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Engagement in science through citizen science: Moving beyond data collection

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Abstract

To date, most studies of citizen science engagement focus on quantifiable measures related to the contribution of data or other output measures. Few studies have attempted to qualitatively characterize citizen science engagement across multiple projects and from the perspective of the participants. Building on pertinent literature and sociocultural learning theories, this study operationalizes engagement in citizen science through an analysis of interviews of 72 participants from six different environmentally based projects. We document engagement in citizen science through an examination of cognitive, affective, social, behavioral, and motivational dimensions. We assert that engagement in citizen science is enhanced by acknowledging these multiple dimensions and creating opportunities for volunteers to find personal relevance in their work with scientists. A Dimensions of Engagement framework is presented that can facilitate the innovation of new questions and methodologies for studying engagement in citizen science and other forms of informal science education.

KEYWORDS

citizen science, engagement, experiential learning, informal science learning, situated learning

1 | INTRODUCTION

Participating in scientific activities is at the core of many informal science learning initiatives, which occur in various settings such as museums, science centers, community centers, online, and in private residences (Falk, 2001; Falk &

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Dierking, 2002). Such activities tend to fall under the umbrella term "engagement in informal science education," which Friedman et al. (2008) define as basic interest and excitement in science. This definition of engagement, however, fails to acknowledge the complexities of the learning process or the experiences of learners. McCallie et al. (2009) note that within the field of informal science education (ISE), engagement is sometimes described as interest-oriented behaviors or interactions and other times as a psychological precursor to learning. Lewenstein (2015) notes that the term engagement is problematic because it holds different meanings across different disciplines. And Azevedo (2015) states "Engagement is one of the most widely misused and overgeneralized constructs found in the educational, learning, instructional, and psychological sciences" (p. 84). Given its multiple usages, debates about the definition and utility of the term engagement highlight the need to clarify its meaning using both theoretical and applied approaches.

Citizen science—the intentional involvement of members of the public in scientific research—is often categorized as a form of informal science learning because of its dual emphasis on research and education (Bonney et al., 2014). Burgeoning research on citizen science is also grappling with how to articulate and study the concept of engagement. Thus far, however, few studies of citizen science have tried to define engagement or have adequately described the nature of participant engagement (particularly in field-based projects and rarely across multiple projects). Typically, engagement in citizen science has been defined through output measures such as the numbers of participants, web pages accessed, data collection, and submission rates, and other appraisals of recruitment, retention, and outreach (Phillips, Bonney, Shirk, Dickinson, & Bonney, 2012). Output measures are especially common for online citizen science projects, which tend to measure engagement through behavioral patterns of data contribution. Such patterns of contributions have been described as "light to heavyweight" (Haythornthwaite, 2009), "low to high" (Eveleigh, Jennett, Blandford, Brohan, & Cox, 2014), and "dabblers; active; or core participants" (Curtis, 2015).

Measuring engagement by quantifying data contribution outputs alone, however, leaves critical gaps in what the full range of engagement means and entails for project participants, who may take part in numerous scientific activities including collecting and submitting data, formulating hypotheses, asking and answering questions, interpreting and analyzing data, and using data as evidence (Bonney, Cooper, et al., 2009). They also may engage in activities such as knowledge acquisition, use of social media, community involvement, and/or interaction with scientists. With growing claims about the learning outcomes that result from engagement in citizen science (Bonney, Phillips, Ballard, & Enck, 2016; Schuttler, Sorensen, Jordan, Cooper, & Shwartz, 2018), empirical research about what constitutes engagement in citizen science is needed.

This paper addresses the following research questions: What are the salient dimensions of engagement in citizen science and how are these dimensions described by participants in different projects? We tackle these questions through a case study analysis in which information about participant experiences has been gathered through semistructured interviews with participants in six different citizen science projects. Framing for our data collection and analysis was informed by various theoretical perspectives surrounding the construct of engagement. This paper presents a review of these perspectives followed by our empirical research applying them to understanding engagement in citizen science.

2 | LITERATURE REVIEW ON ENGAGEMENT

Ample research in other disciplines such as education, psychology, science communication, organizational labor, and information science can inform our understanding of the term and how it can be applied to citizen science. In particular, we draw from the literature on student engagement—which has a robust knowledge base—and volunteer engagement, which has great relevance to citizen science.

2.1 | Student engagement

Engagement has been studied intensively in K-12 settings to describe student dropout rates, school achievement, and high-school reform efforts (Appleton, Christenson, & Furlong, 2008; Furrer & Skinner, 2003; Martin, 2007). In these settings, engagement may refer simply to whether a student completes a task in class or is paying attention. In K-12 settings a focus on student engagement is considered critical, because a lack of engagement is believed to be intricately tied to low academic performance, behavioral issues caused by boredom and feelings of isolation, and high dropout rates (Fredricks, 2011). Some consensus has emerged. First, engagement is malleable and can change over time (Fredricks, Blumenfeld, & Paris, 2004). Second, engagement is integrally tied to learning and is likely a necessary precursor or mediator of learning (McCallie et al., 2009; Skinner & Pitzer, 2012). Third, while engagement is a theoretical construct distinct from motivation (Martin, 2012), the two should be studied together, because both appear to operate within a broader sociocultural system (Crick, 2012). Fourth, contextual factors such as cultural and ecological influences (experiences, friends, family, and community structures) are important in conceptualizing engagement, meaning that a wide sociocultural lens is required to study this concept (Lawson & Lawson, 2013).

Appleton et al. (2008) and Fredricks et al. (2004) both argue that engagement can be conceptualized as a three-pronged "metaconstruct," which includes the affective/emotional, cognitive, and behavioral dimensions. Affective engagement is typically used to describe students' psychological, emotional, and social connections at school, which are positively related to motivation to pursue academic activities. A lack of affective/emotional connections may leave students less engaged, leading to behavioral and disciplinary issues. Research on the cognitive dimension of engagement tends to split into two camps: One focusing on students' effort toward schoolwork (Fredricks et al., 2004) and the other exploring how students think about their learning and make meaning (Cleary & Zimmerman, 2012; Lam, Wong, Yang, & Liu, 2012). Students with high cognitive engagement are said to be much more invested and disciplined with respect to their learning (Newman & Wehlage, 1993). Examinations of behavioral engagement within K-12 settings are quite broad and may include school dropout, behavioral disengagement, absenteeism, and suspensions (Finn & Zimmer, 2012). Other work on the behavioral dimension focuses on positive indicators such as time spent on homework or compliance with school rules (Finn & Voelkl, 1993) and involvement in extracurricular or social activities (Mahoney, Cairns, & Farmer, 2003).

In out-of-school activities, researchers have studied youth engagement by examining variables such as duration (years), intensity (hours), and breadth of participation in addition to the affective, behavioral, and cognitive domains (Bohnert, Fredricks, & Randall, 2010). Some research contrasts static, traditional forms of student engagement with more "agentic" approaches that put youth at the center of their learning, engaging collectively and authentically in action-oriented behaviors that involve active contribution, dialogue, and use of culturally relevant tools and technologies (Reeve, 2012). Such studies could be used as a model for citizen science, which is action oriented and involves contribution, dialogue, and the use of socially mediated tools.

Collectively, studies on student engagement provide strong evidence for examining engagement as a metaconstruct. As pointed out by Christenson, Reschly, and Wylie (2012), however, the subconstructs of engagement may be interrelated. Furthermore, definitional boundaries between affective, behavioral, and cognitive engagement may become diffuse when operationalized, particularly when different researchers use different quantitative measures. Nevertheless, an all-encompassing approach to engagement that includes affective, behavioral, and cognitive dimensions aligns most readily with citizen science experiences, which often involve many complex and intertwined dimensions of feeling, doing, and thinking.

2.2 | Volunteer engagement and motivation

Volunteer services permeate numerous sectors of society including education, social services, religious groups, health, and leisure activities such as sports and the arts. Studies on volunteer engagement typically do not operationalize engagement, however (Vecina, Chacón, Sueiro, & Barrón, 2012). Rather, they examine factors related to recruitment, retention, satisfaction, and motivation, all of which also pertain to engaging in citizen science. For example, Vecina et al. (2012) used vigor, absorption, and dedication to study volunteer engagement and found it to be positively associated with volunteer satisfaction and intention to remain for new volunteers. The same study found that for veteran volunteers, volunteer engagement was positively correlated with a commitment to the organization, which in turn was positively associated with intention to remain a volunteer. Other studies have reported that volunteer motivations are positively correlated with volunteer satisfaction and actual experiences (Farrell, Johnston, & Twynam, 1998). These findings suggest that volunteer motivation, positive experiences, and satisfaction with the activity can lead to further engagement. Understanding motivations, in particular, can help practitioners better understand the psychological needs surrounding engagement that lead to recruitment and retention.

