Interaction design of community-driven environmental projects (CDEPs): A case study from the Anacostia Watershed

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Water is becoming an increasingly precious resource across the world, but citizens can help ensure good-quality water by helping to manage their local watersheds. Local, place-based advocacy projects that are strongly grounded within their geographical area have the potential to inspire environmental change as citizens come together to collectively address environmental challenges in their own neighborhoods. However, less attention has been given to these small, intensely place-based local projects. Our research focuses on the interaction design of technology to support small, local, place-based “community-driven environmental projects” (CDEPs) for water management in the Anacostia River Watershed. Analysis of case study data collected over a 3-y period to identify the needs of CDEP members provides the basis for the interaction design of technology known as NatureNet to support CDEPs. From this research, six design insights for supporting CDEPs are suggested: (i) a shared common endeavor connected to the identity of the members, (ii) ways for newcomers and experienced participants to share a common space and function together effectively, (iii) support for different sources of knowledge, (iv) different modes of participation and ways for participants to express themselves, (v) different ways to express status through diverse opportunities, and (vi) support for porous and changing leadership roles. Taken together, the findings from our study suggest a preference for technology-lite, highly flexible software that supports the diverse needs of CDEP members.

environmental citizen science | interaction design | community-driven environmental projects | CDEPs

Poor water quality (1, 2) and poor air quality (3) affect people in many parts of the world in a multitude of fundamental ways, including by worsening people’s health, impacting food sources, and reducing biodiversity. One of the most straightforward ways to improve air and water quality is to reduce pollution from towns, cities, roads, and industrial and commercial activity. Pollution is a concern to many, but knowing what to believe and how individual actions might have an impact can be challenging (4, 5).

A powerful solution is to encourage citizens to engage directly with local, community-based efforts, such as monitoring, to improve their local environment (1, 3, 6). Multiple benefits result. First, through engagement, people learn about the local effects and challenges of pollution in their neighborhoods and on the people that live there. Second, citizens are able to see opportunities to make a difference by contributing, either individually or collectively, to improve their local environment and make their neighborhoods more sustainable (4, 5). Third, if individuals and groups across the country and the world become involved in local environmental and sustainability activities, a broad global impact could result.

In our research, we have seen citizens take on various kinds of local environmental projects. Here is one such project that demonstrates the power of a citizen to produce significant change in a short time in his local neighborhood:

Fred teaches plumbing at a local community college. He is a very successful instructor who, year after year, has proudly graduated cohorts of trained plumbers knowledgeable about installing and maintaining fittings in all kinds of buildings. However, over the years, Fred has noticed that there is an unaddressed problem in his local neighborhood in the District of Columbia metro area. He sees that individual houses are not adequately coping with the large amounts of rainfall generated by big storms. Huge amounts of water are flooding the streets and gushing into the local Anacostia River, carrying all kinds of junk and pollutants. As a professional plumber who studied watershed management in an Anacostia Watershed Stewards program, Fred understands the best solution is to limit the amount of water overflowing from individual lots and into the street, mitigating the chance that the storm water runoff will overflow the municipal sewage system and cause untreated water to flow directly into the river. One way to do this is to train local residents to install rain barrels on their property to catch the water running off their roofs. Fred embarks on a project to train his student plumbers to, in turn, train local residents about how to install their own rain barrels (Fig. 1). In the course of two weekend sessions, over 300 rain barrels are dispatched for installation. The next step is to record the number of barrels installed by citizens and the amount of water collected.

Fred the plumber’s story is grounded in research observations in which we work with local citizens who train to manage watersheds and, in turn, then train others in their community to manage parts of their watershed. The trainees are known as Anacostia Watershed Stewards because they live in the Anacostia River Watershed. Part of their training involves them in projects with small, local groups from their community, usually involving three to five participants. Each project team plans and carries out self-designed “community-driven environmental projects” (CDEPs) supported by digital technology called NatureNet (<https://www.nature-net.org/>). CDEPs sometimes also harness other parts of the Internet, such as Google Maps, spreadsheets, texting, email, and so on.

