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D 5.1 - Initial Guidelines for Task Design

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Abstract	This deliverable presents initial research conducted on the design of citizen science tasks, with a particular focus on the domain of pollution. We present a typology of task characteristics and properties, as well as associated input devices and affordances, drawn from a large-scale survey of citizen science projects. From this large sample, we identified 81 projects with a pollution-focus, which we classify according to the developed typology. We further present initial research conducted on the question of task design as completed by the ACTION consortium.
Keywords	Citizen science, pollution, task-design, typology, survey

How to quote this document

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Executive Summary

This document sets out an initial set of guidelines for the design of tasks in citizen science projects. We present the current state of the art and summarise existing research around the design and implementation of citizen science projects.

In doing so, we present a typology of citizen science focused on pollution-related projects. We identify four levels of volunteer activity, ranging from passive participation to highly active participation which occurs in restricted contexts such as a given geographic location or on a given day. We note six types of asset used commonly in pollution-focused projects, from data to physical samples and identify 7 key stages of the scientific research process in which volunteers are commonly engaged, with a particular focus on data collection as the most common form in pollution-related citizen science. We cluster and describe common subtypes of this participation, with a focus on both offline and web-based participation methods, before highlighting common technologies and tools used within citizen science, alongside key advantages, disadvantages, affordances and concerns that should be considered in their implementation.

Based on this typology, we further elaborate on key research challenges in citizen science more broadly and pollution-related citizen science specifically, most notably task allocation and delivery, as well as task feedback and implementing more complex input mechanisms and domains. We further present initial plans and current research activities carried out within ACTION to address these issues and initial guidelines based on the typology set out within this deliverable. We conclude by summarising future plans for inclusion in D5.2.

1 Introduction

WP5 will develop a transdisciplinary toolkit of methodologies, guidelines and resources to enable a range of forms of citizen science projects. This work package will build on top of the digital infrastructure and services which make up WP4 and address significant recurring challenges within the implementation of citizen science projects such as incentives and volunteer engagement, quality assurance and impact assessment.

As a core element of WP5, the aim of this deliverable is to provide initial recommendations and guidelines to be followed by ACTION pilots in improving existing projects and setting up new projects, through a large-scale analysis of web- and mobile–based citizen science initiatives and communities focused on areas related to pollution.

To this end, we first present a typology of tasks derived from a variety of pollution-based citizen science projects. Through a clustering methodology, we group the tasks of these projects based on the degree of activity expected by participating stakeholders, the activity the volunteers take part in, the material and data submitted and the affordances associated with those projects and tasks. We then present some preliminary solutions to those issues developed by the ACTION consortium. Based on the findings of our typology and evaluation of the preliminary solutions, we present early recommendations for best practice to be developed further and finalised in later deliverables.

2 Task Typology

In order to identify the types of task present within pollution-related citizen science projects and the associated affordances and practices, we conducted a large-scale analysis of citizen science projects. This chapter outlines the findings of that process.

We note that a number of existing typologies exist, notably Bonney et al (2009), which provides a typology of the tasks and processes involved in citizen science, as well as the processes by which a citizen science project might be evaluated. Additionally, the work of Schaefer and Kieslinger (2016) in developing a graphical matrix of citizen science activities is of particular relevance. Our aim is not to replace or supplant these existing typologies, but rather to apply and supplement existing typologies, while molding them to fit the space of pollution-focused citizen science, which draw on a number of processes and task types found less commonly in other citizen science initiatives.

2.1 Method

Firstly, in order to conduct the large-scale analysis, we developed a sample of citizen science projects drawn from a range of sources. These sources were selected based on how regularly they are updated and the range of projects featured. Since prior experiences had suggested that pollution-based projects are often small-scale, local and given the range of vocabulary used to describe these projects, we chose not to conduct a literature review for fear of biasing the types of project collected. Instead, we chose two major volunteer-produced sources:

1. Wikipedia's "List of Citizen Science Projects"[1]
2. SciStarter[2] projects with the keyword 'Pollution'

Although Wikipedia features articles with a range of quality, the list of citizen science projects is regularly updated with citizen science projects from a range of disciplines. SciStarter is one of the largest databases for citizen science projects, but features thousands of projects and a limited search mechanism and for this decision we chose to select only those projects with the keyword 'pollution'. We identified a total of 308 projects.

We then filtered these lists of projects to include only those projects which had some form of pollution-related aim or goal, as stated within the project web page. These projects were then clustered based on task, activity level, goal and submission materials, as well as the affordances employed within project webpages and applications.

2.2 Activity Levels

Throughout our analysis of pollution-related citizen science projects, we identified four main levels of participation in data collection and data analysis tasks. We distinguish these levels based on the

[1] https://en.wikipedia.org/wiki/List_of_citizen_science_projects
[2] https://scistarter.org/

level of agency offered to – and the effort required of - volunteers, as well as the accessibility of tasks.

2.2.1 Passive

Passive tasks gather data longitudinally or continuously, but involve engagement from volunteers in a single task upfront. The volunteer installs a sensor, device or software program which regularly harvests data. Although there may be a number of minor or secondary tasks associated with these types of task – for example, maintaining the sensor, moving the sensor or transferring data from the sensor to a database – volunteers engage little with the process beyond making the decision to participate and setting up the hardware or software. The most common example of this type of task is air quality monitoring. Ensuring long- medium- or even continued short-term engagement from volunteers is a significant challenge in citizen science projects (Sauermann and Franzoni, 2015) and the vast majority of volunteers contribute for very brief periods. More passive models of participation can therefore be highly advantageous in reducing the effort required of volunteers and thus barriers to entry, as well as the likelihood volunteers will cease contributing. However, this passive engagement offers volunteers limited opportunities to contribute and while (Haklay, 2013) describes such engagement as citizen science, other sources such as Wiggins and Crowston (2012) do not. Passive tasks may offer volunteers additional opportunities to participate, such as building the sensor, but participation remains limited almost exclusively to preparing and enabling data gathering processes.

2.2.2 Opportunistic

Opportunistic projects describe those projects where volunteers contribute actively – by for example gathering data or evidence of interest to the project – but do so during the course of their daily lives or other activities, without the need to go out of their way or invest significant time and effort to gather samples, evidence or data for scientific purposes. One such example is the Open Litter Map project which asks volunteers to submit reports on litter that they come across in their daily life[3]. Although there is nothing in theory preventing participants from engaging in opportunistic projects frequently or in a way they might with more active projects, the topics of these projects tend to be niche, with little guarantee that volunteers will have any observations to report. For example, rather than consistently observing the quality of the water in a lake, an opportunistic project would simply ask volunteers to report changes in the quality of the lake water should they occur and be observed.

[3] https://openlittermap.com/en

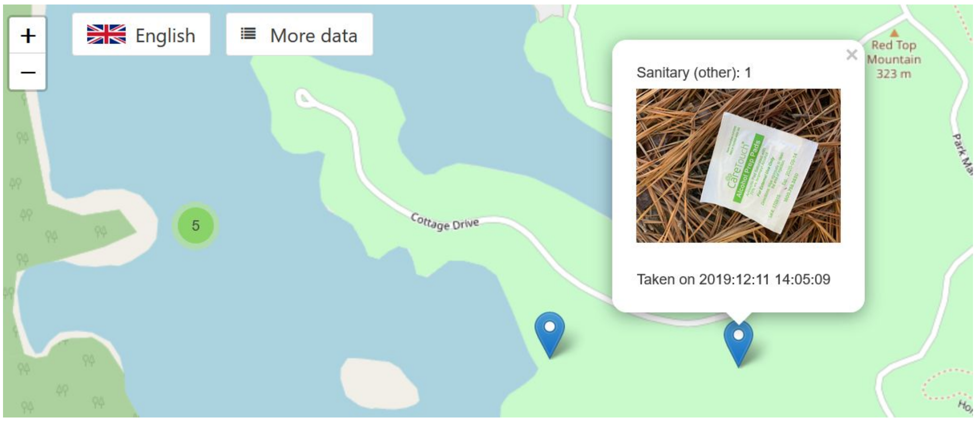


Figure 1 - Open Litter Map visualisation interface showing images, mapping and metadata submitted by volunteers.