Few studies, however, have examined the link between motivation and engagement within the context of citizen science. One exception is a paper by Nov, Arazy, and Anderson (2014), which used self-determination theory (SDT) with social movement participation models to examine three online citizen science projects. Nov et al. found that intrinsic motivation (interest, enjoyment, and satisfaction) was one of four drivers that influenced the quantity of participation, but that it did not affect the *quality* of participation, as defined by the accuracy and precision of observations contributed to an astronomy project. SDT offers a lens to study the underlying psychological aspects of motivation in citizen science because it predicts that intrinsic motivation tends to result in sustained engagement, whereas extrinsic motivations (social pressure, rewards, and punishment, fear) tend to wane over time.

3 | THEORETICAL PERSPECTIVES

To frame our understanding of engagement within the context of citizen science we use sociocultural theories, which view learning as an inherently social process between individuals, mediating tools, and their social contexts and structures (National Research Council, 2009). In particular, sociocultural theories are useful in understanding the mechanisms and processes that enable active learning through real-world experiences (Vygotsky, 1978). For instance, activity theory, an offshoot of cultural historical activity theory, has been used by Roth and Lee (2004) to examine how a local water-quality monitoring project with 7th-grade students supported science literacy and authentic learning to solve real-world problems. Experiential learning, also imbedded in sociocultural learning theory and first described by Dewey (1938) and later by Kolb (2014), also can be applied to citizen science. Experiential learning describes an individual's experience with an activity or situation that facilitates learning interactions between individuals and their environment. The hands-on nature of citizen science aligns well with experiential learning theory because of the tangible experiences that participants can reflect upon easily. In one of the first studies to use learning theory in citizen science, Brossard, Lewenstein, and Bonney (2005) used experiential learning theory to study citizen science experiences and learning by individuals monitoring bird houses in relation to their knowledge and attitudes toward science and the environment.

Another sociocultural theory, situated learning theory (SLT)—first introduced by Lave and Wenger (1991)—provides a lens for examining production and transformation of personal identities, practical skills, and communities of practice through engagement with workplace and everyday activities. Sometimes referred to as situated cognition, this theory embeds learning within the lived experiences of the individual as part of the activity, context, culture, and social practice (Choi & Hannafin, 1995). SLT suggests that increasing the practice of an activity within a community using similar tools and procedures leads to changes in practice and in participation, from novice/ peripheral to an expert or core member. Researchers are increasingly using SLT to examine the role of practice in citizen science as it relates to individual learning, engagement, and identity. For example, Raddick et al. (2009) examined changes in involvement in various tasks as leading to increasing knowledge and engagement within the community of an online astronomy project.

An integral concept that builds on SLT is communities of practice, which also recognizes that all learning is situated and that communities provide the context for learning to occur most effectively (Wenger, 1998). Communities of practice can occur in settings such as schools, workplaces, and organizations, and interactions among community members include cooperation, problem solving, trust building, shared understanding, shared use of mutual resources, and maintaining relations. Ballard, Fernandez-Gimenez, and Sturtevant (2008) describe how ecologists, forest managers, and *Salal* harvesters learning together about forest understory management may have constituted a community of practice. Jackson, Østerlund, Crowston, Mugar, and Hassman (2015) also used Community of Practice, conducting semistructured interviews with Zooniverse Planet Hunters to examine identity shifts among participants. These authors documented the movement of participants from legitimate but peripheral members of the community, to sustained participants, to full members of the community with increasingly central roles in the project.

Whereas many disciplines have examined engagement through a multitude of theoretical perspectives including affective, behavioral, cognitive, and sociocultural lenses, studies on citizen science have characterized engagement primarily through various measures of the quantity of data contribution (Phillips et al., 2012). The field of citizen science is at a turning point, however, and rich discussion regarding the need for more theoretical rigor in how citizen science is studied is underway. To that end, we emphasize theoretical perspectives from experiential learning, SLT, and communities of practice to provide a qualitatively rich and empirically derived understanding of engagement across various forms of citizen science. We believe that our findings will have utility for other areas of ISE as well.

4 | METHODOLOGY

4.1 | Research design

This study is part of a larger research project examining how participation in citizen science supports lifelong science learning (NSF-DRL #1323221). To obtain the results presented here, we interviewed 72 citizen-science participants from six different citizen science projects that represent the range of project models (contributory, collaborative, and cocreated) described in Bonney, Ballard, et al. (2009). This typology of project models differentiates the typical aspects of the scientific process in which citizen science participants are engaged (though part of the current investigation was to discover whether individuals engaged in other activities as well). For instance, "contributory" projects involve participants mostly in collecting and submitting observational data; "collaborative" projects engage participants in collecting and submitting observational data, but also in data analysis and/or interpretation; and "co-created" projects involve participants in many or all aspects of the scientific process beyond data collection, analysis, and interpretation, such as research design and dissemination of findings. The six projects have in common a focus on some form of field-based, environmental monitoring and were purposefully chosen because they represent one of the three model types, and because of their geographic, scientific, temporal, and structural diversity.

4.2 | Project descriptions

Using SLT as a lens for examining everyday learning requires an understanding of the context, content, community interactions, and participation characteristics of such experiences. Here we describe each of the six projects using information gathered through conversations with and webinars by the project leaders as well as reviews of their respective project websites. The six project descriptions and their alignment with SLT characteristics are described in Table 1.

NestWatch (NW) is a nest monitoring project of the Cornell Lab of Ornithology that began as the Nest Record Card Program in the 1960s. The goal of NestWatch is to examine changes in bird breeding biology and reproductive rates throughout the United States and Canada. NestWatch participants tend to be female, mostly well-educated, and over the age of 45. Participants typically are individual homeowners or families or belong to a conservation group, golf course, or community trail of nest boxes. Participants put up any number of nest boxes, ranging from 1 to >100. The NestWatch protocol suggests that after finding a nest, participants monitor it every

TABLE 1 Summary of project description aligned with situated learning theory characteristics

Projects (content)	Description (context)	Project type and structure (community)	Tools/materials (participation)
NestWatch (Nestwatch.org)	Contributory; monitoring bird nest boxes	Individual, some peer-to-peer interactions online	Nest boxes, binoculars, field guide; paper and online data collection, online data submission, online data retrieval, online materials and training
Monarch Larva Monitoring Project (mlmp.org)	Contributory; counting monarch larvae on milkweed plants	Individual and group, some peer-to-peer interactions online	Hand magnifying lens, field guide, ruler, paper and online data collection, online data submission, online data retrieval, online and in-person materials and training
Community Collaborative, Rain, Hail, and Snow Network (cocorahs.org)	Collaborative; measuring precipitation events	Individual, most peer-to-peer interactions online	Rain gauges, measuring sticks, online data entry and retrieval, online materials and training
Hudson River Eels Estuary Project (dec.ny.gov/lands/ 49580.html)	Collaborative; counting glass eels	Group, most peer-to-peer interactions in person	Waders, fyke nets, buckets; paper data collection; online data retrieval, in-person training
Alliance for Aquatic Resource Monitoring (www. dickinson.edu/ allarm)	Co-created; monitoring water quality	Group, most peer-to-peer interactions in person	Water bottles, yard sticks, water conductivity meters, paper, and online data collection; online data retrieval, in-person training
Global Community Monitor (gcmonitor.org)	Co-created; monitoring air quality	Group, most peer-to-peer interactions in person	Air monitoring buckets; paper data collection, in-person training

3–4 days for the remainder of the nesting cycle. The NestWatch website allows participants to contribute data, to download their accumulated personal data to track nesting success, and to access data from other participants across the country. The NestWatch database currently houses more than 300,000 nesting records.

The Monarch Larva Monitoring Project (MLMP) occurs anywhere in the United States, Canada, and Mexico, wherever the favored milkweed plant of monarch butterflies (*Danaus plexippus)* occurs. These spaces can include backyards, nature centers, or parks of various sizes. The majority of MLMP participants are highly educated, older, adult females, although about half of them monitor with children as an educational activity both in and out of school. Participants measure monarch density on milkweed plants by examining a set number of plants and counting the number and life stage of caterpillars on the plants. Some MLMP participants also collect caterpillars and rear them indoors to see if they are afflicted with parasites. Although the majority of participants monitor plants on a regular basis, some individuals monitor more sporadically. MLMP data are submitted online and can be retrieved individually or aggregated among sites. There are currently more than 1,300 active MLMP sites.

The Community Collaborative Rain, Hail and Snow (CoCoRaHS) project started out as a small community-based organization in northern Colorado following an epic rainfall event in 1998, resulting in an "accidental network" but now operates throughout the United States and in Canada. CoCoRaHS gathers precipitation data year-round to track weather across time and space, receiving upwards of 10,000 observations daily, much of which are shared with meteorologists at local, state, and federal agencies. The majority of participants are middle-aged to retired, mostly college-educated White males, although efforts are underway to engage a younger, more diverse audience.

