including amphibians, snakes, birds, and invertebrates. It is notable that some of these videos and photos contained records of behaviors relatively difficult to observe in nature, such as reproductive and predation events.

Although it was not an a priori planned strategy, the establishment of a virtual space of interaction between biologists and citizen scientists was fundamental in different aspects. First, this allowed for a closer relationship between these different social groups, a process that would take much longer if it had depended on face-to-face meetings during field work, which were generally short-term and sporadic. Second, the app turned out to be a surprisingly effective permanent scientific learning space. Through it, for example, the youth debated the correct identification of the photographed species. Instead of passively waiting for the final word from biologists, they brought to the conversation taxonomic characteristics and other information presented by specialists during field work (Figure 1). The research team noticed the younger residents were especially engaged in the task of trying to identify the species. Even when they were unable to photograph a spotted animal, they tried to memorize characteristics they thought were important and then described them in conversations through the application, seeking the opinion of other participants.

Another advantage of using the application was to keep citizen scientists in a constant state of curiosity and interest about the fauna, extrapolating from the short moments of the presence of biologists on site. This was even more important in the context of the COVID-19 pandemic, which made it impossible to carry out field activities for a long period. Although meeting animals is something trivial in that neighborhood, the facilitated and constant contact with the researchers kept the residents in a state of special attention to and interest in the fauna, given the possibility of quick access to scientific information. This gave them the real possibility of going beyond the mere registration of the animal, also knowing its correct identification, telling species apart and knowing more about their behavior and habits.

During conversations through the application, some youth shared their perceptions of the fauna that can be associated with ecological concepts such as rarity, seasonality and microhabitat. For example, on one occasion a resident reported the record of a rare species of frog. Then, older residents reported that the same species used to be common decades ago, starting a debate in the group about the possible causes and environmental impacts that may have made the species rare today. Conversations such as this usually led to a discussion about the need for strategies to conserve the local fauna.

The messaging group had conditions that differentiated it from the social dynamic sustained in and between social groups in face-to-face interactions. The significance of this feature is in the way it included undergraduate and early career researchers in an ongoing process of data and information sharing with the youth, who were all involved in the project. At the same time, it linked the students and researchers to their research interests in real-time. The youth creatively used this "technically bounded interactional space" [24] as a tool to identify animals and plants that they found in their backyards (snakes and insects), bathrooms (frogs and toads), roads and forests near their homes (small mammals, insects, snakes, and toads). Some of the identified species can be seen in Figure 1.

This vignette might seem unremarkable, but it draws attention to the possibilities of digital technology for not only data collection but also the inclusion of a wide array of community members (especially the youth) in science. Such participation goes beyond project development; it is notable due to the empowerment of the youth to rethink their relationships with the forest and between themselves. The reporting of observations allowed the participants to have a voice that began to reshape their interests and concerns, which did not rely on face-to-face interaction. However, it should be noted that interactions through the application tended to become less frequent the longer the time was between face-to-face activities in the community. This suggests the important role of maintaining a schedule of practical activities, such as field trips, even if sporadically. This is critical to

keep citizen scientists excited about issues of interest, as well as to strengthen ties between them and researchers.