2.2.3 Active

Active projects refer to projects in which volunteers must actively take specific actions if they wish to participate, such as visiting certain locations, making specific observations or using smartphone apps. This category also includes the vast majority of web-based citizen science projects with a focus on data analysis activities. The extent to which participation in these projects is truly active varies significantly, from projects where volunteers simply run smartphone applications in a given area, to projects where volunteers must visit an area and sample water or use multiple sensors. Participation in such initiatives is not necessarily long-term – participation in many online initiatives tends to be very brief and often occurs in the form of one-off participation from volunteers who do not return. Nevertheless, this participation is much more ‘active’ than passive projects.

2.2.4 Restricted

Restricted projects are those projects where volunteer participation is restricted to a small number of locations and/or time periods, such as a given date or week or a given park. These restricted projects may require small groups of participants working together or working with experienced volunteers and or scientists and may therefore cover tasks that would otherwise be very difficult for volunteers to carry out alone. Alternatively, this restriction may impact the types of people who can take part – for example, rather than being open to any and all volunteers, the volunteers may need specialist knowledge around science, art or design. Restricted projects tend to use a more event-based methodology to engage volunteers, asking them to attend sampling or analysis workshops, policy workshops or one-off or semi-regular data gathering challenges.

2.3 Project Aims

2.3.1 Action

Action projects are a type of project where the scientific aim of the project is limited or secondary and the main purpose of the project is to engage volunteers in carrying out tasks to improve a local area, such as clearing litter or planting trees. Wiggins and Crowston (2011) describe these projects as predominantly citizen-led, noting that they tend to be carried out by small community groups who self-organise to achieve goals. These initiatives tend to be offline initiatives, without the need for web-based elements and in this sense, it is possible that they may be underrepresented in our sample. Nevertheless, since the outputs of such projects are predominantly physical, there is limited dissemination to allow for easy identification of these projects at any sense of scale.

2.3.2 Conservation

Conservation projects are similar to action projects, except that they have a specific conservation-related goal, which may be achieved through action or through the gathering of data. Unlike action projects, these tend to be scientist-led due to the difficulties associated with conservation (Wiggins and Crowston, 2011). We found little evidence of explicitly conservation-related pollution projects.

2.3.3 Investigation

Investigation projects are perhaps typical citizen science activities, where volunteers gather data or samples in a given location. Such activities may include gathering samples of soil, monitoring the presence of a given species or recording the level of noise in a neighbourhood. Although there is no requirement necessarily that these projects have online elements, we noted a significant variation in the use of web-based features within this category. Projects ranged from those that relied on a smartphone app to gather and report observations to those where submissions were made manually on paper. This category described the majority of the pollution-related projects identified.

2.3.4 Virtual

Virtual projects can be seen as a subset of investigation projects, in that they also support scientific research and have similar data gathering goals. In virtual projects, however, activities are carried out entirely online and there is no need to travel to a physical location or carry out a physical activity to gather data. This was a somewhat rarer category of project, as the majority of projects requested volunteers to physically make observations or gather samples. Nevertheless, some projects offered volunteers the opportunity to add information to previously gathered images, samples, or reports entirely through project websites. INaturalist, for example, features a number of pollution projects which ask volunteers to gather images of specific phenomena, but also ask volunteers more widely to visit the project pages and to classify, tag or otherwise offer feedback on images to increase their usefulness for scientists.

2.3.5 Education

In education projects, the tasks taking place are carried out primarily for learning purposes and any scientific research which may take place serves a predominantly education-related goal, rather than being intended to further collective knowledge. The majority of the education projects identified within the sample were designed for school groups to learn about science or specific concepts such as water purity, water pollution or water sampling. Such projects generally relied on a series of one-off events, during which the school children would have the opportunity to work with existing volunteers, project scientists or others with specialised knowledge and without any long-term plan for the gathered data.

2.4 Assets

2.4.1 Data

Among the most common assets used within the sampled projects was data, such as GPS data and sensor data, generated automatically by devices. The use of automatically generated data as an asset was generally associated with tasks that would be difficult or costly for volunteers to carry out themselves, such as GPS location data, air quality sensor data or water quality sensor data. Data as an asset was strongly associated with the use of sensors or bespoke smartphone apps.

Note that we distinguish between *data* and *text* assets, as a reflection of the role of volunteer participants. If sensors generated and submitted data *automatically*, then the associated asset would be data. If conversely the sensor generated a number which had to be noted and submitted manually by a volunteer, then the associated asset would be text. Text assets reflect greater autonomy but also greater task burdens on volunteers than the use of automatically-generated data assets.

2.4.2 Audio

Audio assets were extremely rare in the sampled projects and associated solely with noise-pollution projects. We found 5 projects featured the opportunity to automatically gather data by exposing a smartphone or sensor to sound, as well as one project which asked volunteers to manually record sources of sound or noise in their local area. Nevertheless, we did not find any evidence that volunteers would or even could submit audio recordings to these projects or any other.

2.4.3 Video

Video assets were also rare in the sampled projects and we did not find any evidence of volunteers being asked to capture videos of phenomena which they observed. We did find one project – Industrial Smoke Hunting – which presented volunteers with videos of industrial chimneys, which volunteers were then asked to label as containing smoke or not. However, these videos were short three second loops and much more similar to gifs than true videos. We note that video recordings tend to be much larger in size than other assets (particularly images or text) and it is unlikely that a project that asks volunteers to make recordings would scale well in terms of data storage.

2.4.4 Image

Images were one of the most common assets gathered within the sample projects, often supplementing text to provide additional information or evidence of an observation. Capturing of images to serve as evidence of observations has long been a common quality assurance technique in citizen science (Wiggins et al, 2011).

2.4.5 Sample

Some projects asked volunteers to gather samples of potentially polluted materials -- biological material, water or soil -- for later analysis by scientists and potentially limited analysis by volunteers. Such projects tended to be more specialised and would generally be somewhat restricted, with volunteers asked to gather samples in groups or at specific locations. The most highly specialised projects would then ask volunteers to conduct analyses on the gathered samples. In simpler projects, volunteers would merely count the number of samples or briefly describe the appearance of the sample.

2.4.6 Text

Text-based reports were associated with a wide range of projects, with volunteers asked to provide brief descriptions of phenomena they had observed or numeric data that they had captured. In some cases, text-based asset submissions offered similar data to data-based asset submissions, but with the volunteer responsible for taking the measurements and reporting it, rather than automated submission from a smartphone or sensor.

2.5 Scientific Processes

Although tasks within citizen science often describe the practise of gathering or analysing data, we noted a number of stages of the scientific process present within pollution-based citizen science projects, each with its own distinct associated tasks. In this section, we lay out the processes identified, the frequency and projects in which they occurred and the tasks associated with these processes.

2.5.1 Defining Questions

During our analysis, we identified just 2 projects which allowed volunteers to define research questions – AirQuality Trek and SPLASSH. In AirQuality Trek, volunteers were given the opportunity to rent or purchase sensors to allow them to gather evidence of any form of air pollution that the chosen sensor could record, without specific restrictions on the type of question to be addressed. Similarly in SPLASSH, volunteers had the opportunity to set up a water quality project, defining an area, research question, method and any outputs. Nevertheless, neither project offers volunteers complete autonomy to decide research questions – AirQuality Trek volunteers are restricted to gathering data on air quality and only data which can be gathered through the sensors on offer, while SPLASSH volunteers must gather data on water quality from rivers or lakes.

2.5.2 Gathering Information

Gathering information describes the process of carrying out research on a predefined research question to inform the design of the methodology and the course of the research itself. Although there were no formal restrictions preventing volunteers from carrying out their own research to inform their behaviour – for example, choosing where to conduct the sampling – only AirQuality Trek and SPLASSH featured the opportunity for this gathered data to influence the proposed method at a significant level. In all other projects, the methodology and research problems were predefined and the influence of any gathered data was limited at best.

2.5.3 Developing Hypotheses

As with information gathering, although projects did not necessarily restrict volunteers from developing their own hypotheses prior to commencing their activities, only AirQuality Trek and SPLASSH offered volunteers full autonomy in defining and researching specific hypotheses. It is likely that more educational activities where citizen scientists work alongside professional scientists also encourage volunteers to develop hypotheses in some form, but we did not find enough evidence to conclusively state when and where this might occur.