In our research, we recognized that being local and place-based are key features of CDEPs. Much as political power is derived from local areas and political concerns are driven by local issues, we observe that the key to understanding what

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Fig. 1. Local residents collect and learn to install rain barrels. Details of the event were posted to NatureNet (A) and included pictures of people learning how to install the rain barrels and socializing during the event (B).

contributes to successful CDEPs revolves around understanding the needs of the small, local groups involved in the CDEPs.

CDEPs are distinct from most other citizen science and local advocacy projects in that they are intensely place-based and strongly grounded within the geographic and cultural spaces of local communities. CDEPs develop from the initiative of local individuals or small groups; neighbors and neighborhoods are at the very core of these projects. Leadership is often light and may be distributed rather than strong and centralized. CDEPs tend to be small, in terms of both the number of participants and the scale of the effort they undertake. They may be ephemeral and happen only as needed, or they may be ongoing with intermittent and varying degrees of activity. While some citizen science and other kinds of projects may share some of these similarities, we argue that most citizen science projects are different from CDEPs in terms of their mission, scale, and technical infrastructure.

In this paper, we examine the technical and social affordances of the NatureNet technology platform that is designed to support the CDEPs in the Anacostia Watershed (<https://www.anacostiaws.org>) in Maryland and the District of Columbia in the United States. We also briefly examine how the design of software to support these CDEPs differs from the design of larger citizen science projects. Of course, all projects are different, but to illustrate this point, we selected iNaturalist (<https://www.inaturalist.org>) for comparison because it is considered successful based on its longevity, number of participants, amount and quality of data collected, and support for smaller taxon or geolocation-based projects. We argue that even though iNaturalist supports small community groups, CDEPs require a different way of thinking about interaction design of the software platform and the project itself. Highly flexible, easy-to-use technology is needed that we refer to as “technology-lite.”

Specifically, we ask: What are the interaction design affordances needed to support CDEPs, and how are CDEPs different from a large citizen science project like iNaturalist?

The roadmap for this paper begins by defining citizen science and CDEPs, which we later firm up with research evidence. Next, we describe the Anacostia Watershed Society and the Anacostia Watershed Stewards Academy (WSA), which represent the context for our research. We then introduce the NatureNet platform used by CDEP members. Using affinity space (AS) theory for examining data collected from a case study, we identify key dimensions for successful CDEPs. Based on the case study analysis, we discuss key features of interaction design to support CDEPs. We also use these dimensions to compare and contrast how CDEPs and iNaturalist differ as a way of illustrating how CDEPs are different from large citizen science projects. The paper ends by proposing six “design insights” for CDEPs and suggests future research needed to further substantiate these insights.

Citizen Science and CDEPs

We consider CDEPs to be a special case of the broader category of citizen science and environmental education and advocacy projects. In this section, we define and provide a brief overview of citizen science projects, followed by a discussion of the similarities and differences observed in CDEPs. Later, we elaborate on these observations by drawing on AS theory (7, 8).

Citizen Science. Citizen science involves a partnership between citizens and scientists to carry out a scientific project (9–11). There are thousands of citizen science projects involving millions of participants researching environmental issues, biodiversity, and other areas of science (12). During the past 10–15 y, many citizen science projects have employed digital technologies, particularly smart phones and the Internet, to leverage their

reach and impact across time and geographical zones. While scientists have employed ever-increasingly sophisticated technology for decades, smart phones and the Internet have enabled scientists to partner with hundreds, thousands, and even millions of citizens in ways that could only be imagined 15 y ago.