Many CoCoRaHS participants are self-described “weather nerds” who track weather as a hobby, but appreciate having their weather observations permanently stored for them. Participating in CoCoRaHS typically involves <5 min/d checking a rain gauge, usually in one’s backyard, and entering the data online. Some participants take extra measurements of water content in snow, evaporation, and drought impacts. Although most participation is done individually, CoCoRaHS provides monthly educational webinars through YouTube and other forms of social media. Personal and project-wide data are accessible and downloadable via the website.

The Hudson River Eel Project (EELS) started in 2008 and operates regionally along a 150-mile stretch of 12 tributaries along the Hudson River in New York State. EELS has more than 500 volunteers including high-school students and teachers, college interns, watershed groups, and small family groups. Most of the adult participants are White, highly educated females, often working in formal school settings. The American eel and its life history are considered mysterious and charismatic, resulting in a high participant retention rate. Once or twice a week between March and May, volunteers coordinated by the New York State Department of Environmental Conservation (DEC) don waders and carry buckets to large fyke nets positioned in tributaries, where they catch and count thousands of juvenile “glass eels.” The eels are then transported and released above the dams that obstruct their migration. Some participants have taken on leadership roles, modifying or adapting protocols to specific sites or spearheading the inclusion of new sites along the Hudson. Data are recorded on paper forms and left in a secure location where the DEC collects and then uploads them to an online site. Data are compiled by the DEC and then available for download for each site.

The Alliance for Aquatic Resource Monitoring (ALLARM) is a stream monitoring program that began in 1986 and is run out of Dickinson College to provide technical assistance for monitoring the health of watersheds throughout Pennsylvania. Originally developed for helping communities deal with acid rain, ALLARM now focuses on shale gas fracking and watershed protection and restoration. Typically, communities self-organize over a local issue or concern and turn to ALLARM for help in training to develop and implement water-quality monitoring protocols. Most volunteers are female, adult retirees who live in rural farming/hunting communities and may already be involved with a local watershed group. ALLARM organizes training throughout the state to help groups develop their goals for monitoring, create study designs, and develop protocols for data collection, analysis, and interpretation. ALLARM also provides decision trees for communicating and disseminating data to local municipalities. Participants typically make monthly visits to their site(s) throughout the year, conducting visual, biological, and/or chemical assessments of watersheds. A variety of data collection tools are used including syringes, pipettes, water conductivity meters, and calibration solutions. Although ALLARM provides rigorous quality assurance and quality control (QA/QC) training, the group’s philosophy is that communities have full ownership of how their data are used and shared. Currently, a central database gathers information on sites being monitored for shale gas fracking, from which participants can view, submit, and download statewide or local data.

Global Community Monitor (GCM) began in 2001 in California as a grassroots effort to monitor local air pollution. GCM quickly spread to other states in the United States and other areas such as the Philippines, India, and South Africa. Sometimes referred to as “Bucket Brigades,” GCM teaches communities how to collect air samples; lobby elected officials; meet with local, state, and federal agencies; and empower communities to have a voice through the air quality data they collect. GCM participants are typically female and younger; education levels are not known. GCM participants often live on the fence line of heavy industry such as fracking, oil refineries, and steel mills and tend to be working class and members of communities of color. Most communities join after becoming aware of emissions because of localized health issues and reach out to GCM for assistance with gathering defensible air quality data. GCM teaches communities how to choose sites for air collection buckets, collect data, send data to certified air quality labs, and use results of analyses as an organizing tool to open lines of communication with industry to either improve regulations or, in some cases, cause the industry to shut down. Participants may choose to engage in some or all aspects of the GCM protocol. GCM data are maintained within the communities, which determine how best to share and use the information.

4.3 | Interview guide

We developed a semistructured interview guide to identify topics in advance of interviews and to support a systematic flow to data collection (Patton, 2002). Major sections within the guide were informed by the a priori themes from the above-mentioned literature, including effort (duration and frequency of participation); motivations; affective dimensions such as interest and emotions; behavioral aspects of engagement, that is, what participants do on behalf of the project; what engagement means to participants (both cognitive and affective); and social/project connections.

Sample questions from the interview guide are listed below and the entire protocol is available in the Supporting Information Appendix.

- What was it that led you to start participating in _________ project? What did you expect the experience of participating in this program to be like? Probe: What were you hoping to get out of it? (Motivation).
- Could you tell me what this project has meant to you since you started? (Affective).
- Please describe all the activities that you do or have done as part of this project (Behavioral).
- Please describe any activities undertaken to learn about the protocol (Cognitive).
- Do you see yourself as part of the _________ project? For example, do you feel connected to the people and organization that run this project? Probe: What makes you say that? (Social).

4.4 | Participants

Participants for this study were drawn using a maximum variation sampling method to identify a diverse variety of participant experiences and to identify patterns and differences among participants of the six projects (Patton, 2002). To select interviewees who represented various levels of involvement, the six project leaders provided characteristics of what they felt would constitute a "basic," "moderate," and "high" level of involvement for participants in their particular project. Several themes were common across (most of) the projects, including: Frequency of data submission, the quantity of sites monitored, diversity of activities, communication with project staff or other participants, and leadership activities. These characteristics were summarized and supplied as a reference tool to help each project leader identify, with some level of consistency, approximately three to five project participants exhibiting basic, moderate, and high project involvement. In identifying these interviewees, project leaders also were asked to consider diversity in demographic variables such as geography, gender, and ethnicity.

The initial sampling frame across all six projects was 101 adults over the age of 18. In March 2014, we sent an email to each individual inviting them to participate in the study. Three emails were returned as bad addresses, eight individuals never responded, and seven responded but declined to participate. The remaining 83 individuals agreed to be interviewed. Institutional review board approval for protection of human subjects was obtained in accordance with researchers' institutions before the start of interviews.

4.5 | Data collection

Each of the 83 participants was interviewed and audio-recorded by telephone by one of four researchers between April and June 2014. Each interview lasted from 60 to 120 min and interviewees were sent a $25 gift card as a token of appreciation. Audio files of the recorded interviews were sent to a commercial transcription service, Verbal Ink, for digital transcription. To ensure confidentially, names of all interviewees were changed. Due to poor audio quality 11 interviews could not be transcribed, resulting in 72 interviews that could be analyzed. The relative distribution of the 72 participants, categorized initially as basic, moderate, and high, are presented in Figure 1. Only NestWatch had equal representation among the three levels. The majority (58%) of interviewees were female. This

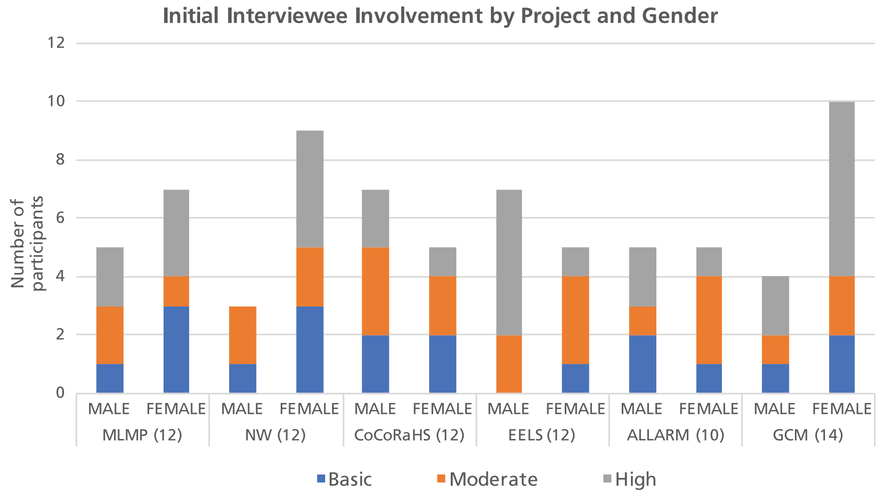

FIGURE 1 Initial distribution of interviewee involvement across projects and by gender. ALLARM: Alliance for Aquatic Resource Monitoring; CoCoRaHS: Community Collaborative Rain, Hail and Snow; EELS: Hudson River Eel Project; GCM: Global Community Monitor; MLMP: Monarch Larva Monitoring Project; NW: NestWatch [Color figure can be viewed at wileyonlinelibrary.com]

skew was especially apparent in NestWatch (75%) and GCM (71%). Mean duration participating in a project was 4.20 years across the six projects.