2.5.4 Designing and Coordinating

The act of defining and coordinating the study to be carried out involves careful consideration of the tasks to be carried out, the materials to be used during the tasks, the location at which the task is to take place and the usage of any gathered data or samples. In the majority of cases, the design of the study was predefined and the only input from volunteers at this stage was in putting into practice the actions. The Anglers Riverfly Monitoring Initiative expanded on this by using a pre-defined method, but leaving the specific implementation and refinement of this method to members of local groups with specialist knowledge and training, who would then define the location and the specific elements of the task to be used at a given location. These group leaders would also oversee the task and the use of the data. Beyond these projects, we identified a group of educational projects which involved volunteers in defining the method to be followed, but the degree of autonomy offered to volunteers was limited and this group largely assisted volunteers in defining a pre-selected method.

A subtask of this process involved allowing volunteers to choose or otherwise influence which factors to investigate, without necessarily offering volunteers complete control over the design of the study method. In the Boeren en Buren project, scientists asked volunteer farmers to give their opinions and feedback on which local pollution issues should be monitored to achieve the project research aims. Smart Citizen Kit offered volunteers the option to choose which sensors to set up and by extension, which factors to monitor. Again, however, this was not a widespread task in the sampled projects, occurring in just these two projects.

2.5.5 Data Collection

Data collection was by far the most common task assigned to volunteers in the pollution-related projects. All but one of the projects studied asked volunteers to contribute to gathering – or otherwise producing – data. The specific form this data takes varies strongly (see section 3.3 – assets) and in some projects, the 'data' in fact takes the form of samples such as butterflies, water from a river or soil. In this sense, the samples serve as a kind of pre-data, where some form of analysis is necessary to extract the data to be used. Please see section 3.5 – tasks for a more detailed analysis of the high number of distinct tasks involved in the data collection process.

2.5.6 Data Production

It is necessary when dealing with the sampled projects to distinguish between data collection projects – those in which volunteers are responsible for gathering data or samples – and data production projects. We define data production projects as those in which volunteers do not gather data, but rather work with pre-existing data or assets to enhance the value of the assets for scientific purposes. **Virtual** projects, then, would be data production projects as the volunteers are not tasked with collecting data, but rather producing additional data to assist with scientific tasks. Previously some have referred to these tasks as data analysis tasks (see for example Tinati et al., 2015), but in a pollution context there are projects which involve much more complex data analysis processes. Where data analysis involves analysing gathered data or samples, data production describes preparing the data for analysis.

One such example would be labelling images gathered by volunteers or gathered automatically, through tagging or categorisng processes. The Brooklyn Atlantis project, for example, presents volunteers with images gathered automatically through robots fitted with cameras and asks the volunteers to tag or otherwise label those images to explain the contents and allow filtering of images. Nevertheless, data production was also strongly linked with data collection, with a number of projects asking volunteers to add labels or descriptors to the samples and data that were gathered, including data they gathered themselves. Similar to data collection tasks, this process included a number of distinct tasks and is therefore discussed further in section 3.5 – tasks.

2.5.7 Data Analysis

Data analysis describes the process of working with the gathered data or samples to conduct chemical or statistical analysis as a means of resolving research questions. In sample gathering projects, we note that the type of analysis required often involved specialised equipment or resources, as well as specialised knowledge and as a result was often restricted to laboratory settings. While some projects did offer volunteers the opportunity to take part in this process, it was only under observation from experienced scientists at pre-arranged events and therefore somewhat restrictive. Furthermore, in all projects where this occurred, more detailed analysis was carried out by scientists in laboratory conditions after volunteers had finished.

2.6 Tasks

When examining the data collection and data analysis elements of the citizen science process, we identified 10 key tasks. Here we describe those tasks, with examples and – where available – interface images from the sampled projects.

2.6.1 Installing and Maintaining

A task shared by each of the passive projects identified through the sampling process was the task of installing and maintaining the sensors to be used to gather data during the project. The level of autonomy available to volunteers is generally very low in these projects, with the pollution topic and specific sensors to be used almost exclusively pre-determined by the project scientists. Participants have the opportunity to decide where to install the sensor, but beyond this the majority of decisions are made for volunteers.

2.6.2 Building

An extension of the installing and maintaining task, a number of passive projects offered volunteers the opportunity to build their own sensor to be used in the task. The complexity of sensors varies strongly – from a makeshift water pollution sensor made using sheets of plastic and wire, to complex sensors requiring the use of an Arduino or even circuit boards with soldered modules. More complex sensors are associated with group workshop sessions during which volunteers develop sensors with supervision and assistance from project scientists.

2.6.3 Sampling

Sampling tasks cover the gathering of any form of sample by volunteers. In spite of the name, sampling projects do not necessarily require volunteers to submit *samples*, but instead sampling was also a core element of those projects which asked participants to submit textual or numeric records. Samples served three main purposes – for submission for analysis by scientists, for analysis by volunteers or for recording (with the sample returned rather than submitted). In almost all cases, the gathered samples were samples of water – either river, lake or ocean water – although one project asked volunteers to gather samples of plastics and another asked for volunteers to gather butterflies as samples.

2.6.4 Tagging

Tagging tasks ask volunteers to take existing assets – in the sampled projects, exclusively images – and to add descriptions of those assets in the form of a typed tag. In all of the sampled projects, the tags were intended to describe the contents of the image, such as identifying species contained within images, or identifying the type of litter present in the image. In the Litterati project, this tagging process was augmented by an AI programme which assisted volunteers in identifying the type of litter they had collected. Such a feature was not present in other tagging projects, but the iNaturalist project allows volunteers to review tags given by other users and this serves a similar quality assurance purpose.

Tagging tasks are distinct from categorisation tasks in that the volunteers produce the tags (and by extension, categories) themselves, with few restrictions on the tags to be produced. One project – Brooklyn Atlantis – extended this tagging task, allowing volunteers to select which elements of the image they wished to tag (see figure 1). Brooklyn Atlantis also offers few recommendations, guidance or restrictions on what to tag and therefore differs strongly from the other projects within this category.

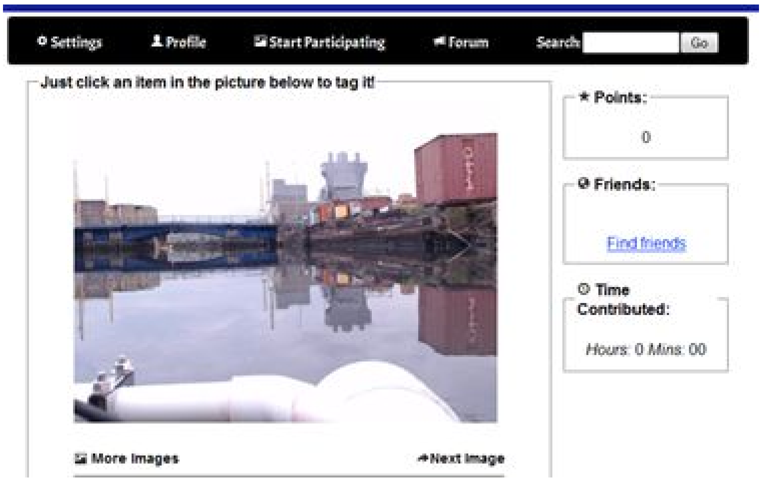


Figure 2 - The Brooklyn Atlantis project allows volunteers to choose elements of the photo to tag

2.6.5 Categorising

Categorising projects serve a similar purpose to tagging projects, asking volunteers to take images or other assets and assign them to one of a set of predefined categories based on specific features such as content. Where categorising projects differ from tagging projects is largely in the degree of autonomy and agency offered to volunteers. In tagging projects, volunteers can enter the tags themselves and therefore can decide for themselves what to tag. In categorising projects, the volunteers have no control over the categories. This can be problematic in the event that assets arise which cannot easily be placed into one of these categories – for example, where the quality of the asset does not allow for its content to be distinguished, although scientists can still derive some information from these categories[4].