A few examples of citizen science projects that focus on nature and the environment include the following: iSpotnature, developed for learners studying biology and ecology at the Open University in the United Kingdom (13); iNaturalist, developed to document biodiversity (<https://www.inaturalist.org>); eBird, developed to collect data about bird occurrences (14); and GalaxyZoo, developed to help tag already collected astronomy data (15), which later scaled to form the Zooniverse platform (16), which supports a wider variety of projects. A key aim of these projects is to leverage the power of the crowd to crowd-source and scale their ability to collect and/or analyze very large volumes of trustworthy data for scientific research (17, 18). While some citizen science projects have strong community components (e.g., local bioblitzes in iNaturalist, project creation platforms in Zooniverse) (16), few, if any, of these projects set out from the beginning to develop technology that deliberately encourages development of small, place-based, local community projects. Although some researchers do recognize the importance of community aspects in relation to mobile applications [e.g., Community2Go (19), social creativity support (20), as a way to increase participation (21, 22)], they do not deliberately seek to support CDEPs.

CDEPs. CDEP is a term that we coined to describe how some communities drive the development of their own small environmental projects (23, 24). These projects arise from needs identified by community members, who then find ways to develop projects to address these needs. Typically, projects are local and place-based, but they may take advantage of various forms of technology, especially digital technology. The examples that we discuss are characteristically small in terms of the number of participants involved (often fewer than 5, usually under 10, and rarely more than 20 people). They could be larger by becoming conglomerates of several distributed projects.

We characterize a CDEP as a “small project created by a small group of participants who emerge informally, driven by the needs of a local place-based community.” The place where the group comes together has a strong influence on who joins the CDEP, its goals, and its leadership. In the case of the Anacostia Watershed Society, potential organizers emerge from the WSA programs. The overall aim of these CDEPs is to contribute to the health of the Anacostia Watershed (<https://www.anacostiaws.org>) in general and to a particular local part of the watershed (e.g., local stream, section of the river) specifically. Members of these CDEPs may focus on different activities, including collecting trash, removing invasive species, recording and monitoring species, installing and monitoring rain barrels, creating rain gardens, planting and documenting trees, leading educational walks or boat trips, and much more.

As exemplified in the earlier excerpt regarding Fred the plumber's CDEP, carrying out CDEPs involves significant amounts of leadership, effort, and problem solving on the part of community members, who typically bring diverse interests, skills, and backgrounds to the CDEP. CDEP work includes the following:

- i) Identifying a feasible project to address a need in the local community
- ii) Securing the needed resources to carry out the project (e.g., supplies, space, knowledge, skills, funding)
- iii) Motivating and engaging community members to get involved
- iv) Organizing the work, people, and materials
- v) Carrying out the project
- vi) Gathering and analyzing data from the project
- vii) Communicating the process and results to others who can use the information (e.g., WSA participants present their projects at follow-up meetings with peers from their program, advocacy groups, larger citizen science projects, and local state government officials interested in environmental issues)

CDEP members may collect data about a wide variety of issues, including, for example, the amount of trash collected, number of species identified, and number of rain barrels installed. These data may be used for science (e.g., to document species, might become part of a larger citizen science initiative), for advocacy (e.g., to get funds for cleanups, to provide pressure for changes to laws), or to educate school students and other citizens about their watershed. While many of these projects are similar to citizen science projects in that accurately recording, analyzing, and documenting the data are important, the scale of the effort is usually modest, even compared with small citizen science projects. If local governments or other nonprofit organizations pay for the activities of the CDEPs, then they typically require them to collect and submit data. In such cases, funding is modest, and the scale of the project is small.

The concept of a CDEP builds on similar ideas from health (25), national neighborhood crime watch programs (nnw.org), development (26), and management (27) in the context of community-driven development (CDD). CDD projects, like CDEPs, are based on the underlying philosophy that communities are the best judges of how such projects can best impact and improve the lives of citizens in their own communities. Therefore, the community should have responsibility for planning, building, monitoring progress, and evaluating the projects. The research that forms the focus for this article involves a collaboration with the Anacostia Watershed Society's (<https://www.anacostiaws.org>) WSA, which we briefly describe below, along with the NatureNet technology that supports the WSA's CDEPs.