4.6 | Data analysis

Using the information from our literature review, we created an initial codebook to provide a blueprint for identifying salient themes in the interviews (Patton, 2002). Analyzing interview transcripts relied heavily on open coding to break down, examine, compare, conceptualize, and categorize data (Strauss & Corbin, 1997). For each interview, coding methodology included carefully reading each line of transcription and categorizing it into one or more major nodes or subnodes as defined by the codebook. A single line of text was frequently coded into more than one node or subnode. We used a constant comparative method to assure that the codebook reflected the diversity of interviewees (Creswell, 2003; Strauss & Corbin, 1997). For example, within each interview, we compared multiple instances of a single subnode for measures of consistency (within that interview). We also compared the consistency of subnodes between interviews. When we encountered contradictions, we conducted additional coding, which often resulted in the formation of new subnodes. When finalized, the codebook contained 10 major nodes and over 120 subnodes. The 10 major nodes included: Barriers, effort, facilitators, affective/feelings, cognitive/learning, motivations, nonproject activities, project activities, social/project connections, and science or environmental identity. For the purpose of this study question, we focus the rest of the analysis on the most commonly referenced themes that also aligned to our literature review. Codebook definitions of these major themes are described in Table 2.

Transcribed data were imported into NVivo (QSR International), which automatically quantifies the number of individuals (labeled "sources") that are coded for a node or subnode and the number of times that a particular node is mentioned (labeled "references") across the entire data set. Using the *sources*, as the unit of analysis allows for detection of the *breadth* of a particular node across the sample. Using the *references* as the unit of analysis provides an understanding of the *depth* of a particular node. A portion of the text was coded as a single reference for as long as it referred to a unique node or subnode uninterrupted in the text transcription, regardless of the length of the passage. If a node is mentioned by nearly all participants but referenced relatively infrequently, interviewees as a whole did not spend much time discussing it. If the number of references is large compared to the number of

TABLE 2 Major nodes of engagement, aggregated and sorted by number of references across all six projects and 72 sources (interviewees)

Major nodes	Description	References
Behavior	Observable aspects of participation—both the number and kinds of different scientific practices, tasks and/or activities that participants engage in as part of the project	4,797
Motivation	The underlying psychological need for why someone does something expressed as initial cause for participation or why they stay involved in the project	2,761
Affective/feelings	Expressions of feelings or emotions about specific activities, other people (friends, family members), or other living and nonliving things (plants, animals, places)	2,066
Social/project connections	A sense of belonging to the project or the extent to which individuals feel allegiance to a group expressed through interactions with participants, project leaders, and connections to the larger scientific community	1,684
Cognitive/learning	Thinking about the situated aspects of engagement, that is, applicable content and real-life contexts to support learning and individual reflection on their learning	1,533

sources, that node was probably very important for a small number of individuals who spent considerable time detailing it. Nodes that have high numbers of both sources and references were discussed at length by a majority of interviewees and were of high importance.

We used interrater reliability to increase interpretative validity. In this process, two researchers coded six interviews in common (one from each project) on two separate occasions and then ran an interrater reliability test using the NVivo software. The initial reliability for these six interviews using Cohen's κ was 0.71, for all nodes, equally weighted. This κ is considered to have "fair to good agreement" on the NVivo/QSR website (www.qsrinternational.com) and "substantial agreement" by others (Viera & Garrett, 2005). The analysis for the second set of interviews yielded interrater reliability of 0.84, which is considered extremely high agreement (Viera & Garrett, 2005). Each of the two researchers then separately coded the remaining 60 interviews. To organize themes we used "classical content analysis," which takes into account the frequency of code utilization, and is able to inform important concepts that can also be analyzed quantitatively (Leech & Onwuegbuzie, 2007).

5 | RESULTS

An overall snapshot of our content analysis is provided in Table 2. The data set is summarized according to the major nodes and ordered by the aggregated number of references within that node, from greatest to least. Although the results show some differences among project and project type, these differences have not been tested for statistical significance.

The next section describes and discusses each of the major nodes shown in Table 2; affective, behavioral, cognitive, social, and motivational factors and the associated subnodes.

5.1 | Learning/cognition

While coding for the cognitive dimension of engagement we focused on participants' examples of applying knowledge in real-world contexts and the ways in which participants reflected on their learning. We also looked specifically at the tools and resources that respondents described drawing from during the course of their engagement to support their learning. Aggregated across all projects, those responses are presented in Table 3.

TABLE 3 Descriptions and most commonly reported subnodes coded under the major node "learning"

Learning	Participant describes…	Sources	References
Experiential learning	Something they learned because of direct observation or "hands-on" experience with the project.	60	361
Project resources/artifacts	Using project resources and artifacts for new knowledge acquisition	59	254
Pre-existing knowledge	Knowledge that they brought with them to the project	52	256
Learning from others	Learning through interactions with others	47	306
Increased awareness	Increased awareness of some phenomenon as a result of participation	46	131
Understanding of science process or citizen science	New understanding of or appreciation for citizen science, how science works as a function of engaging in science practices, or understanding of citizen science or their role in science through citizen science	43	123
New skills	New skills or tool use acquired as a function of practice	24	53
New behaviors	Undertaking new behaviors and activities as a result of participation	6	11

Across projects, 60 of 72 (83%) interviewees described learning through direct activities and experiences with the project, which we classified as experiential, and illustrated in the quote below by a NestWatch participant.

I've added another nest box here, for example, we'll see what—who's going in and out of there and what they're doing and I'll be able to observe those guys and learn a little bit more about what's going on around me in terms of the birds that I can see more of these kinds of things, it increases my observations on it and so forth, and I'm trained as being an observer anyway, so that's important (Jay, NW).

Examination of the number of references to learning by project showed some variation with respect to the experiential learning node, with a disproportionate number of references (about 30%) coming from NestWatch participants.

An almost equal number of participants (59) described learning new knowledge through training, materials, and resources provided by the project. The quote below from a GCM participant highlights the influence of project materials leading to increased awareness, a common theme among GCM participants, likely as a result of the technical aspects of air quality, which is heavily reliant on chemical concepts:

I was seeing my world behind, I don't know, colored sunglasses or whatever. And everything was beautiful and all this and then having those sunglasses removed and having a different set of spectacles, you start to say I've got a different reality that I've got to deal with. And so, they helped me by giving me a perspective. They helped me by putting a name to some of the chemicals in the area (Serge, GCM).

Approximately 72% (52) of participants described drawing on pre-existing knowledge that they brought to the project, suggesting that participants joined citizen science projects to continue to pursue an interest or hobby:

I would say I was predisposed to science from when I was little, and an interest in landscape issues and water issues and forestry issues and the like. So, I don't know if it's changed anything, but it's allowed me to get in deeper and closer and to be able to do this stuff that I didn't go into as a career (Shalin, MLMP).

In addition to learning new content, a majority of participants described an increased awareness of the connectivity of living things; this was especially salient in the EELS project:

One of the things is that I have … a better understanding of how all the little parts make the whole picture. Who would've thunk, … that collecting and counting glass eels coming out of the Hudson … into their little streams would have any kind of impact at all? (Rochelle, EELS).

Sociocultural theories of learning describe tools as important mediators in the learning process, and all six projects provided experiential opportunities for participants to gain new skills in using a variety of tools and equipment, as exemplified by this quote:

We divided up into small groups and we were given maps and shown where drilling was taking place. So that was an important part and then of course we were given time to have hands on practice with meters and were shown how to measure, take a water sample. Calibrating our meter and then using the sample that they had brought with them, to take the readings and each of us did that (Madeline, ALLARM).

More than half of all interviewees (43) also described their own understanding of the science process and/or citizen science, as influenced by their project participation. The quote below highlights a participant's understanding of the potential of citizen science:

NestWatch is successful because there's an awful lot of data points and an awful lot of people. I mean, there are 800 or 900 people watching Carolina chickadee nests in the United States. Where are you going to find 800 or 900 people in a research department you're going to send out and say, "Go find this and go look at this and collect this in the next three or four months," I mean, it's impossible. So citizen science provides a very powerful tool for data collection over a wide area, and that's very important (Jay, NW).

In some cases, participants described instances of learning, that were difficult to categorize, so we classified them as "other learning." These instances were particularly prevalent in the GCM project, with nearly one-third of the references in the "other learning" category. For instance, Layla from GCM described having to learn the politics of the air quality monitoring effort and the need for community involvement:

Sadly, I have learned that the regulators that are supposed to be doing all of this are, seem like often they're protecting industry. They're not doing the job that they should. So, it's up to communities if they think there's a problem to find out and educate themselves and get the word out.

Adele, also from GCM, described learning about the kinds of careers that will have the most impact in her community and her decision to switch careers:

So many people would think well why would you switch from environmental studies … to public relations and communications, and my biggest reason for doing that was my work with Global Community Monitor in the sense that we don't need any more scientists necessarily to interpret the data and to be able to sift through it.