A subtask of categorising tasks found within our sample was *collaborative categorising*, where two volunteers are asked to categorise assets at the same time. In the Night Knights project,

[4] See for example: https://blog.snapshotserengeti.org/2012/12/14/we-need-an-i-dont-know-button/

this activity is converted into a game, where volunteers can earn points and progress by identifying the same category as their partner. Redundancy has been used effectively in other categorising projects to ensure the accuracy of submissions – the Snapshot Serengeti project features over 90 categories for volunteers to choose from and yet is able to achieve high accuracy with just 5 volunteer submissions. Night Knights uses a similar quality assurance process, but by gathering submissions collaboratively and simultaneously.

Figure 3 - Night Knights classification interface showing categories, image, points, time remaining and progress count

2.6.6 Supplementing

An alternative or additional task to tagging/categorising, supplementing tasks ask volunteers to offer qualitative data based on their own experiences which expands on pre-existing data, particularly where that data has been gathered automatically or by sensors. One such example is the Curio project, which asks volunteers to offer their local knowledge to explain possible sources of air pollution. In the two projects where supplementing forms a large part of the task asked of volunteers, it functions largely as a more complex and more detailed form of tagging.

Figure 4 - Curio data visualisation interface showing individual image, tags and supplemental 'story'

2.6.7 Observing

Observing tasks describe those in which volunteers are asked to observe a local area and produce textual reports of specific phenomena in that area – for example, the number of seagrass plants or the clarity of the water. Observing also occurred alongside sampling, with volunteers first gathering a sample, making an observation from that sample – for example, water clarity or the number of plastic objects within the sample – and then returning the sample to where it had been gathered.

2.6.8 Recording

Recording was a common task within the sampled projects, with volunteers asked to create images or other assets as they make their observations. Recording as a task appears to correlate with opportunistic workflows, where volunteers are asked to make recordings of phenomena they observe. However, in the sampled projects a wide variety of projects asked volunteers to gather images as evidence of their reports. In the sampled projects we found no evidence of other assets being recorded beyond images.

2.6.9 Mapping

Mapping projects ask volunteers to report a particular phenomenon by submitting location data for that phenomenon, alongside a text or image. This location data occurs in one of two methods: automatically, through GPS data from a smartphone and manually, through the volunteer reporting the location or finding it on a map interface. Mapping data is intrinsically-linked with sensor-based projects, which all reported the location of the sensor and in many cases made this public. However, each of the opportunistic projects sampled involved mapping elements and many of the restricted projects had an inherent mapping element, in that the project occurs in one of a predefined set of locations. However, mapping data was rarely the main focus of a project in these contexts and it was predominantly passive sensor and opportunistic projects in which mapping data played a more critical role. In active and restricted projects, the main data to be submitted would be the phenomenon itself. Conversely, in passive projects, the gathered data are inherently linked with the location in which they were gathered and in opportunistic projects, the main submission is the reported location of the phenomenon.

2.6.10 Matching

Matching projects ask volunteers to find which of a range of assets are the best match – finding matching sounds or images. Only one of the pollution-related projects sampled featured a matching based activity. The Lost at Night project asks volunteers shows volunteers an image of a light polluted city and asks the volunteers to find which of a number of examples best matches that image, in order to identify where the pollution was observed. Matching may also occur in a number of other projects to allow tagging or classifying – a volunteer may wish to match their sample with a number of example images to identify the sample – but we found no concrete evidence of this in the sampled projects.

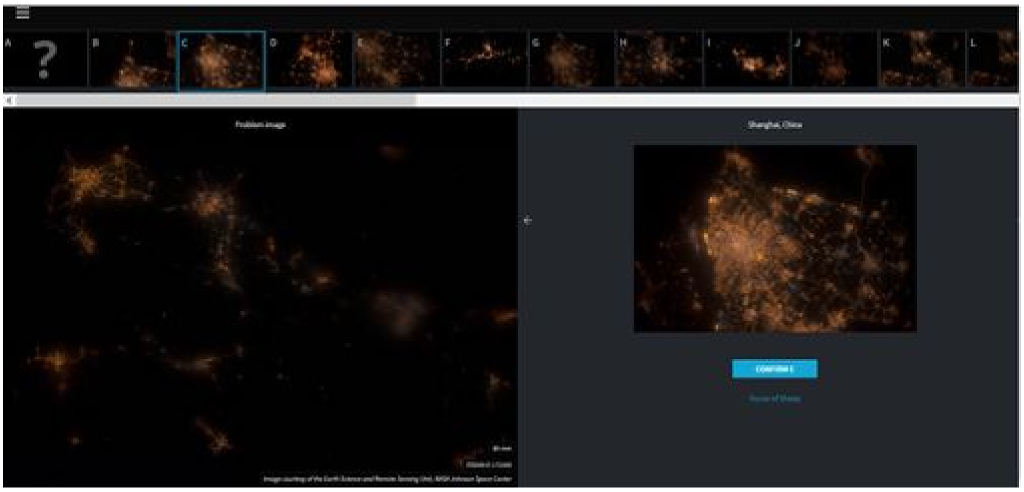


Figure 4 The Lost at Night project interface shows volunteers a range of images and asks them to find the most accurate map

2.6.11 Exploring

Exploring was a somewhat more nebulous task, where the aim of the activity would be to come up with new ideas, tasks and areas on which to focus for research. There was insufficient evidence within the sampled project webpages to determine the specific nature of this task. However, in the projects where such activities were described, they were reserved for scientists or those with specialised knowledge and occurred only in very restricted contexts. In contrast with the other tasks described, exploring appears to be associated with a research stage prior to question definition. Where this exploring stage extended to volunteers, it instead took the form of workshops.

2.7 Input devices and affordances

2.7.1 Offline input -- paper forms and physical samples

Offline input methods describe the use of paper forms and/or physical samples, delivered via the post or in person by the volunteer to project scientists and administrators. These methods are closely associated with more ‘limited’ task types, where volunteers work alongside scientists and administrators, so that they can submit the samples at the same time. Conversely, the need to carry a pen and paper make such input methods poorly suited for opportunistic citizen science activities and may result in data-loss in contexts outside of ‘limited’ task-types, due to the need for volunteers to remember to submit the form and/or sample.

Another situation in which the use of handwritten paper forms was common in the sampled projects was when volunteers would be asked to produce multiple records in a relatively small period of time. This predominantly occurs in species monitoring contexts, where a volunteer may need to – for example – record all of the bird species that were observed over the course of an hour. Rather than ask the volunteers to use smartphone interfaces, which may be time-consuming and result in a volunteer missing particular species, instead the volunteer makes a simple record on a paper form which can then be submitted and recorded by project scientists.

A third situation which uses these offline methods is the gathering of physical samples. Where samples require careful analysis using potentially dangerous, complex or expensive equipment, such activities would be beyond the abilities of many volunteers. Instead, in such cases, volunteers are asked to deliver the sample to a scientist who can then arrange for the necessary analysis to be completed.

Finally, the use of paper forms and other offline reporting methods was also relatively common as a secondary submission option for those volunteers who were less familiar with smartphones or who otherwise would have difficulty submitting using conventional technology. These offline methods allow volunteers

2.7.1.1 Advantages:

- Simplicity and familiarity -- paper forms do not require specialised training or familiarity with specific technologies, making them easier to fill out than online and smartphone-based interfaces
- Relatively cheap upfront cost -- forms can be designed without specialist programming knowledge, leading to reduced development time and cost over smartphone and web-based interfaces
- Ideal for demographic groups who are less likely to have the necessary knowledge or opportunities to access smartphones and/or internet-enabled computers.

2.7.1.2 Disadvantages:

- Requires data-input on the part of scientists/administrators
- Less-reactive: cannot adjust form based on prior responses
- Opportunities for error during completion – e.g., missing questions, incorrect responses – with limited opportunity to flag-up errors to volunteers in a timely manner.
- Data-gathering process slower and less immediate than the use of smartphones/web-enabled devices. Potential for data-loss should volunteers neglect to submit completed forms and/or samples.