The WSA

The Anacostia Watershed Society is a nonprofit organization based in Bladensburg in Maryland. Its mission is “to protect and restore the Anacostia River and its watershed communities by stopping pollution now, restoring natural systems, and reconnecting the community to the river” (<https://www.anacostiaws.org>). The Anacostia River flows into the Potomac River and then into the Chesapeake Bay and out to the Atlantic Ocean. While parts of the Anacostia Watershed suffer greatly from pollution, a recent bioblitz held in the area identified 522 unique species (<https://www.anacostiaws.org>). The Anacostia Watershed Society employs educators and naturalists to educate the community about watershed management through a program called the WSA.

The WSA is a volunteer training program that was created before our research partnership began with the Anacostia Watershed Society. It is a citizen-centered program designed to equip individuals with the resources, tools, and knowledge to serve as leaders in their local communities on watershed issues. Stewards participate in eight to 12 class meetings and experiential outings. They then have up to a year to develop and complete a project in their own communities that involves storm water management and community education. These projects cover a wide range of topics ranging from educational boat tours to creating, planting, and maintaining rain gardens in local churches or schools and more.

The trainee stewards engage members from their local community to participate in their CDEPs, which they lead and organize. Upon course and project completion, the stewards become master watershed stewards, qualified to lead other community-driven projects.

A 2014 survey of three WSA programs in Maryland and the District of Columbia revealed that trainee stewards are predominantly female (64% female and 36% male), white (78% white and 22% nonwhite), highly educated (89% reported at least a college degree), and older (mean age of 51.5 y and median age of 53.5 y) (28). Although diversity of participation remains low, efforts to recruit underrepresented populations, such as new immigrants, have recently generated increasingly diverse participation in the program.

NatureNet

Originally, the NatureNet (<https://www.nature-net.org/>) software platform was developed as a tabletop application and piloted at a nature preserve in Colorado in 2013 (29). Visitors to the preserve

were invited to borrow mobile devices from the visitor's center and to submit nature observations as they walked trails. The research team engaged a group of naturalists to work with them to design iterations of NatureNet through participatory design (30, 31). The naturalists shared numerous design ideas, such as creating scaffolded activities so that visitors had specific goals as they walked through the nature preserve, building in question and answer components and quizzes to support engagement and learning in the nature center and facilitating home use of NatureNet through a website to reinforce ties after visitors left the preserve (17, 18).

In the spring of 2015, the NatureNet research team began working with the Anacostia Watershed Society to collect data to modify the NatureNet platform to support the WSA programs, especially the CDEPs, and other local projects. Through working with the WSA, we realized that supporting the CDEPs initiated by the watershed stewards was different from collecting data for typical citizen science projects (12). The WSA educators also wanted features to support the WSA CDEPs, such as project folders for each watershed steward.

Today's NatureNet consists of a website (<https://www.nature-net.org/>), an interactive display in a community center and for use in WSA classes and on computers at home, and iOS and Android mobile "apps" that support collection of data and community interaction for CDEPs. Fig. 2 shows the NatureNet website and the mobile app. Options to "Explore", go to "Projects," submit "Design Ideas" to help tailor the software, go to the "Communities" page, and submit "Contributions" are shown along the top of the website. Examples of pictures contributed by project participants, with likes and comments, are shown in the Fig. 2A, *Left*. Fig. 2A, *Right* shows a map with locations where data were collected.

The Projects page lists the projects for different CDEPs, where the CDEP members can store data, notes, or project plans, for example. Project members can also create new projects and submit design ideas to request feature changes to the NatureNet platform or report usability problems. The software development team acknowledges receipt of design ideas and logs them for discussion, and schedules appropriate software development resources. However, like other projects that involve citizens (22, 32), getting WSA CDEP members to use digital technologies like NatureNet can be challenging. CDEP members work on projects on their own time while doing other jobs, so time, family commitments, technology access, or slow Internet

connections, for example, may deter participation. Our research team is aware of these issues and adapts the platform to alleviate some of the barriers by, for example, making registration and sign-in simpler and generally making the technology increasingly tailored to the particular needs of participants.