We purposely did not ask questions about specific science content that participants learned because other studies have already shown the immense potential for citizen science to help participants learn content-specific topics (see Brossard et al., 2005; Crall et al., 2012; Evans et al., 2005; Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011; Trumbull, Bonney, Bascom, & Cabral, 2000). However, judging from these interviews, participants are clearly applying content knowledge to their real-world contexts and thinking deeply about their engagement and their roles within various communities.

5.2 | Social and project connections

In coding for social dimensions of engagement, we looked for instances where participants described a sense of belonging to the project or the extent to which they felt allegiance to a group. Lave and Wenger's (1991) early discussions of situated learning and legitimate peripheral participation were particularly helpful for examining social interactions that facilitate relationship building (coded as "relations"), expanding one's role in the project, using mutual resources, and sharing knowledge. All 72 participants described social relationships that were important to them with respect to the project (Table 4).

One surprising finding was the consistency with which social relations were described across all projects. For example, all but five of the 72 interviewees described the importance of personal relationships that they had established, in particular with the project leader or organization, but sometimes with other project participants. The fact that personal relationships were referenced 764 times also points to the depth and value that interviewees placed on these relationships. For example, an MLMP participant said:

TABLE 4 Descriptions and most commonly reported subnodes coded under the major node "social/project connections"

Social/project connections	Participant describes…	Sources	References
Relations	Collaboration or social interactions with others as a key aspect of doing some kind of project activity	67	764
Using mutual resources	Using systems or tools to coordinate or communicate a shared practice. For example, participants may describe the use of the listserv or in-person training to take part in a shared activity	62	395
Using shared knowledge	Sharing one's own competence or accessing that of others to reflect on what they do and know (as well as to reflect on what they don't do and don't know)	44	162
Role expansion	Behavior that reveals attention to a wider range of tasks than is typical or usual, helping to move the individual from periphery to more core membership and facilitate stronger project connections. For example, an individual describes becoming a leader and training others, or taking part in civic engagement opportunities such as going to town board meetings	22	191

They asked for letters of recommendation when Karen got the scientific—when she got that scientific award. They apparently put them into a pool, pulled out some of the top letters and they went out and sent out those letters of recommendation. The people whose letters were selected got an invitation to the White House. I sat there and looked at it and I got an invitation to the White House (David, MLMP).

Another example of the importance of connecting with the program leaders comes from the EELS project:

The folks that work in _(agency?)__, it's my feeling that they consider me to be one of them, somewhat of a peer type of feeling. Certainly not a colleague and I'm not employed by the state. I'm not a paid intern. I'm just an old man who loves standing in a creek on rainy days and counting eels (Dion, EELS).

Dozens of interviewees also described relationships formed between the participants:

We have a little kinship. Especially those of us that go through winters together… When I say "we," we all function within some type of a discipline and some type of approach and things like that. It's easy to make a "we" out of that (Mark, CoCoRaHS).

Likewise, an ALLARM participant explains:

So, again, the social interactions of all those people form a synergy that makes initiatives just keep kind of happening, and keep getting born out of this energy that happens when you bring people together. And then people want to be a part of it. You don't want to get left out (Madeline ALLARM).

The personal relationships forged through participation highlight the general sense of belonging and allegiance to the project, organization, and even other participants.

Almost 90% (62 of 72) of interviewees also described using mutual resources for sharing knowledge, evidence of the important role that training materials, websites, listservs, and publicly available data have in making participants feel part of scientific practice:

They had a diagram showing the different instars and I was trying to print it out and I couldn't. So I just sent in an email saying … "Look, can you get me a copy of this?" And they replied right away. Like they're very good about getting back to you if you're involved (Grace, MLMP).

Two-thirds of the participants described the importance of using social interactions to share knowledge and enhance their engagement in the project:

I feel like people would do anything for the other person. It is just a warm, sharing, interesting group of people…Like, one lady who comes to the site found this study about eels in the Chesapeake Bay about big numbers, so we were expecting big numbers at our site this year. And stuff like that. I think… I didn't expect to broaden my own social network, you know. That was unexpected when it happened (Jade, EELS).

About a third of interviewees also described increasing their responsibilities within the project and expanding their role from a more peripheral, less engaged participant to a more central, core member, edging toward a leadership role:

Well, I would say that because of GCM introducing me to this whole citizen science issue and activism and affecting change and since we had such success here in Tonawanda, it's just opened up this new door of opportunity for me. I mean, they were the beginning of all of this for us here in Tonawanda. GCM is a part of the whole change that happened but it all started with GCM so there's been a number of people and organizations throughout the whole Tonawanda Coke campaign that changed my life. But I would say that GCM was the initial organization that sort of spearheaded all the chain of events (Juliann, GCM).

I never thought of myself as a trainer. But I feel like it's a—it's been a good thing for me, as a retiree, I'm getting old enough that I think about what's my legacy, what do I leave behind, what do—I have no children, so what is my contribution to the world and humanity or whatever. So I think training other people is one way to pass on skills that can go further than just me looking in boxes and enjoying the birds for myself (Abby, NW).

These findings demonstrate the critical role that social interactions have on engagement in citizen science. Although the importance of social interactions with other participants appeared more often in projects whose structures facilitated more group/social interaction (EELS, GCM, and ALLARM), all projects emphasized the value of meaningful interactions with project leaders and a sense of belonging to the project.

5.3 | Feelings/emotions (affective)

Throughout the interviews, participants described their feelings and emotions, often without any prompting, other times with intentional prompting. In coding for the affective dimension of engagement, we paid attention to participants' descriptions of feelings or emotions toward specific activities, other people (friends, family members), or other living and nonliving things (plants, animals, and places). We also coded when these descriptions connoted a positive or negative tone, because highly positive or negative emotions can influence an individual's experiences and thus their engagement (Russell, 2003). In all, feelings were referenced nearly 2,100 times by the 72 interviewees (Table 5). At the end of the interview, participants were asked to briefly summarize what the project meant to them; this also elicited strong feelings, most of which were extremely positive. Some of the affective states that we coded in the interviews were related to feelings of commitment, efficacy or confidence, excitement, interest, recognition, credibility, uncertainty, and surprise in terms of new ideas or unique experiences.

An array of variability in feelings and emotions was evident among the six projects, highlighted in Figure 2 and categorized by the number of times that a feeling was referenced. "Commitment to some aspect of the project" was universally mentioned across all six projects. Efficacy or confidence as a result of participation was mentioned relatively less, but most often by GCM (recall, GCM had more interviewees than all the other projects). Participants reported excitement most often in the EELS and MLMP projects, which was evident by the way in which they spoke about their participation.

But I would say for sure last year, so the 2013 season, we had some major catches of eels that had not been experienced before in any of the net sites and has not been experienced since. So our biggest catch day was over 8,000 eels, and I wasn't there for the 8,000, but I was there for a day we caught 6,000 glass eels! And it was just tremendously exciting for us to see those numbers! (Lea, EELS).

Interest in the project, content, tool, or experience was most often described by CoCoRaHS participants, most of whom entered with a strong interest in weather or meteorology. Participants described feeling surprised and/or having new experiences consistently across five of the six projects, with ALLARM participants not mentioning it very much. Concerns about QA/QC were most often heard from CoCoRaHS participants, who often expressed frustration with other participants who were not following the regimented protocol of submitting data every day. GCM and ALLARM participants also expressed QA/QC concerns about the integrity of their own data and how the information would be received by others. To a lesser degree, participants described feelings of pride from

TABLE 5 Descriptions and most commonly reported subnodes coded under the major node "feelings/emotions"

Affectives	Participant describes...	Sources	References
Positive	Enjoyment, comfort, fun, appreciation	64	614
Negative	Discomfort, uncertainty, nervousness, dislike, frustration, sadness	62	425
QA–QC concerns	A stated concern to act responsibly, particularly regarding accuracy in data collection or concern about the responsibility of others	57	255
Commitment	Being dedicated to the idea, the project, the environment, or the science behind the project	54	205
Surprise/new ideas or experiences	Encountering something they hadn't expected, or discovering something new	53	136
Interest	Feelings of interest resulting from the interaction between them and some specific content, tool, or project experience	47	154
Excitement	Feelings of excitement about their participation in the project	46	242
Uncertainty	Doubt or uncertainty about some aspect of their participation or the project	35	132
Efficacy or confidence	Having confidence, agency or self-efficacy in their participation in the project	30	67
Recognition or credibility	Feelings related to being recognized or valued by others for their participation	29	72

Note. QA–QC: quality assurance/quality control.