2.7.2 Smartphones and mobile devices

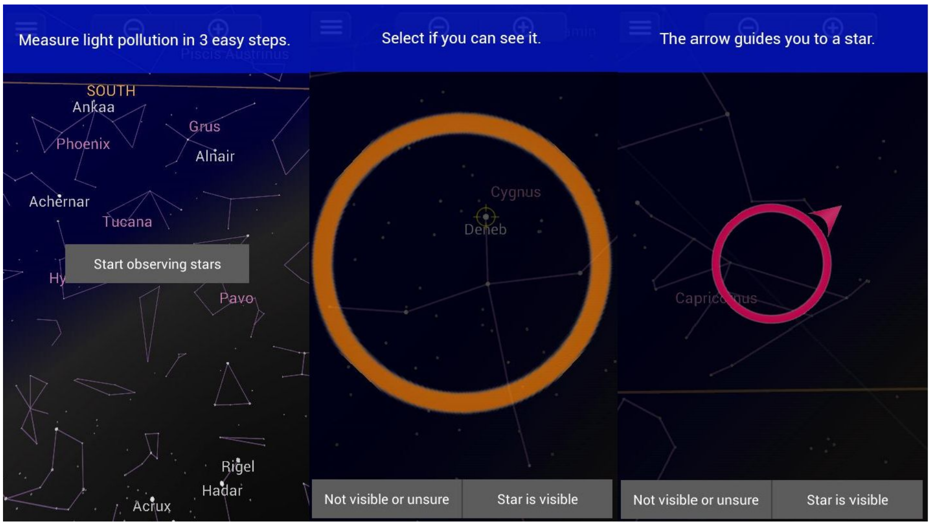
Smartphone input methods describe the use of a smartphone to run a software application for the purpose of gathering data, or less commonly to gather assets such as images or recordings for use in web-based input methods. Although in theory there is nothing preventing the use of a smartphone to engage with web-based input method projects on a mobile basis, we note that none of the sampled projects appeared to deliberately design for such an opportunity. On the contrary, the web-based input projects were all designed to allow for input at a later time or from the comfort of one's own home. We therefore distinguish between these two input methods, but acknowledge that there may be some opportunity for overlap.

The ubiquitous nature of the smartphone -- as well as the wide range of affordances that modern smartphones offers – makes it particularly valuable and almost essential for opportunistic citizen science activities. Using their smartphone device, volunteers can gather accurate location data through GPS, take images or video recordings using their camera and if necessary, make notes, without needing to carry additional tools or technologies with them.

We identified three broad categories of project that used smartphones as an input method. The first referred to those projects which did not use a custom-built application. These projects used relatively simple data gathering processes – usually a photograph taken with the phone and a brief report – and did not differ significantly from the simplest offline or web-based projects other than making use of a smartphone to supplement the data gathering process.

The second category conversely describes those projects which did make use of customised applications. These applications serve to guide volunteers through the data gathering and data submission process and varied greatly in complexity. The Curio project, for example, simply provided volunteers with an online form for reporting observations. While this form was embedded in the app, many of the same functionalities could be achieved through an offline printed form, or a conventional website.

On the other hand, other projects made use of significantly more specialised and unique input methods. One such example, Loss of the Night, uses a highly interactive data collection process during which the app makes use of GPS and gyroscopic data provided by the smartphone to guide volunteers towards the location of a star, significantly simplifying the data gathering process in a way that would be much more difficult to achieve without such affordances. The volunteer is then asked to record whether he/she can see the star and thereby contributes valuable data on the quality of the night sky in his or her location, as recorded through GPS.



The Loss of the Night App uses the gyroscopic and GPS affordances of a smartphone to guide the data collection process

In the third category of smartphone-based apps, the smartphone serves a sensor and gathers the majority of the necessary data for a volunteer. One such example are the Globe at Night and Dark Sky Meter apps, which measure the brightness of the night sky using mobile applications. While these are not sensor projects in the truest sense – volunteers must still engage with the app, provide particular information fields and make decisions as to when and where to record data – the app gathers the bulk of the data in these situations with minimal effort on the part of volunteers.

We found no examples of passive smartphone-based input methods. In all of the sampled projects, the volunteer must make a conscious effort to commence the data gathering process and agree to the submission of data.

2.7.2.1 Characteristics and key affordances:

- **Portability** – smartphones are small and commonly carried, meaning volunteers can easily have applications and features on hand as and when they require them.
- **Camera** – cameras are common features among the majority of smartphones, allowing volunteers to gather images or video recordings of phenomena, either as evidence of their submission or to allow further analysis by domain experts.
- **GPS** – Global positioning satellite compatibility is a common feature in many smartphones, allowing volunteers to quickly and easily gather reliable and accurate data concerning their location, rather than having to rely on their own understanding of a location with which they may be unfamiliar or which they cannot reliably report.
- **Applications** – the majority of smartphones currently available use either Apple's iOS or Google's Android operating system allowing volunteers to run applications designed for these operating systems on their smartphone device.
- **Internet connectivity** – volunteers can connect to the internet using their smartphone device and thereby upload images and data (provided they have a Wifi or mobile internet connection).

2.7.2.2 Advantages:

- Pervasive: The pervasiveness of smartphones – and in particular, Android or iPhone devices -- means that designers and project scientists can generally assume volunteers will have access to such a device and the associated affordances without the need for potentially costly equipment such as satellite positioning devices and cameras.
- If using applications, the data gathering process can be combined with a tutorial process or react to volunteer submissions, allowing for identification of potential missing or incorrect data during the submission process. Alternatively, the app can be designed to remove opportunities for human-error altogether where possible.
- Although more specialised features may vary and the quality of specific components may vary, generally speaking, smartphones have a core set of affordances and features which designers can generally rely on for the purposes of designing and implementing an app.

2.7.2.3 Disadvantages:

- Relies on the presence of a mobile-internet or wifi signal, which in some locations – particularly remote or rural locations – may not be present.
- The large number of smartphone designers means that different handsets and models will have different characteristics. The Dark Sky Meter app, for example, only runs on iPhones because the large number of Android devices makes it infeasible to accurately gather data from the various different cameras used.
- Reliance on the use of smartphones may alienate certain demographics who are unfamiliar with smartphone applications, lack access to smartphones or lack access to reliable internet connections.
- Designing for smartphones relies on programming knowledge and a solid understanding of iOS, Android or both systems.

2.7.3 Web-based input platforms

Web-based input methods describe the submission of data through a web-based portal (i.e., website). In the majority of cases, these data and/or samples are first gathered by volunteers at a different location, which they then submit upon returning home or at a later date and time of their choosing. In a small number of cases, the data are not 'gathered' in the conventional sense, but rather generated as the volunteer completes tasks through the virtual platform, by for example labelling images that have been previously gathered.

It is important to highlight that the use of web-based portals is not necessarily mutually exclusive with offline or smartphone-based projects. For those projects where data are gathered and then submitted online, the gathered data must first be recorded, either as handwritten notes or through capture using a smartphone device (particularly in the case of images. Web-based portals also offer a range of other features which serve to augment the data gathering process, providing information to volunteers or intended as incentives for participation.

One type of project which is relatively unique to these web-based portals are the so-called 'data analysis' projects (Tinati et al, 2015) in which rather than gathering data, volunteers are presented with pre-gathered data and assets and asked to augment these data with supplementary information to allow for their use in research. This is not data analysis in the most common sense, but rather a form of data processing in which the volunteers enable more automated forms of data analysis through their activities.

Although there are no significant restrictions which would prevent such activities being completed on a smartphone device, we found no evidence of smartphone applications designed for this purpose in the domain of pollution. One likely explanation for the absence of such apps is that the main affordances offered by smartphones are unnecessary for this purpose – there is no need to travel anywhere to carry out such activities and features such as GPS and camera technologies are not required to classify the data.

2.7.3.1 Characteristics and key affordances:

- **Connectivity --** Interfaces with smartphones, sensors and many other devices, allowing for gathered data to be uploaded to portals even if a device is itself unable to achieve internet connectivity.
- **Semi-ubiquitous** -- computers are common in the developed world, both in the home and in other locations such as libraries allowing convenient access.
- **Ease of accessibility** -- no need for specialised software applications. Accessible through a simple internet browser.

2.7.3.2 Advantages:

- Somewhat simpler to design for than smartphones, due to the availability of project designing tools and templates such as Zooniverse's Panoptes system.
- Greater processing power than smartphones, allowing for more complex programmes and features
- Can allow for passive and longitudinal data gathering if consistently connected to the internet and necessary hardware and software (for example, temperature sensors).