Theoretical Frameworks

Throughout our research partnership with the Anacostia Watershed Society, we have looked for theory that can guide us to understand and respond to the stewards' needs. For example, we explored Fischer's "communities of participation" (20, 33), which advocates inviting community participants to contribute to early minimalist prototypes with the aim of the community taking ownership of the software. This approach was helpful for engaging watershed stewards who were already quite technology-savvy, but some stewards had difficulty in determining what kinds of suggestions to offer.

We also explored crowdsourcing to capitalize on the "wisdom of the crowds" (17, 18), with limited success. Asset-based community development (ABCD) (26) has additionally been a useful theory for understanding ways to encourage and help CDEP members to look within their own community for resources and skills before seeking outside support. There is a tendency for local, community-driven groups to underestimate the skills and knowledge that they have within their own group. For example, there may be group members with technical skills or management skills that could be useful to the project. The ABCD theory helps raise awareness about this tendency so that project leaders first look within their own community for resources and then to closely related communities with which they engage (e.g., Chesapeake Bay Trust programs) and local government programs before spending time writing proposals for resources that they do not need, may not get funded, and take time away from more productive activities.

Communities of practice (COP) theory (34–36) implicitly influenced the design of early versions of the NatureNet platform before we realized that the feedback from CDEP members seems to require more support for diversity and flexibility in the widest sense, as well as low barriers to entry to use the technology. In other words, WSA CDEP members asked for a technology-lite version of NatureNet. In contrast, COP theory has been most successful in business and marketing contexts

Fig. 2. NatureNet is composed of a website (<https://www.nature-net.org/>) available on laptop computers and a large display integrated into a community center (A) and a mobile app available for iOS and Android (B).

(37), which are more structured and hierarchical (38). In addition to COP theory, the reader to leader theory (watershedinfo.umd.edu/) influenced early ideas about how to provide scaffolding for participants as they increased their knowledge and use of NatureNet. This social and technical scaffolding aimed to support participants as they move from being readers, to being casual contributors, to being regular contributors, to being collaborators, and then to taking leadership roles.

We also recognized that CDEPs can be viewed as rich learning contexts for interest-driven environmental learning. Clegg et al. (24) found that stewards' learning happens in three phases: First, stewards develop an awareness of watershed issues through participation in an 8- or 12-wk set of introductory courses in the WSA program; second, awareness leads to a collaborative learning phase as stewards work with each other to develop projects related to storm water management in their own communities; and third, stewards return to their communities with awareness of themselves as a "community force" (24). Design affordances of mobile and community-based technology can help to support participants at these different stages (24).

Having explored these theories, we found that AS theory (7) speaks more directly to the needs of most CDEP members. Therefore, this analysis began with synthesizing relevant AS literature (7) into a set of six dimensions most relevant to the context of CDEPs. We then used these dimensions to deductively code the interviews with the two WSA naturalists and a sample of CDEP project members. Next, we applied the dimensions to an analysis of iNaturalist with the aim of justifying our assertion that CDEPs are different from large citizen science projects like iNaturalist.

The AS theory suggested that the following are needed to support WSA CDEP projects:

- i) A shared common endeavor connected to the identity of the members
- ii) Ways for newcomers and experienced participants to share a common space and function together effectively
- iii) Support for different sources of knowledge (e.g., deep as well as broad knowledge, internal knowledge from the project, distributed knowledge from different sources, tacit knowledge)

- iv) Different modes of participation and ways for participants to express themselves
- v) Different ways to express status through diverse opportunities
- vi) Support for porous and changing leadership roles

Results

In the Introduction to this paper, we asked: What are the interaction design affordances needed to support CDEPs, and how are CDEPs different from a large citizen science project like iNaturalist? In the discussion that follows, we focus on how the interaction design of NatureNet does or could support WSA watershed management CDEPs. The discussion is framed around the six dimensions revealed by the AS theory analysis. It also draws upon differences with iNaturalist (<https://www.inaturalist.org>).