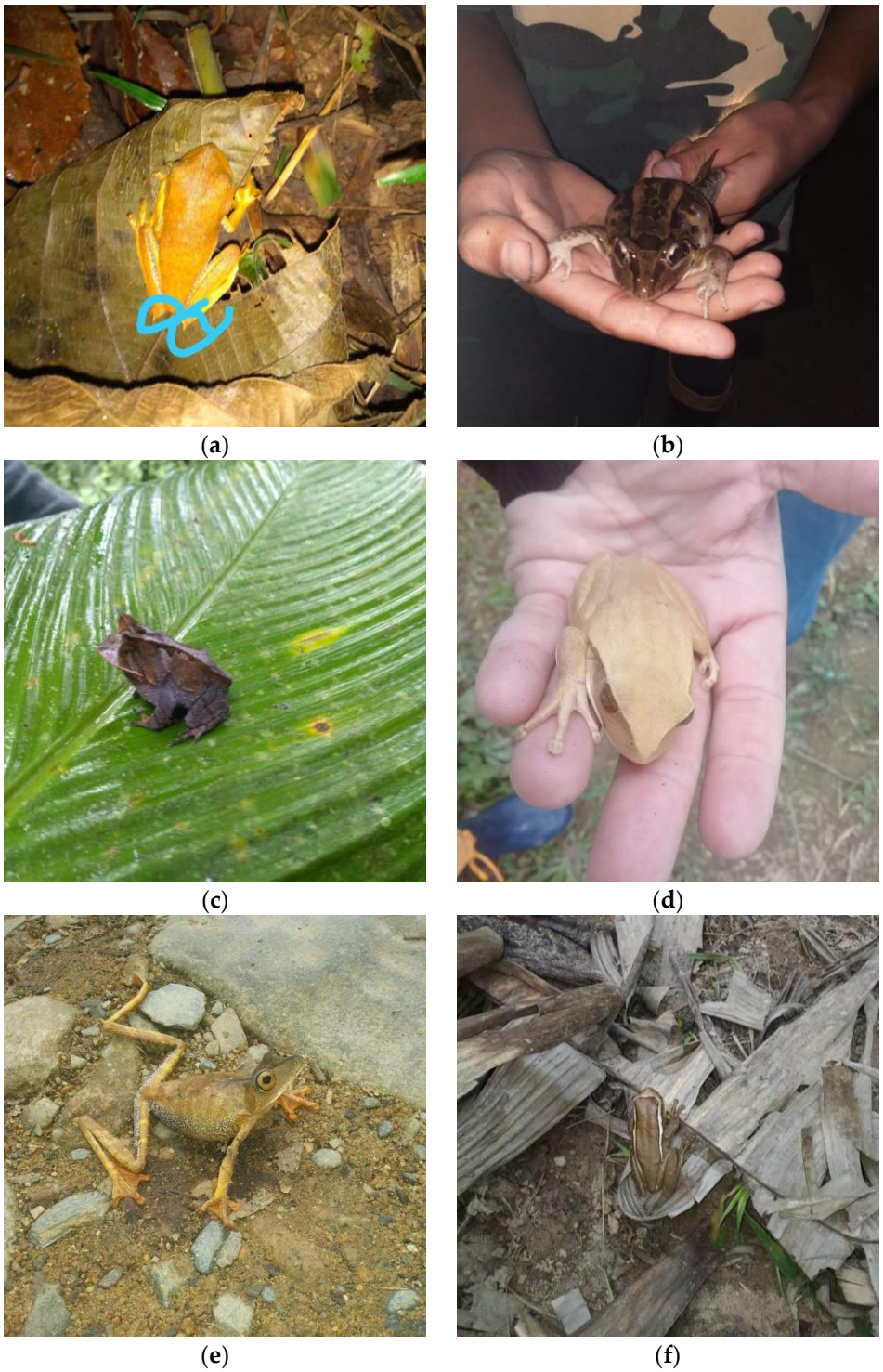

Figure 1. Photographs of anuran species recorded by citizen scientists for identification by researchers. (**a**) *Boana semilineata* (Spix, 1824), one of the citizen scientists highlighted in the photo (in blue) the calcar on heels, a key feature to identify the species in question; (**b**) *Leptodactylus latrans* (Steffen, 1815); (**c**) *Proceratophrys boiei* (Wied-Neuwied, 1824); (**d**) *Boana raniceps* (Cope, 1862); (**e**) *Boana semilineata* (Spix, 1824); (**f**) *Trachycephalus mesophaeus* (Hensel, 1867).

4. Discussion: Affordance and Citizen Science

Different strands in Science and Technology Studies (STS) demonstrate that it is not adequate to analyze technology separately from society because it precludes our ability to understand the social and political aspects inherent to the relationships established between them [24,35,36]. In an effort to make sense of the relationship between technology and society, work has emerged around the concept of affordance [23]. Gibson [23] proposed the possibilities for action afforded by an object are dependent on its materiality; that is, affordances are the possibilities for human action unfolding from the objects in the world. In this view, although the materiality of artifacts is independent of human actions, the potentialities emerging from that are not. This means that artifacts offer opportunities for human agency in a non-deterministic way, thus enabling and constraining it depending on the emergent use of these opportunities from situation to situation.

Hutchby [35] highlights the contribution of the idea of affordance in directing our attention to the constraining and enabling conditions of technological artifacts. Thus, the materialities inherent in technologies are assumed to be analytical objects when studying social phenomena. By materiality, we mean not just the concrete physical existence of technology but also the different forms these take:

"To be clear, "materiality" does not refer solely to the materials out of which a technology is created and it is not a synonym with "physicality." Instead, when we say that we are focusing on a technology's materiality, we are referring to the ways that its physical and/or digital materials are arranged into particular forms that endure across differences in place and time. Such a definition suggests that the usefulness of the term "materiality" is that it identifies those constituent features of a technology that are (in theory) available to all users in the same way." [24].