2.7.3.4 Disadvantages:

- Stationary and require access to power and wired/wifi connection.
- Prohibitively expensive or otherwise unreliable in certain countries and areas.
- Unsuitable for certain demographics who may find the use of computers and internet browsers difficult.
- Reliant on volunteers first gathering data/records, allowing for errors to be introduced at an earlier stage which can then be difficult to correct.

3 Research Challenges in Task Design

3.1 Classifying the Projects in our Database According to this Typology

During the production of this deliverable, we identified a total of 81 pollution-related citizen science projects. Table 1 shows each of these projects, classified according to the typology presented in section 2. Limited information could be gathered for 5 of these projects which are currently available and which may not be launched again in the near future.

Name	Task	Pollution	Activity Level	Project Aim	Asset	Input Device
Air Casting	Sensor, Observing	Air Pollution	Passive/active	Investigative	Data, text, image	Smartphone
Air Quality Citizen Science	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Air Quality Egg	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Air Quality Treks	Problem definition, coordination, sensor	Air Pollution	Passive	Investigative, Action	Data	Sensor
AirVisual	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Almere Meet Water	Sample collection, Observing	Water Pollution	Active	Investigative	Data/Text/Sample	Offline/Web-enabled
Andean Biotic Index App	Species Monitoring	Water Pollution	Active	Investigative	Data, image, text	Smartphone
Anglers Riverfly Monitoring Initiative	Observing, Sampling, Coordinating	Water Pollution	Active	Conservation, Investigation	Sample, text, data	Offline
Arts Catalysts	Exploration, Art and Asset Creation	Pollution	Restricted	Action, Education	Various	Offline
BEACH	Observing	Water Pollution	Opportunistic	Investigative	Data	Web-enabled

Beach Observer	Observing, image creation	Water Pollution	Opportunistic	Investigative	Data, image, text	Smartphone
Big Microplastics Survey	Sampling, Sample Analysis, Coordination	Plastic Pollution	Active	Investigative	Data, Sample	Smartphone/ Web-enabled, Offline
Big Moss Map	Travelling, Observing	Air Pollution (tangentially)	Active	Investigative	Data	Smartphone/ Offline
BIMAG	Species Monitoring	Agricultural Pollution	Active/Restricted	Investigative	Data	Offline
Boeren en Buren	Issue selection, sensor	Air Pollution	Restricted?	Investigative	Data	Sensor
Brooklyn Atlantis	Tagging	Water Pollution	Active	Virtual	Text	Web-enabled
Changing Currents	Sampling, analysis	Water Pollution	Restricted	Education	Other	Offline
Che Aria Tira	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Cities At Night	Classifying, Mapping	Light Pollution	Active	Virtual	Data	Web-enabled
Cittadini per l'Aria	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Ciudadanos Científicos	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Clean Air Council Climate Tracker	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Community Air Quality Monitoring (Mapping for Change)	Sensor	Air Pollution	Passive	Investigation	Data	Web-enabled, sensor
Curio	Observation, mapping, qualitative	Air Pollution	Active	Investigative	Data, Image	Smartphone

	data gathering					
Cyanotracker	Image creation, observation	Agricultural pollution (tangentially)	Opportunistic	Investigative	Text, Image	Web-enabled (social media)
Cyber Citizen	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Dark Sky Meter	Sensor	Light Pollution	Active	Investigative	Data	Smartphone
Dust Duino	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Earth Co Lab	Collaborative Scientific Activities	Various	Restricted	Investigative	Various	Offline
eOceans	Observing	Water Pollution	Opportunistic	Investigative	Data, image	Smartphone
Exposed Soil = Pollution	Unknown	Unknown	Unknown (Active?)	Unknown	Unknown	Unknown
Field Notes	Exploration, Art and Asset Creation	Polution	Restricted	Action, Education	Various	Offline
Fresh Water Watch	Sampling, Sample Analysis	Water Pollution	Active	Investigative	Data	Offline, Web-enabled
Georgia Adopt A Stream	Problem definition, method definition, sampling, sample analysis, observation	Water Pollution	Active	Investigative	Data	Web-enabled
Globe at Night	Observing	Light Pollution	Active	Investigative	Data	Web-enabled, Smartphone
Great Lakes Environmental Monitoring with	Sensor, Sampling	Water Pollution, air pollution	Passive	Investigative	Data	Offline

Passive Sampling						
Hack the Panke	Sample collection, Observation, Sample analysis	Water Pollution	Restricted	Investigative	Various	Offline
Humus Sapiens	Sample collection, Sample Analysis	Agricultural Pollution	Restricted	Investigative	Sample	Offline
Hush City	Observing, mapping	Noise Pollution	Opportunistic/ active	Action, investigation	Data, Audio, Text	Smartphone
iNaturalist	Image creation, observation, species identification	Various	Opportunistic, active, restricted (project dependent)	Investigative	Image, Data, Text	Web-enable d
Industrial Smoke Hunting	Classifying	Air Pollution	Active	Virtual	Data, video	Web-enable d
InfluenzaN et	Unknown	Air Pollution	Unknown	Investigative	Unknown	Unknown
ISeeChang e	Observation, image creation	Various	Opportunistic	Investigative	Data, Image, Text	Smartphone
Jug Bay Macro-inve rtebrate Sampling	Unknown	Unknown	Unknown	Investigative	Sample	Offline
LA Bucket Brigade	Observing	Pollution	Opportunistic	Investigative	Data/Text	Offline
Litter-free Digital Journal		Plastic Pollution	Active	Action, investigation	Data, Image, Text	Smartphone
Litterati	Observing, image creation, tagging	Plastic Pollution	Opportunistic/ Active	Investigation, Action	Data/Image	Web-enable d
Litterbug (Dreckspot z)	Observing, image creation, tagging, mapping	Plastic Pollution	Opportunistic/ Active	Investigation, Action	Data/Image	Web-enable d

Loss of the Night	Observing	Light Pollution	Active	Investigative	Data	Smartphone
LTER	Sensor, Observing	Air Pollution, Water Pollution	Active	Investigative	Data	Sensor/Web-enabled
Making sense	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Marine Debris Tracker	Observing	Plastic Pollution	Opportunistic	Investigative, Action	Data, Image, Text	Smartphone
MPCA Citizen Water Monitoring Program	Observing	Water Pollution	Active	Investigative	Data, Sample	Offline, Web-enabled
Night Sky Light Pollution	Observing	Light Pollution	Active	Investigative	Data	Web-enabled
NightKnights	Game	Light Pollution	Active	Virtual	Data	Web-enabled
NixNox	Sensor	Light Pollution	Passive	Investigative	Data	Sensor
Noise Tube	Observing, qualitative data	Noise Pollution	Opportunistic/ Active	Investigation	Data	Smartphone
OPAL Water Survey	Sampling, Sample Analysis, Observing	Water Pollution	Active	Investigative	Text	Offline, Web-enabled
Open Litter Map	Observing	Plastic Pollution	Opportunistic	Investigative, Action	Data/Image	Web-enabled
Pakistan Air Quality Initiative	Sensor, Observing	Air Pollution	Passive, Active	Investigative	Data	Sensor, Web-enabled
Pieris Project	Sampling	Pesticide Pollution (tangentially)	Active	Investigative	Sample	Offline
Public Laboratory Remote Field	Sensor	Air Pollution	Passive	Investigative	Data	Sensor

Logger Electronics						
Reef Life Survey	Species Monitoring	Water Pollution (tangentially)	Restricted	Investigative	Data	Offline
Samen meten samen weten	Observing	Water Pollution	Restricted	Investigative	Data, Text	Offline, Web-enabled
Scientists Work With Communities to Improve Urban Microclimate	Observing	Air Pollution (tangentially)	Restricted	Investigative, Action	Data	Offline
Seagrass Watch	Observing	Air Pollution (tangentially)	Active	Investigative	Data	Offline
Servizi Ecosistemici del Parco di Aguzzano	Mapping, Observation	Air Pollution	Active	Investigative		
Sherman's Creek Watershed Monitoring Program	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Smart Citizen Kit	Sensor	Air Pollution, Noise Pollution	Passive, but can choose what to monitor	Investigative	Data	Sensor
Sound Around Town	Sensor, observing	Noise Pollution	Passive/active	Investigation	Audio	Smartphone
SPIN-City	Image Creation	Air Pollution	Opportunistic	Investigative		
Storm Drain Labelling	Action	Water Pollution	Active	Action	N/A	Offline