A Shared Common Endeavor Connected to the Identity of the Members. CDEPs focus on community and the place where the community is located. Maps are therefore an obvious feature. However, our observations suggest that much more important than Google Maps are ways of finding information about the community, local resources, others who could be involved in a CDEP, and easy communication. Simple websites with community information are an obvious addition to share information. For instance, a website was developed for WSA CDEP members (watershedinfo.umd.edu/) to provide links to groups that the CDEP members might want to contact, such as the Chesapeake Bay Trust, various local protection groups along the watershed, local government offices, other CDEPs, local directories, and Environmental Protection Agency maps.

NatureNet also offers participants the opportunity to comment on and shape the platform to better meet project needs through a Design Ideas feature (Fig. 3). However, in general, the Anacostia CDEP members are not technology-oriented, and many did not understand what was expected as a "design idea."

Similarly, NatureNet contains a feature to enable CDEP members to put their project information into folders online. This feature was requested by a WSA naturalist trainer who strongly encouraged the stewards to use it. Even so, many stewards preferred not to put their projects online even when a folder was created specifically for them. We will continue to monitor use of this feature, which may be most relevant to long-term projects.

Fig. 3. Design ideas feature shows ideas that are under discussion (A) and archived ideas that are either completed or put on hold (B).

Some WSA CDEP members also use technology-lite platforms like Facebook (39) independently or along with NatureNet.

Ways for Newcomers and Experienced Participants to Share a Common Space and Function Together Effectively. Participants in CDEPs vary in terms of their knowledge about the topic, confidence with technology, diversity of experience, ethnicity, and culture. Therefore, having as few barriers to entry as possible is desirable. For example, registering, signing in, and providing a personal profile all require effort and can inhibit participation. For this reason, the NatureNet development team decided to opt for open entry.

iNaturalist and many larger projects provide help and mentoring for new users in the form of online help or a chat and guided tours. While these approaches help users who have some experience of technology, they are threatening to some CDEP participants. Recently, we tried using a short video clip to introduce the NatureNet software and motivate participation. We are monitoring the impact of this approach.

Language translation may be helpful for some participants, but language translation alone is not enough. More attention to a community's culture and the ethnicity of participants is needed. For example, NatureNet researchers have tried to engage participants from minority and underserved groups, such as African Americans and Hispanic Americans living close to the Anacostia River, in issues that are particularly relevant in their neighborhoods. Changes to the software have not yet been explored in depth, but working with local church groups and engaging leaders from these communities have been successful for drawing in people who probably would not otherwise participate. In terms of software design, the winning strategy appears to be flexibility, a strategy strongly advocated by AS theory (7, 8).

Supporting Different Knowledge Sources. Providing access to and respecting a wide range of different knowledge sources, including trusting local knowledge, was requested by CDEP participants as mentioned earlier. For example, discovering that a particular church community is interested in an area of the stream where a CDEP is located may be used to entice more participants into

participating in the CDEP. Similarly, developing web pages with information that focuses on small local areas was requested.

Different Modes of Participation and Ways for Participants to Express Themselves. Enabling participants to communicate and contribute in different ways respectfully addresses diversity in terms of participants' skills, interests, time, needs, culture, knowledge, and technical "know-how." Some ways that designers make it easy for participants to link to other citizen science and advocacy groups include through the use of Facebook, Instagram, and Flickr for discussions and sharing photographs. iNaturalist also uses email, Twitter, and chat to publicize its featured contribution of the week and other messages. The NatureNet platform has been designed to encourage participants to help others by adding comments to photographs, as well as liking and offering design ideas (Fig. 4). Some of the other approaches just mentioned are also being explored.

Different Ways to Express Status Through Diverse Opportunities. Many participants want to learn and improve their knowledge and be recognized for their contributions (22). Some of the large citizen science apps have strategies to support this need. For example, iNaturalist has capitalized on the social interaction of participants to comment on contributions, help classify contributions, and confirm contributions to be of research quality. The incentive for doing this for some users is to gain more prominence on leaderboards. iSpotNature has a different reputation system that takes biological expertise, helping others, and contributing to iSpotNature into account.