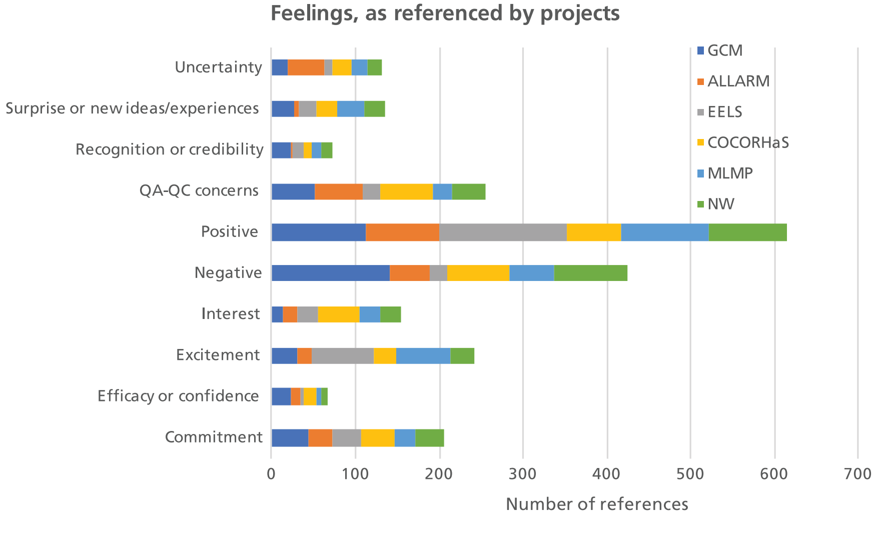

FIGURE 2 The diversity of feelings referenced by participants in the six projects. ALLARM: Alliance for Aquatic Resource Monitoring; CoCoRaHS: Community Collaborative Rain, Hail and Snow; EELS: Hudson River Eel Project; GCM: Global Community Monitor; MLMP: Monarch Larva Monitoring Project; NW: NestWatch; QA–QC: quality assurance/quality control [Color figure can be viewed at wileyonlinelibrary.com]

recognition or credibility they received from others. Lastly, uncertainty emerged to some degree in all projects, but ALLARM participants, in particular, were uncertain about where their data go and how they are used.

In addition to coding different feelings, we also coded whether the feeling was generally positive or negative toward some stimulus, sometimes referred to as “core effect” (Russell, 2003). Although all interviewees shared negative statements, GCM had a disproportionate amount of dialogue that was negative, owing to the deep level of concern and worry expressed for local communities. NestWatch also had a fair share of negative emotions, likely due to the fact that participants see both life and death as a function of observing breeding cycles of birds. Positive emotions were heavily referenced and also fairly consistent across all projects, but EELS participants were especially verbose in attributing positive feelings toward the project.

That fact that most of the participants were so candid with their feelings during this interview highlights the importance that these projects had in their lives. Emotions, while often strong and passionate, were overwhelmingly positive. The diversity and strength of these emotions suggest that for almost everyone, these experiences were about much more than simply collecting data; they underscore the important role that emotions play in engagement.

5.4 | Motivations

To understand the role of motivation in engagement, interviewees were asked specific questions about why they began participating in citizen science, what their expectations were for the project, and what made them continue. Aggregated across the six projects, the most commonly mentioned motivators were environmental concerns (20% of all *references*), contribution (12%), interest (10%), and community concerns (9%). Looking at the total percent of *sources*, the order changes slightly with 85% of interviewees describing environmental concerns, 81% mentioning contribution, 77% describing a specific place, 72% citing interest, and 71% social connections. Other important drivers such as learning, enjoyment, scientific credibility, education, political distrust, and career are listed for each project in Table 6, and sorted by the most to least number of references. Taking into account the nodes with both the highest proportion of references and sources, the three main drivers remain an environmental concern, contribution, and interest.

Comparing motivations among project types highlights some interesting differences (Figure 3). Notably, the co-created projects disproportionately represent the environmental concern node with 329 references (nearly two-thirds of all references). Of these references, 243 were from GCM participants, highlighting the incredible depth of importance that environmental concern has for them. Similarly, nearly 82% of all references to community concern came from GCM participants. Only co-created projects mentioned “political distrust” as a driver for participation and GCM also had a disproportionate number of interviewees (10 of 14) mention the need for scientific credibility as a strong motivator. Conversely, the contributory and collaborative participants were much more likely to mention interest, contribution, and enjoyment. ALLARM and EELS, two projects with a strong regional footprint, were most likely to mention attachment to a specific place, whereas MLMP participants more often mentioned attachment to natural places more generally. Additionally, the EELS project, with its emphasis on working with middle- and high-school-aged students, cited education more often than any other motivation.

These data suggest that participants in co-created projects are greatly influenced by extrinsic motivations such as worry or concern, whereas participants in contributory and collaborative projects are more intrinsically motivated. We are not suggesting that extrinsic motivations are bad; in fact, many subforms of extrinsic motivation, especially those dealing with values such as environmental concern—labeled as identification and integration by Ryan and Deci (2000)—can be very effective in heightening personal commitment. Most participants had multiple motivations, however, confirming previous work that motivations to participate in citizen science are multifaceted (Raddick et al., 2010).

5.5 | Project activities (behavioral)

Common notions of what it means to engage in citizen science tend to focus on what participants do as a function of the project, most often described in terms of volunteer data collection. In our examination of what participants do, we

TABLE 6 Descriptions and most commonly reported subnodes coded under the major node "motivations"

Motivations	Participant describes…	Sources	References
Environmental concern	Environmental issues/concerns that are important to them and that they want to address, such as environmental health, air and water quality, climate change, conservation of habitat or species, and weather	61	533
Contribution	Wanting to make a contribution (whether to science, the environment, education, or community) as motivation for participating in the project	58	316
Interest	His/her interest in a topic or issue as motivation for participation	52	271
Community concern	Any issues directly impacting a community or the need to bring people together and/or the need to empower community members	26	225
Education	Any issues/problems in education that motivate them to participate (e.g., the need to get students interested in science or the environment, the need to increase students' connection with nature).	28	207
Place specific	Attachment or connection to specific places or types of places, including the built environment as well as the natural environment; includes connections to places because of people or community reasons, as well as or separate from ecological systems or natural places	56	206
Enjoyment	Personal enjoyment, fun, excitement, or satisfaction as a motivation for participation	45	204
Learning	Learning as a motivation for joining or staying engaged	47	191
Social connections	A desire to be with like-minded people or being introduced to the project by someone as a motivating factor	51	169
Scientific credibility	The need to obtain data or evidence that can be used to defend a claim; or desire to engage in scientific work as a motivation	38	105
Place—nature	Being outdoors or in nature in general, as a motivation to participate	24	73
Political distrust	Concern or mistrust of political forces as a key motivation for participation	11	68
Career	Being motivated to do citizen science because it would benefit their job or career in some way	17	67

focused on the observable, behavioral aspects of engagement to understand not only the various forms of data collection, but also the other numerous activities that participants undertake. Thus, we divided "Project activities" into two broad categories: data collection and "extra" activities. *Data collection* was referenced over 1,500 times and included the following tasks: classification, counts, equipment usage/setup, identification, measurement, observation, gathering samples, site selection, life stages, timing, and "other." Using equipment was heavily referenced, as was observation, taking samples, and nonproject tasks such as driving to sites and taking photos. *Extra activities* included the non-data collection forms of behavioral engagement that participants mentioned such as submitting data, communicating with others, and asking questions and further divided into scientific and socially based activities. The aggregated list of activities across all projects is shown in Table 7. If an equal number of people mentioned the activity within a project, the activity that had the most references was deemed more common.

Without exception, the two most common activities across all six projects were data collection and general communication about the project with others, including friends, family, the general public, and decision makers. Whereas the prevalence of data collection as the main activity for citizen science participants is not surprising, the

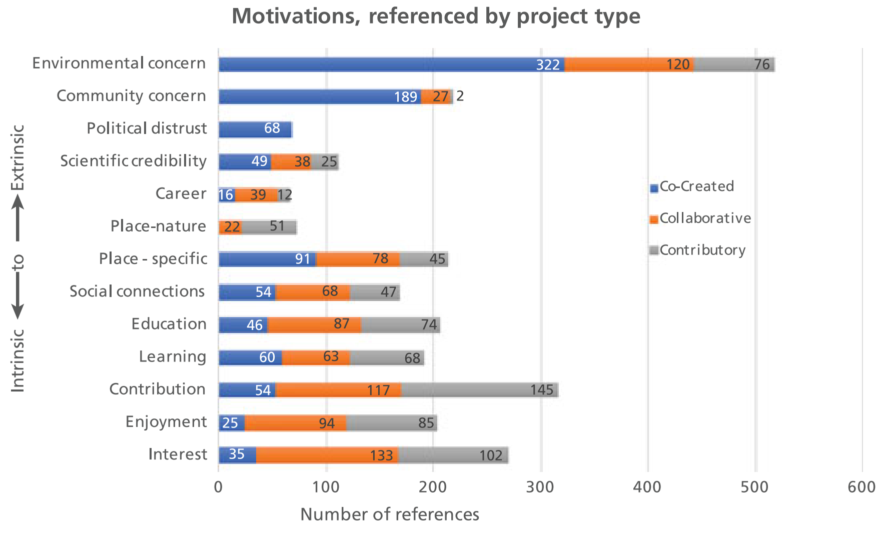

FIGURE 3 Motivations referenced by project type, grouped according to more extrinsic motivations on top, to more intrinsic on bottom [Color figure can be viewed at wileyonlinelibrary.com]

high number of participants who referred to communication between themselves and project leaders/scientists, other participants, and members of the public was surprising and gives added emphasis to the social aspects of science practice. “Learning protocols” as an activity was described by nearly all interviewees, and more than 80% of interviewees described submitting data or reports.