Stormwater Management Research Team	Sampling	Water Pollution	Active/Restricted	Investigation/Education	Text, Data, Image, Sample	Offline, Web-enabled
Stream Teams	Sampling, observing	Water Pollution	Restricted	Investigative	Sample	Offline
Surfrider Foundation	Observing	Water Pollution	Active	Investigative, Action	Sample, text, data	Offline, Web-enabled
Trees Please	Tree Planting	Air Pollution	Active/Restricted	Action	N/A	Offline
URI Watershed Watch	Observing	Water Pollution	Active	Investigative	Data, sample	Web-enabled
Vlinder	Sensor	Air Pollution	Passive	Investigative	Data	Sensor
Volantari per natura	Sensor, Observing, Sample Gathering, Sample Analysis	Air Pollution, Water Pollution	Passive/Active/Restricted	Investigative	Data, text, image, other	Sensor/Web-enabled/Offline
Water Quality Monitoring	Observing, Sampling	Water Pollution	Active/Restricted	Investigative	Data	Sensor, Offline
WaterInsights	Sampling, Sample Analysis	Water Pollution	Active	Investigative	Data	Smartphone

Table 1 - Pollution-related citizen science projects identified during typology production process

It should be noted, however, that there are potential shortcomings in our methodology. Although our findings suggest the majority of projects within this space follow an investigative-methodology drawing on smartphones and web-enabled devices, we note that this outcome is likely to have been influenced by the methodology selected. In particular, more action-based projects tend to be led by small local community groups (Wiggins and Crowston, 2011). Given the difficulties associated with creating smartphone apps and or a significant web-presence, such groups are less likely to possess an easily identifiable website, making it difficult to find action projects through a web search. At the same time, however, these groups do not tend to have scientific research as a tangible end-goal and other methods for identifying projects -- including a review of scientific literature -- are also unlikely to identify evidence of these groups.

Moreover, our findings suggest that pollution-related projects are often somewhat localised, occurring in national, regional or even urban boundaries. In some cases, this was particularly problematic -- activities such as the Stream Teams project, for example, consist of a large number of individual and distinct initiatives taking place across the US, each with the potential for minor variation. This typology and project selection should not, therefore, be seen as exhaustive. It is highly likely that a significant number of projects exist which could not be identified or adequately classified using the methods we have chosen. We aim to build upon and expand this list by developing relationships with key stakeholders and experts within the citizen science and pollution spheres, to allow for identification of those projects which would otherwise go unrecognised or unacknowledged.

3.2 Challenges

3.2.1 Task Allocation

The allocation of tasks can be problematic in citizen science. If given full autonomy and choice, volunteers have a tendency to choose tasks or assets which they find intrinsically motivating, which can result in insufficient coverage or heavy completion of popular tasks, while less popular tasks are ignored (Nakamura et al, 2018). Efforts to encourage the completion of unpopular tasks through incentives or by highlighting the importance of less popular tasks have been found to have negligible effects on task completion (Nakamura et al, 2018; Simperl et al, 2018). The Zooniverse platform sought to overcome this phenomenon by assigning assets at random and removing the option for volunteers to choose which images they classify -- a method which has been re-used in a number of other citizen science projects (Reeves et al, 2017; Tinati et al, 2015). However, this has not always had the desired effect -- volunteers can perceive projects as uninteresting and fail to contribute if they are presented with ‘uninteresting’ images, requiring inserting images with specific content into workflows (Tinati et al, 2015). This in turn effectively wastes volunteer effort by asking volunteers to contribute classifications when an answer is already known.

An additional issue with task allocation concerns submission accuracy. Subjects which are rarer or with which volunteers have less familiarity can be engaging, but at the same time are associated with lower accuracy. One such example is the Zooniverse’s Snapshot Serengeti project, where volunteers consistently classify rarer animals incorrectly (Swanson et al, 2015). Recent work has suggested that assigning tasks based on volunteers’ backgrounds, knowledge and interests can have a significant impact on the accuracy of data submissions (De Lellis et al, 2019).

We note a third concern specific to the types of projects identified during this analysis. Many of the sampled projects had a location-related element, asking volunteers to gather data locally or to perhaps travel to a given location. Given population distributions, this inevitably results in a signifcant imbalance in the locations from which data are submitted. While in some contexts this may not be problematic -- if studying air pollution, having many submissions from within urban environments may be desirable -- in others, this may be problematic.

A key research challenge then, within task allocation, concerns finding alternatives to random task allocation which address concerns of data quality and volunteer engagement. What might these alternatives look like and what factors and characteristics should be accounted for in designing these alternatives? And how might we design data collection tasks to better account for geographic distributions and this imbalance in contributions?

3.2.2 Task Feedback

Citizen feedback is important as it allows people to contribute more meaningfully, build skills and remain engaged.

The provision of feedback within citizen science is a current outstanding question within citizen science, as well as whether feedback should be provided at all. Feedback on submissions is relatively rare and usually restricted to quantity-related measures such as the number of submissions made, the number of submissions still to be completed and estimated time of completion (Reeves et al, 2017). In fact, many projects are specifically designed to prevent volunteers from viewing the submissions of other volunteers, for quality assurance purposes (Mugar et al, 2014). This in turn can be problematic, as volunteers may complete a large number of submissions inaccurately, with little opportunity to learn how they are performing (Kim et al, 2014; Simperl et al, 2018). At the same time, projects are increasingly offering discussion and communication platforms, which allow volunteers to communicate with one another and potentially share feedback to encourage self-improvement and learning (Reeves, 2017). Nevertheless, there is little evidence for such improvement in the majority of platforms (Luczak-Roesch et al, 2014).

3.2.3 Task Delivery

The majority of citizen science research has explored medium to long-term projects which last weeks, months or even years and/or which involve one-off participation over a single day. While there has been some exploration of real-time or near real-time task delivery, this has often focused on the context of paid crowdsourcing -- see for example: Boutsis and Kalogeraki, 2014. However, analyses of existing projects have identified short-term projects or initiatives with differing characteristics and design and management needs (Curtis, 2018; Reeves et al, 2018). Activities such as the Bioblitz -- a 24-hour drive to gather data through activities such as species monitoring () -- have highly different goals in terms of outreach and inevitably have highly different volunteer engagement patterns when compared to more conventional longer-term projects (Baker et al, 2014). A number of outstanding questions remain in this area, such as the efficiency and effectiveness of such approaches compared with more conventional methodologies (Foster et al, 2013). While platforms such as the Zooniverse and EyeWire have made extensive use of such short-term initiatives and even combined these methodologies with longer-term activities, little is currently understood about how best to design and deliver such methods or even their advantages and disadvantages when compared with more traditional citizen science.

3.2.4 Complex Input Domains

Citizen science initiatives must strike a delicate balance between being accessible to volunteers who may lack scientific expertise and training, while gathering accurate, valid and full data that is suitable for use in scientific research. In some cases, where the domain is highly specialised, this requires the development of complex interfaces to enable data input. The EyeWire project, for example, uses WebGL to display MRI scans of mouse retina for volunteers to trace, converting a 2D image into a 3D model that a computer can read (Kim et al, 2014). This interface is highly challenging to use and it can take volunteers hundreds of hours and thousands of submissions to learn how to make these submissions (Kim et al, 2014; Simperl et al, 2018).

While we did not find significant evidence of such complex interfaces within the sampled projects, we nonetheless note that many of the concerns associated with such interfaces are present within the context of pollution. For example, even otherwise very accessible data such as numeric or graphical data gathered by sensors may be too highly specialised for volunteers to understand. Similarly, graphical representations of How then should projects design for complexity in tasks and how might they ensure they remain accessible to volunteers?

3.2.5 New Interaction

Citizen science has adopted new tech easily - Ushahidi (mobile), social media, AR/VR etc.
Speech-based is really interesting, but no one has looked at it yet

Conversational interfaces are currently on the rise: more and more applications rely on a chat-like interaction pattern to increase their acceptability and to improve user experience.
In the last few years, with the renewed interest on artificial intelligence and machine learning, autonomous agents and chatbots are experiencing a new popularity. The availability of intelligent services at our fingertips – being it voice search on mobile or personal assistants at home (like Siri, Google Assistant, Alexa, etc...) enormously increased the interest around the so-called conversational interfaces. The goal is to provide the user or customer with a natural interaction pattern that resembles the human dialogue, even when the counterpart is a computer.
This is also in line with the continuously increasing use of messaging applications, especially on mobile devices.