At present, NatureNet does not employ such strategies because the CDEPs that it supports are too small. Furthermore, research suggests that emphasis on competition (e.g., in leaderboards) can create threatening environments, particularly for underrepresented groups and women (40). Instead, NatureNet relies on the community to comment on contributions, as mentioned above, which can have the effect of informally providing opportunities to improve one's status within the community.

Supporting Porous and Changing Leadership Roles. We observe that leadership in CDEPs is often distributed. For example, WSA stewards

Fig. 4. Example on NatureNet showing (circled in red) liking behavior in the map (A) and commenting behavior in the expanded post view that includes a project description, a preview of uploaded project Portable Document Format files, and the option to download (B).

become project leaders who have the passion and energy to form a group and develop a CDEP. As the group works together, other members may take on specific leadership roles for particular aspects of the project. For example, in a rain garden project at a school, a teacher may provide leadership by gaining permission for locating the project on the school grounds by approaching the head teacher or school governing board. A participant who is good with finance may lead on working out the cost of making the rain garden and develop a budget to support the project. Participants in Anacostia Watershed projects have told us that they would like more support for different leadership roles (e.g., links to templates for designing websites and spreadsheets for making budgets). We are determining how best to provide this support.

Discussion

In this paper, we define a CDEP as a project that is typically small in scope and involves only a few participants who come together informally in a local community to address a local need that is strongly place-based. We argue that CDEPs have different interaction design needs from most large citizen science projects like iNaturalist. Primarily, our research suggests that CDEPs need highly flexible software that is very easy to use (i.e., technology-lite) and that supports diversity of interests, skills, technical experience, and cultures and small, short-term projects.

Data collected during our 3-y study led us to examine several theories to understand CDEP members' needs. This paper describes the result of an in-depth analysis framed by AS theory. In sum, this analysis speaks to the need for different forms of flexibility. Further research is needed to test the efficacy of the six design insights identified from this research in other contexts, as well as to refine them.

Compared with a project like iNaturalist, we observe that CDEPs are small and may cover a wide range of topics without feeding into a central mission. It is therefore questionable whether standardized, one-size-fits-all software support is appropriate. While iNaturalist provides a useful starting point for comparison, more research is needed to compare CDEPs with other citizen science and advocacy projects. Future research will test the efficacy of the definition of CDEPs using qualitative and quantitative experimental methods. We will also compare CDEPs at the Anacostia Watershed with those from other contexts.

Other areas of future work will include validating the effectiveness of CDEPs by developing metrics to describe their success. We will report on the impact of CDEPs of different sizes and different life spans. Some may be short-lived and benefit from software that is designed explicitly for that kind of interaction (41).

We are also especially interested in the role of CDEPs in different kinds of communities, such as established versus newly forming communities, homogeneous versus heterogeneous communities, communities with high versus low socioeconomic resources, and ethnically diverse communities.

CDEPs have, we believe, the power to educate people about environmental issues and to help them to see and become engaged in local environmental issues. Collectively, CDEPs could have a global impact. While many factors influence the uptake and success of CDEPs, good interaction design has a major role as society increasingly relies on technology.

Materials and Methods

To understand, identify, and define WSA CDEPs, we carried out a case study over the 3 y of the project and analyzed some of the data using AS theory (7, 8) as described below.

Case Study. Case study methodology was appropriate for this study because the concept of a CDEP is new and not well understood; thus, identifying variables for an experimental study is premature (2, 42–44). Some researchers note that case study data are often impressionistic, particularly in the early stages of a study (35). Other researchers identify specific data sources, such as documentation, archival records, interviews, direct observations, participant observation, and physical artifacts, each of which has its own strengths and weaknesses (2). Case studies are also believed to offer a reasonable approach for studying phenomena in real-life contexts in which the boundaries between the phenomena and the context are unclear (2). Analyzing case study data involves giving meaning to impressions that may be first impressions rather than following a strict protocol (35). The data collection process tends to be intensive, concurrent, interactive, and iterative (33).