Figure 4 highlights differences across projects, with activities, split into social and scientific practices as determined by the proportion of people (sources) mentioning that activity. Activities that were not directly social or scientific in nature (e.g., learning protocols and habitat improvement) or which had very few sources mentioning them (designing investigations and adapting or modifying protocols) are not included in Figure 4.

For the science-based activities, “exploring data” was more often described in the contributory (NW and MLMP) and collaborative (CoCoRaHS and EELS) projects than in the co-created (ALLARM and GCM) projects, signaling perhaps an insufficient online infrastructure for sophisticated data exploration (this was also mentioned as a common barrier for co-created projects). However, for social-based activities, participants in co-created projects more often described attending meetings and communicating project findings (rather than simply communicating *about* the project), particularly to media, state, and federal agencies, than participants in other project types. This is likely a function of the typical goal of co-created projects to gather and share data with their community to seek answers and solve problems on potentially harmful environmental issues and associated risks. Another interesting observation in Table 6 and Figure 4 is that the science activities considered more difficult and requiring increased critical thinking—such as managing or compiling data, forming hypotheses, and designing investigations—are cited relatively less across all the projects. This suggests that these citizen scientists tended to participate in more routine aspects of science processes such as collecting, submitting, and exploring data.

Perhaps the most interesting finding is that for three of the six projects (GCM, CoCoRaHS, and NestWatch), “using data” to back up a scientific claim or make decisions—typically considered the pinnacle of citizen science project activities—was cited by at least half of participants. However, the ways in which participants used the data they collected looks very different among the projects. For example, one NestWatch participant used data to make better management decisions that will help improve the nesting success of bluebirds. An MLMP participant, concerned with declining monarch numbers, used the data to infer trends over time. A CoCoRaHS participant described numerous uses of the data for commercial as well as public consumption. Interviewees from the EELS project routinely presented the data in classrooms for students to use as part of scientific labs and inquiry

TABLE 7 Descriptions and most commonly reported subnodes coded under the major node "behavior"

"Behavior"	Participant describes...	Sources	References
Data collection[a]	Collecting data (e.g., counting larvae eggs, counting bird eggs, counting eels, recording amount of rainfall)	72	1591
Communicating with others[b]	Communicating general information about the project to others (exclusive of findings)	72	813
Learning protocols	What they did to learn about the protocol or how to participate	70	271
Submitting data or reports[a]	Submitting data or sending out reports	62	214
Communicating findings to others[b]	Communicating findings or project results to others including family, friends, the general public, and decision makers	55	288
Exploring data[a]	Exploring publicly available data from the project, either online or on paper	47	157
Getting updates and feedback[b]	Obtaining updates or feedback about the project	47	126
Recruiting participants[b]	Efforts to recruit people into the project	44	137
Use data[a]	Providing examples of using the data as a source of evidence to defend or critique claims or make decisions	33	102
Training participants[b]	Training new individuals to take part in the project	32	125
Using standardized methods[a]	Their use of standardized tools, methods, or documentation as part of their participation	32	79
Analyzing or interpreting data[a]	Analyzing, manipulating, or interpreting data that he/she has collected	32	71
Coordinating participant activities[b]	Coordinating trainings, events, or data collection from others related to the project	31	164
Asking questions[a]	Asking and attempting to answer questions or choosing or helping to define questions.	30	67
Attend meetings[b]	Attending meetings related to the project.	29	122
Managing-compiling data[a]	Compiling, managing, or organizing their own data or other people's data	28	76
Forming hypothesis[a]	Formulating a hypothesis relative to the project	18	35
Habitat improvement	Activities to improve or restore habitat or local landscape	12	33
Study design investigations[a]	What they did to design their own study such as planning and implementing an investigation, designing data collection methodologies, collecting samples, or data	8	32
Adapt or modify protocols[a]	Things done to adapt or change the protocol	5	10

[a]Scientific-based activities.
[b]Socially based activities.

exercises, although they themselves don't use the data. The ALLARM participant used the data to communicate about the health of local watersheds and the GCM participant used data to enhance scientific credibility when presenting to state and local agencies that have long ignored residents' complaints of toxic pollutants in the air. The fact that participants in all projects described using project data for their own ends is an important finding, because this behavior is typically associated with co-created projects as a way to empower individuals and communities and even help to democratize science (Cooper & Cavalier, 2016). Although not mentioned by everyone, some participants are using citizen science data to deepen their engagement within the project context and in some cases to help make real changes in their communities.

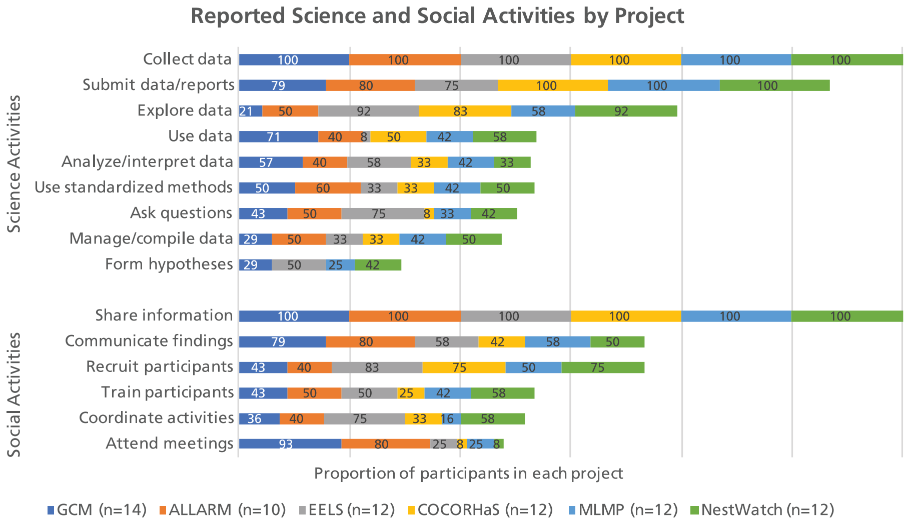

FIGURE 4 Proportion of participants in each project who mentioned conducting social and scientific project activities. ALLARM: Alliance for Aquatic Resource Monitoring; CoCoRaHS: Community Collaborative Rain, Hail and Snow; EELS: Hudson River Eel Project; GCM: Global Community Monitor; MLMP: Monarch Larva Monitoring Project [Color figure can be viewed at wileyonlinelibrary.com]

6 | DISCUSSION

Our study builds on pertinent literature from multiple disciplines to empirically operationalize engagement in citizen science through the analysis of qualitative interviews of 72 participants in six different environmentally based projects.

The depth and volume of interviews allowed for deep examination of the construct of engagement, resulting in a proposed framework to operationalize and identify key aspects of it, illustrated in Figure 5. From our data, we are able to suggest a definition of engagement in citizen science as the "emotional, behavioral, cognitive, and social experiences that initiate and sustain lifelong learning and that are largely influenced by motivational factors." This working definition goes beyond previous efforts to conceptualize learning and engagement in informal settings, particularly from the LSIE strands, through empirical examination of how learners characterize their experiences

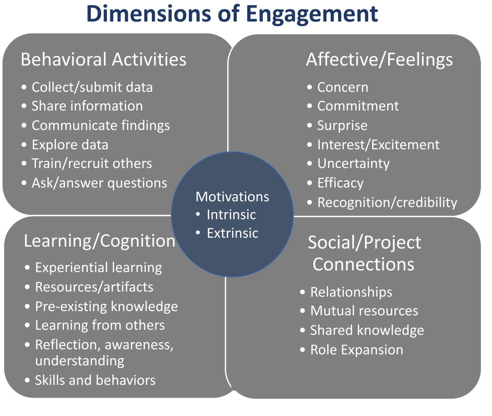

FIGURE 5 Proposed Dimensions of Engagement Framework [Color figure can be viewed at wileyonlinelibrary.com]

with citizen science. Within each dimension of the framework, we provide a list of the most commonly cited examples, in descending order from most to least frequently sourced. These examples should not be considered exhaustive, however. Similar to consensus found in educational research, we find engagement to be malleable, integrally tied to learning and motivation, and dependent on contextual factors such as cultural and ecological influences (Lawson & Lawson, 2013). Each of the dimensions was emphasized differently by interviewees depending on the project, the project type, or even the group structure. For instance, extrinsic motivations were strongest in co-created projects and intrinsic motivations strongest among contributory and collaborative projects; social project connections were strongest among projects operating in group-like structures; and behavioral activities beyond data collection, submission, and sharing information varied widely depending on the project structure, as did sources of learning. We argue that these variations result largely from the unique contexts, both cultural and ecological, of the different projects.