Hutchby [35] argues that affordances are manifested by the human practices triggering them, adding that there is an interplay between the technological artifact and affordances embedded in other objects and beings in the natural environment, such as rocks and animals. We point to the interplay of agency and situated context in understanding the affordances of technology, and in that we agree with Galazka, Edwards, and Harding [37]. They argue the interplay between human practices and the materiality of technological artifacts does not occur in a void but in the context of social norms, rules, values and power relations which vary from place to place. The organizational arrangements of places and objects cannot be neglected in favoring an overemphasis on personal behaviors. Furthermore, human agents cannot be understood as abstract entities because they cultivate specific subject positions (e.g., actorhood) in their life trajectory in interplay with a context.

This conceptualization is significant because it indicates that the possibilities for action emerging from a messaging group need to be explained in terms of the affordances it raises, not simply in the context of citizen science activities, but also in terms of the actions it enables in the context of a rural community established in a protected nature conservancy territory (otherwise experienced as a fairly inhospitable rain forest). The historical formation of the Guapiruvu community is strongly marked by land and environmental conflicts, revealing a condition directly related to the status of a global hotspot of biodiversity and ecosystem services that are attributed to the region where the community is located [38]. Put another way, Guapiruvu is of international environmental significance but it is also a community riven by land battles and social inequalities. It is because such affordances are inherently unpredictable that we need to present a more reflective account of citizen science that calls into question a strictly instrumental view on how digital participation can transform science [39].

Similarly, situating the analysis of affordances in relation to the conditions of embeddedness sedimented in different places and contexts is essential to understand how interactions between people, technologies and places inform the emergence of socio-material practices.

4.1. The Affordances of a Messaging Group

Given our interest in the potential of the messaging group and the contextual aspects of the place where the activities were held, it is necessary to investigate the materialities of the instant-messaging app as a social media. The categories of Instant Message (IM) or Mobile Instant Message (MIM) applications include a range of tools such as Whatsapp, Skype, Snapchat, iMessage, KakaoTalk, WeChat and others [40,41], which can also be considered as social media platforms [42].

Instant-messaging apps allow the formation of closed groups, configuring a form of chat room enhanced with the content-sharing resources in this digital tool. The instant-messaging application allows the sending of authorial written messages and the forwarding of messages received in other groups or individually. It also allows the sending of photographs, videos and audio recorded by the senders, as well as the forwarding of similar content produced by other people. The app's features allow users to edit registered and shared photos, enabling them to mark up and highlight the images themselves. Group members can also tag one another. This functionality allows the directing of questions to members and the facilitation of arguments and counterarguments among members. Tang and Hew [40] believe the use of emoticons, photos, stickers, audio, humor and self-disclosure contribute to developing more friendly, trusting and close relations because these characteristics amplify the possibilities of expressions beyond verbal cues. Leonardi and Treem [36] define this as the affordance of association, which permits the establishment of "connections between individuals, between individuals and content, or between an actor and a presentation".

In our case, the naming of the youth group as "CCG-AMA" allowed the strengthening of the project's identity. The Portuguese acronym means "Citizen Science in Guapiruvu—Friends of the Forest". As the group used the instant-messaging app Whatsapp, which is a free digital tool, the only cost to access it was shared by the community in maintaining the internet access point in the community hall [41]. The affordances of *immediacy* and *delay* in conversations were central to overcoming internet access barriers. Although it could be seen as contradictory, IM offers both possibilities simultaneously. While the first means the possibility of quicker access by message senders and receivers, besides the possibility of sharing audio-visual content in real-time, the latter makes participation and engagement easier because the receivers can load the shared content any time after it was sent or when possible or desirable [41].

Correspondingly, Leonardi [24] points to persistence as a typical affordance of social media platforms. This is related to the possibility of reviewing the history of the conversation at any time. It enables the users to re-engage with specific points at a later moment [24,36]. Immediacy, delay and persistence are also related to the affordance of asynchronicity. It affords a temporal distancing in the engagement of receivers after the sender shares the content in the social media platform [24]. These affordances are essential for the interactions between young people and researchers to be sustained over time. In addition to the barriers to internet access in the community, the researchers involved in the project had the opportunity to answer questions about animals at the end of the day or on weekends. The lay members took the questions as puzzles, combining the knowledge acquired in the field work and face-to-face interactions with content searched on the internet. Most interactions aimed at identifying animals lasted for hours and even days, allowing other members to engage in the conversation.