The case study method allowed for detailed contextual analysis of events and relationships that occurred over multiple cohorts of WSA volunteers and reflects the complexity of developing and implementing local environmental projects. Our approach involved two members of our research team participating in a WSA cohort and completing CDEP projects (2). Additionally, between May 2015 and March 2018, the research team collected data from 10 cohorts of adults participating in the WSA ($n = 76$ total, in cohorts ranging from four to 15 participants), as well as two instructors and 15 master stewards who had completed CDEPs. The University of Maryland, College Park Institutional Review Board approved the study to work with human subjects through expedited review. The aforementioned participants who took part in the WSA sessions, including using NatureNet technology, provided signed consent forms approved by the University of Maryland, College Park Institutional Review Board. During the past 2 y, 72 projects have been initiated, some by pairs, of which 18 projects have been completed. The others are still underway.

The data collected include documents, archival records, interviews, direct and participant observations, and artifacts as described in [SI Appendix, Table](#)

Table 1. How the six dimensions from the AS theory analysis are reflected in the interaction design of iNaturalist

AS dimensions	iNaturalist
Shared common endeavor connected to the identity of the members	Participants join an already defined endeavor stated in iNaturalist's mission statement
Ways for newcomers and experienced participants to share a common space and function together effectively	iNaturalist's experienced users help newcomers via established tasks, such as validating data to climb up leaderboards
Support for different sources of knowledge (e.g., deep as well as broad knowledge, internal knowledge from the project, distributed knowledge from different sources, tacit knowledge)	Different types of knowledge are formalized in iNaturalist (e.g., identification guides, rules for engagement); there is support for knowledge distribution (i.e., sharing) through the data validation process and social network
Different modes of participation and ways for participants to express themselves	Participation and expression on the platform are quite standardized; there is scope to ask questions and comment on data collected by others, and there are different language versions
Different ways to express status through diverse opportunities	Status is defined by positions on different leaderboards; status must be earned, and competition is strong
Support for porous and changing leadership roles	iNaturalist's directors take a prominent and active role within the iNaturalist community; they comment, send out messages in response to suggestions from the community, organize and participate in bioblitzes, and attend meetings and conferences; other individuals can take leadership of bioblitzes and in other projects that have been created on the iNaturalist platform

51. While all these data inform our understanding, in this paper, we focus on the analysis of the interviews using AS theory.

AS Analysis. ASs are a theoretical lens used to understand spaces where people engage in learning. Rather than strictly defining a set of people who are the prototypical learners, the theory instead describes a set of conditions, usually in online spaces, that are conducive to the formation of productive learning communities. While, historically, ASs have been described as online spaces, including online gaming groups and communities supporting the writing and distribution of fan fiction, the theory focuses on the interests of the participants, so it can be used in many different contexts where interest drives or guides participation and activity (7).

Analysis of iNaturalist Using the Six Dimensions from the AS Analysis. iNaturalist is a large citizen science project, established in 2008, that typically collects around 20,000 observations per day from thousands of participants. As of July 27, 2018, iNaturalist users contributed over 13,600,000 observations of plants, animals, and other organisms worldwide (<https://en.wikipedia.org/wiki/iNaturalist>). It also supports over 17,000 projects (<https://www.inaturalist.org>) that focus on a range of topics ranging from bioblitzes to school science

projects. These projects use the same infrastructure (e.g., templates to describe the project, leaderboards), and the data they collect contribute to iNaturalist's mission of recording biodiversity data from across the world.

Table 1 shows how the needs of WSA CDEP members, as identified through the AS analysis, compare with the needs of iNaturalist participants, as reflected through the interaction design of the iNaturalist platform, and a comparison of CDEPs is provided in *SI Appendix, Tables S1 and S2*.

In summary, what stands out from this analysis is that iNaturalist is clearly structured to support its mission of collecting large volumes of biodiversity data, whereas CDEPs are small, locally based, and much more diverse. Additional information that highlights these differences is provided in *SI Appendix, Tables S1 and S2*.

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