Starting with the cognitive/learning dimension, the majority of interviewees described what we classified to be experiential learning as the main component of their engagement. These results are not surprising given the hands-on nature of citizen science, but few studies have used the lens of experiential learning to examine practice in science (see Brossard et al., 2005 for an exception). Participants also brought a great deal of pre-existing knowledge into the projects, lending support to the importance of building on the interest in science topics as a way to engage learners (Friedman et al., 2008; Hidi & Renninger, 2006; National Research Council, 2009). Our findings also highlight the fact that citizen science is a natural conduit to gaining new content-specific knowledge and increasing awareness of ecological principles and connections, which has been described elsewhere (Bonney et al., 2016; Jordan et al., 2011). In thinking about their engagement, participants also described an acute understanding of their role in citizen science, and in some cases to the scientific enterprise more broadly. Moreover, many interviewees, especially in the contributory and collaborative projects, expressed satisfaction with their current role, knowing that their data were being compiled and stored in a central location, and most importantly, being used to answer important questions that were personally relevant and meaningful to them.

One of the most interesting results of this study was the importance of the social dimension, particularly social relationships between participants and project leaders for sustaining and enhancing engagement. Whether participants are working alone or alongside others, having strong, respectful relationships can elevate trust between participants and project leaders. Charismatic leaders add to the appeal of relationships, but what we heard most often was a sense of mutual respect, the importance of being heard, and the value of timely feedback. These are not new ideas for citizen science, but are excellent reminders that meaningful relationships take continued work to maintain over the long term. Another important finding about the social dimension of engagement was the number of participants who described ways that their roles in the project changed and sometimes expanded over time, for example, through increased responsibility such as taking notes at a meeting, compiling data, or training new participants. Such role changes could be further explored in the context of Lave and Wenger's (1991) description of legitimate peripheral participation, where group members share tools and practices that, over time, support transitions from peripheral/novice members to core/expert membership in a community. Leveraging social and project connections and the tools of scientific practice also help to reinforce notions of a community of practice, even if an intentional community of practice is not the goal of such efforts (Wenger, 1998).

Very little is known about the role of feelings and emotions with respect to engagement in citizen science (Larson, Cooper, & Hauber, 2016). Considering the affective dimension, however, our data reveal a myriad of feelings intricately tied to project engagement. Citizen scientists are extremely committed individuals who care deeply about their local environment, their community, and the quality of the data they collect. They experience positive and negative stimuli that influence emotional dispositions including interest, excitement, surprise, efficacy, and uncertainty. In turn, these emotional dispositions can influence attitudes, values, behaviors, and overall experiences (Fishbein, 2008), which we argue play an important role in project engagement.

Analysis of motivation to participate showed that, as found in previous research, motivations are complex and multifaceted. Aggregated across projects, motivations were driven mostly by environmental concern, contribution, and interest. One notable finding was the prevalence of extrinsically leaning motivations among co-created projects, versus intrinsically leaning motivations in contributory projects. Research suggests that behaviors driven by intrinsic motivations (pleasure, interest, and enjoyment) are more likely to be sustained over time than behaviors driven by extrinsic motivations such as fear, guilt, or worry (Ryan & Deci, 2000). Although further study is needed to fully understand the role of motivation in engagement, data from these interviews suggest that motivation is a key facet of engagement, and likely influential to all the other dimensions; hence its central location in Figure 5. The centrality of motivation in engagement also has been described by Raddick et al. (2013), who suggest that deeper involvement may be driven by different motivations.

The behavioral dimension of engagement includes the activities and tasks that participants do on behalf of the project. To say that these citizen scientists are far more than data collectors is an understatement (Eitzel et al., 2017). Within each project, interviewees described a multitude of tasks ranging from data collection to communicating with others to using data for backing scientific claims. Our research paints a picture of the diversity, applicability, and importance of citizen-collected data for all participants in these projects, irrespective of project or project type. Yet, across the field of citizen science, there appears to be growing emphasis on wanting participants to do more, participate more often, and engage in deeper ways. Interestingly, however, across all projects in this study, very few participants reported engaging in what might be considered higher order science process activities such as forming hypotheses or designing original investigations. Across the interviews, participants described being happy in their niche as "data collectors" (even when some did more than collect data). In fact, most participants had little desire to conduct statistical analyses or read technical papers, let alone conduct their own investigations—they were happy to "leave that to the scientists." Similarly, in examining online citizen science projects, Curtis (2015) emphasized that the goal for projects should not necessarily be to encourage movement to upper levels, because many participants are happy to contribute simply at a basic level. This begs the question, why should projects that aren't developed to support higher order process skills be expected to deliver on such lofty goals? Perhaps this is more probable in the Irwin (1995) tradition of citizen science, which focuses more on participant engagement in policy than in data collection, or the "activist" form of citizen science as described by Cooper and Cavalier (2016) where individuals are taking leading roles in influencing decisions that directly affect them. However, at least for more traditional forms of citizen science, projects should strive to provide support for the *potential*—rather than the *expectation*—for participants to move within different levels of engagement in a manner that suits their time commitments and inclination.

Importantly, our findings from the behavioral dimension leave us wondering about the precision of the typology described in Bonney, Ballard, et al. (2009) and Shirk et al. (2012) that is based on involvement with the science process. Whereas Bonney, Ballard, et al. (2009) hypothesized that co-created projects engage their participants more deeply in the science process, the behavioral data presented here are less definitive because few obvious patterns were detected among co-created, collaborative, and contributory project types with respect to science process activities. Our data highlight the diverse and complex ways that participants in different projects engage in scientific and social practices. While useful for thinking about different project structures, the passage of time and empirical data has shown that the typology oversimplifies the complexity of how individuals engage in citizen science. The Dimensions of Engagement framework is a first step toward demonstrating the complexity of not only how participants engage, but also the factors that help them reflect on their engagement.

Despite the richness of our data, our work does have some limitations. These center around its qualitative focus, which can be subjective, and the fact that the qualitative responses were then quantified into the source and reference counts. For example, Maxwell (1992) describes interpretative validity, or researcher bias, where data are selectively chosen or interpretations of meaning subjectively formulated that are consistent with researcher expectations. Although we made efforts to minimize researcher bias through peer debriefing and interrater reliability, it can never be completely eliminated. Another limitation is generalizability to external communities, which is not recommended in qualitative studies. Internal generalizability, that is making inferences about a participant's life that were not expressed during the interview, also is a common limitation in qualitative research and one that we sought to minimize through our analysis processes. Finally, because this study did not use a grounded theory approach, we acknowledge that the interview protocol, which was based on existing literature and our own experiences, reflected our a priori perspectives. This, in turn, influenced the questions we asked, thereby limiting the universe of responses.

7 | CONCLUSION

Our findings build on existing literature to create a clearly defined framework that operationalizes citizen science engagement across environmentally based citizen science projects. We examined the literature base on student engagement to frame the dimensions for affective, cognitive, and behavioral engagement, all of which played a prominent role in the projects we studied. SLT and Wenger's (1998) early work on communities of practice provided structure for understanding important social project interactions including relationships, using mutual resources, sharing knowledge, and role expansion. These seem especially rich for a deeper and more nuanced examination, particularly with studies using social network analysis to understand online interactions.

The Dimensions of Engagement Framework highlights the multitude of ways that participants in citizen science projects contribute themselves emotionally, behaviorally, cognitively, and socially to this collective endeavor. Citizen science practitioners can use the framework to examine what aspects of these dimensions are well facilitated by their project and where additional effort could be made to leverage other dimensions that can enhance participant experiences and project relevance. Although this study was not aimed at developing specific instruments to measure engagement, recent efforts through the Developing, Validating, and Implementing Situated Evaluations (DEVISE, NSF-DRL #1010744) project have provided the field of citizen science with a suite of instruments to measure constructs well aligned to our framework dimensions including interest in science and the environment, efficacy, motivation, skills of science inquiry, and environmental stewardship (Phillips, Porticella, Constas, & Bonney, 2018).

We hope that this framework will facilitate the development of improved methodologies for the continued systematic study of citizen science globally. Future work should continue to expand or modify the framework in a larger population so that generalizations across the field can be inferred and utilized. With additional modification, the Dimensions of Engagement framework may also prove useful in other forms of informal science learning.

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