These results are significant because they emerged as an unanticipated consequence of the research design. The group's creative use highlights the active role of young people in enriching participation, emphasizing the collaborative character sought by the project. While not anticipated, the characteristics and implications of this emerging socio-material practice adhere to the project's objectives.

4.2. De-Naturalizing Participatory Models of Citizen Science

The socio-material practice identified points to the importance of a more nuanced approach to participation in citizen science. Although it is reasonable to recognize the potential for democratizing science by expanding public participation through the use of online tools [39], it is necessary to recognize the diversity of society. Basic conditions of transport and communication infrastructure are necessary to the effective democratization of the right to science through online participation. Even if this is the case, participation in data analysis will not necessarily lead to improved living conditions and scientific citizenship.

The idea of a networked science placing the intelligence of the crowd as its new paradigm [39] neglects these constraints due to the implicit universalism. Fleischman et al. [43] argue that forest restoration should be informed by marginalized people. Similarly, we argue that citizen science should prioritize the participation of the people living in global hotspots [38] where citizenship conditions are not fully guaranteed [21,44], especially for young people and children. Our case illuminates the enabling conditions of the messaging group and its affordances in the uses made by the youth engaged in the citizen science. They perceived that the app offered an opportunity for discovery in situations recurrent in their everyday lives (e.g., to see a snake in their garden or to find a toad in their bathroom), thus transforming their relationship with this kind of situation. This new context transformed their understanding of the forest with it becoming a new world of concern [45]. For example, when considering that animals have a materiality which does not change from context to context, we suggest the possibility to ask scientists in real time about the potential risks posed by a snake helped trigger a new relationship with animals that seemed dangerous. This is evidenced in the creation of an informal group called 'Hands that protect' aimed at diffusing ideas and practices toward avoiding the killing of snakes while promoting their collection and release into the forest.

The queries of the youth in the messaging group worked as triggers for knowledge exchange, thus adding new layers of meaning to the recurrent situations when the participants met reptiles and amphibians in their everyday life. It is important to acknowledge that the social media in use configured a closed digital community but that this was reinforced by face-to-face interactions during fieldwork and interactions within the messaging group. The combination of both the face-to-face interactions and virtual messaging engendered a recursive effect. The observations made during fieldwork activities informed the kind of querying realized within the social media group and vice-versa. This interplay also redefined the regular social roles enacted by scientists and non-scientists. The young inhabitants acted as guides in the fieldwork activities due to their attachment to that place. They also began to defy their taken-for-granted assumptions about the everyday—woods, streams and ponds—when introducing these to the scientists. It is reasonable to assume that the queries and explanations realized by the non-scientists and scientists during the fieldwork activities were central in provoking the curiosity of the local inhabitants.

Both lay people and specialists benefited from that. For the youth, the iterations triggered the challenging of taken-for-granted assumptions about the animals, also provoking the infusion of new meanings. The fear of snakes permitted explanations around the low risks posed by them, thus giving space for curiosity and enchantment. The disgust toward tree frogs and toads triggered curiosity about their ecological role in the biological controlling of unwanted insects such as mosquitoes, thus giving room for appreciation and respect. For the researchers, it was a clear opportunity to communicate science and promote scientific literacy. It also forged the chance to establish a permanent link with a biodiversity global hotspot in a region presenting a high degree of heterogeneous forms of life while pressured by human action [38].

We would suggest that the technology did not work just as a tool, but as a relevant element enabling uses which triggered the establishment of new relationships between people, places and tools within the community. This may be seen as a call to scientists engaged in participatory citizen science to pay more attention to the role technology plays in their projects [24]. The iterative process between face-to-face activities and digital inter-

actions set in motion processes that lead to new socio-material practices which transformed the relationships established between the inhabitants and their home. The character of the communicative space afforded by the messaging group in combination with the possibilities of picturing and audio recording permitted the emergence of this unintended outcome. We note a digital community materialized through the periodic interplay between face-to-face and remote interactions that linked common-sense experiential knowledge with the specialized techno-scientific knowledge of the scientists engaged in the activities.

4.3. Implications for Citizen Science Practitioners

The Guapiruvu case is an example of public participation in scientific research that takes into consideration the significance of context in shaping co-creation. At a broad level, the example demonstrates the possibilities of participation when individuals are given space to actively think about how they engage in projects. Allowing such agency had a number of benefits, including enabling community members to reflexively participate in ways that implicitly recognised the opportunities and barriers confronting participants in the community. Our initial observation for project leads of such endeavours is to recognize the benefits of encouraging participants to "test" how they might participate rather than being too prescriptive in project design. Acknowledging that projects unfold indicates that projects can change the way persons see and experience this work.

In turn, treating digital technology as more than just a tool recognizes the scope to use it in multiple ways to support citizen scientists in the field and the community. This has the potential to transform the project and the community involvement, thereby opening up the scientific process to scrutiny from science and social inclusion lenses. Here, we see ways to couple science work with citizenship work to create the context for those in deprived areas to facilitate their right to science [3,21,26,44].

5. Conclusions

This exploratory study set out to reflect on the limitations of existing participatory models of citizen science which have focused on the benefits of face-to-face interaction in developing the educational and scientific benefits of co-creation. We have not set out to criticize important contributions to a discussion of citizen science that evidence the importance of social relations and interactions. Rather, by developing a situated account of citizen science, we have suggested that our understanding of context needs to take into consideration both the social and natural environment into consideration as these features naturally shape how individuals engage with digital technologies, which can have both intended and unintended consequences. As pointed out by Treem and Leonardi [36], "affordances are unique to the particular ways in which an actor, or a set of actors, perceives and uses the object". We suggest that the idea of digital technologies as a technical fix for data quality and comparability purposes is too narrow. Instead, our case considers such technologies through the affordances they enable presents multiple opportunities—some expected and some not. The involvement of the youth was not just an example of data collection but also represented a far more fundamental set of opportunities to reimagine how they lived in their community and how they saw the forest. In that sense, the adaptation of the messaging group from an organizing tool into a mechanism that challenged a dominant way of thinking cannot be underestimated. This was unexpected, but at the same time, reveals the potential of such artifacts to re-invigorate the actorhood of the youth living at the edges of modern society.

Citizen science projects are always situated [22], meaning that they are exist in socio-historical contexts, which conditions the possibilities for acting and thus the outcomes of these projects. While much attention has been given to the scientific benefits attributed to public involvement [17,39], it is perhaps less expected to show how such work can create a context to build the citizenship rights of participants [21]. Acknowledging the move to involve the youth in exploratory research in the forest created a new set of possibilities and, through the artful adaptation of the technology, offered opportunities to build a

community of likeminded junior investigators. The engagement of the youth with the digital technology is also significant in the way the creation of such dialogue between the youth and researchers ignited a level of activism despite the challenging natural conditions and the lack of technical infrastructure in Guapiruvu. The youth were resourceful in how they used the technology, determined to engage despite the limitations they confronted. Such a response furthers our argument that digital technologies are not simply technical fixes, but they are also the source for meaningful engagement with the natural world. Participation called into question how the youth lived and what was important to them as they passed through the forest. In informing human agency, face-to-face activities stimulated a brand-new behavior. The new messaging group, in performing a digital continuation of those activities, afforded the photographing, sharing and tagging behaviors of the animals the youth encountered on an everyday basis.

In summary, we suggest our work clarifies the consequences of social media use for organizing [36] through citizen science led by the youth living in vulnerable rural communities rooted in areas of high ecological interest. This, enhances our understanding of the mutual constitution of technology and society in processes of knowledge co-production.

Author Contributions: The authors contributed at all stages. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the EPSRC Global Challenges Research Fund Institutional Scholarship (2017); Cardiff University (2018); FGV Pesquisa (2018); HEFCW GCRF Small Project (2019); ESRC—Impact Acceleration Account (2021); and Cardiff Business School (2021).

Institutional Review Board Statement: The study was approved by the Comissão Nacional de Ética em Pesquisa—Conep (National Research Ethics Committee) from Brazil. With the following protocols codes, 3.360.537 from June 2019 and 3.583.534 from September 2019.

Informed Consent Statement: Written informed consent has been obtained from the subjects to publish this study.

Data Availability Statement: The authors declare that the data are unavailable due to privacy or ethical restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

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