Also in the area of questionnaire design and administration, interaction design is increasingly looked at as an important ingredient of a digital solution. Growing attention is devoted to how a survey is administered to its users for data collection and new form of questionnaires with a colloquial form through a chat-like Web interface are now appearing. Just to make a couple of examples, SurveyMonkey [https://www.surveymonkey.com/] gives the possibility to share a survey through a Facebook Messenger channel and Typeform [https://www.typeform.com/] focuses all its competitive differentiation on user interface and interaction.

4 Current Research

4.1 Task Allocation

In our current work, we are experimenting with new methods of task allocation, using minimal information regarding volunteers, to improve accuracy and engagement without the need for lengthy initial data collection. As a test case, we are using paid crowdsourcing and the context of disaster relief, but we believe these results have wider, significant implications for citizen science, including pollution.

During initial experiments, we have used content, classification data and subjective opinions from volunteers to divide images and textual data based on task difficulty. Using Mechanical Turk, we have recruited paid crowdworkers, to partake in one of three conditions: randomly assigned tasks, predominantly difficult tasks and predominantly easy tasks. Our aim is to compare accuracy, completion time and quantity of submissions for workers in each of the three conditions, to better understand how difficulty influences participation and performance.

Further applications of this research within the sphere of pollution and citizen science could consider the impact of difficulty on volunteer performance, particularly in the context of multi-stage projects where volunteers are asked to complete multiple tasks. By carefully controlling at which point in the workflow these tasks are introduced to volunteers, we aim to improve volunteer performance without the need for lengthy or costly training processes.

4.2 Task Feedback

As a further method for improving volunteer performance and engagement, we are carrying out experiments exploring the outcomes of providing expert-generated and automatically generated feedback to volunteers. Similar to our work in task allocation, we have selected Mechanical Turk and the domain of disaster relief as an initial area for exploratory research, although we believe the findings can be applied to citizen science.

In terms of opportunities for task feedback, we have identified three potential areas which can be easily implemented in web-based crowdsourcing platforms -- both paid crowdsourcing and citizen science. The first of these is expert generated gold standards, in which volunteers first respond unsupported, but are informed if their answer differs from those of domain experts, offering volunteers the chance to learn by revealing the ‘correct’ answer. Alternatively, we propose expert-generated guidelines, where volunteers are shown hints, tips and instructions provided by domain experts, allowing volunteers to learn and improve without necessarily being informed of ‘correct’ or ‘incorrect’ answers. Thirdly, volunteers may be exposed to the answers generated by the crowd and informed when their answers do not match the majority opinion provided by other volunteers.

4.3 Task Delivery

In our current work, we have analysed the delivery of short-term citizen science projects in which a large number of assets are released with an associated deadline of approximately 48 hours. Volunteers are then expected to complete in effect an entire project within just 2-3 days. Our analysis of these systems shows that although a large number of volunteers make few submissions, under the right circumstances, highly active volunteers can complete tens of thousands of submissions -- more than may be gathered in other projects in as many as 3-6 months. The specific factors which influence this heavy participation are as yet unclear, but we note that heavy contributors tend to make use of integrated discussion platforms. Moreover, these short-term projects make heavy use of social media dissemination and live broadcasting to attract the interests of volunteers, with a recurring schedule that allows volunteers to anticipate such activities. Although these projects were not directly pollution-related, we note strong similarities with the bioblitz movement used in some pollution project contexts.

4.4 Complex Input Domains

High-level description of VCE, focusing on taboo mechanism, different starting points, small map. Evaluation data

We have developed a Virtual City Explorer -- VCE -- to allow for more complex forms of input and to allow workers and volunteers to define and complete tasks in a geographic, urban environment remotely and without the need to physically visit a location. When participants use the system, the task engine implements a new exploration task based on predefined settings and assigns a point within the predefined area at which the explorer begins. The main element of the task is a window which displays Google StreetView and which can be manipulated in the same way that StreetView can, increasing familiarity for volunteers. Participants then explore the area through StreetView and identify items and areas of interest, which they then record and image through a built in image-capture function. These can then be triangulated and compared for quality assurance.
To ensure the diversity of submissions, the VCE features a taboo mechanism. This allows requesters to define certain pre-recorded items of interest as ‘taboo’, preventing volunteers from marking them again. Additionally, start points can be generated at random or selected manually to promote exploration of otherwise under-considered areas.

We are currently evaluating the VCE and more information on the system, the evaluation process and the outcomes can be found in the linked publication[5].

4.5 New Interaction

Studying communities in citizen scientists activities is becoming increasingly of interest and therefore we describe hereafter a methodology to study drivers of human behaviors inside

[5] https://arxiv.org/pdf/1901.09264.pdf

communities of citizen scientists through surveys using the CONEY toolkit, explained in deliverable 4.1.

To start, the key point is to have clear in mind the goal of the study and which is the phenomena to measure and analyse. Then a study of the state of the art of existing methodologies and guidelines can follow; for example, pre-existing questionnaires from literature on the same topic can be taken as inspiration. This guarantees that the study is reliable and up to date to current research on the topic.

Since the study of human-generated information usually implies the identification of latent phenomena (also named latent variables or subscales in literature) that may be correlated and may influence the investigation main goal, the survey has to include some questions inspecting these factors.

While designing the survey it's important to balance the length of the survey with the amount of information to be collected. For this reason the selection of a subset of questions is a step that cannot be missed during the survey design phase. A too long survey risks to be too boring for survey compilers and this can lead to lower-quality data collection.

After the question selection, the next step is the actual creation of the survey flow using the CONEY Create component. At this stage the "storytelling" is added to the survey, by defining the survey as a sequence of questions and conversational elements (text, images and gif) to make the survey more enjoyable and to help personalizing the conversation flow. By using this conversational elements it is possible to guide users more closely during the survey filling and give to the compilers personalized interviews based on the answers given.

Below, as an example guide, we present the list of steps followed to set up a survey to study citizen scientists motivation within the TESS network initiative [https://tess.stars4all.eu/network/]. In this campaign citizens are mainly involved in a data collection task, which consists in hosting and installing photometers to measure the level of sky brightness to fight light pollution.

Step 0: Goal definition

The survey aims to evaluate the level of motivation of participants to the TESS-photometer Citizen Science projects. Thus, the main investigation goal is the global motivation of participants.

Step 1: state of the art

We searched in the literature existing questionnaires and surveys used to evaluate the level of motivations of participants to Citizen Science projects. We discover that a "motivation for Citizen Science Scale" has been defined by The Citizen Science COST Action after an overall analysis of 280 items harvested from 32 papers, categorized to represent 18 types of motivations to participate in citizen science projects. We decided to use the 58-item questionnaire to measure citizen scientists' motivation developed here as a starting point to define our TESS-motivation survey.

The 18 categories of questions are based on the basic values defined by Schwartz. Further details in his article "An Overview of the Schwartz Theory of Basic Values", (Schwartz 2012).

Another reference we looked at is the case study "The social fabric of citizen science—drivers for long-term engagement in the German butterfly monitoring scheme" (Richter, 2018). It was useful as a comparison example and it helped us to select the most relevant questions among all the previous 58.

Step 2: latent variables definition and questions selection

Starting from the set of categories of the 58-item questionnaire, we selected the categories that are more relevant for our case study (*self-direction, stimulation, hedonism, achievement, power, conformity, benevolence, universalism*). We also add 6 new custom categories to better analyze this specific use case; they are *routine, data usage, belongingness, info, engagement and pay*. Overall, they represents the 14 latent variables of the model we use for the analysis.

Then we made a selection out of the 58 questions, in order to make the survey shorter and less boring, and we add some custom questions to better fit the specific use case. We decided to keep the survey balanced by selecting two questions for each of the latent variable. We customized the formulation of the questions in order to make them more specific to the TESS photometer context. Overall we obtained a list of 28 questions.

We made this selection using an excel file in which we listed all the questions, sorted by compilation order; we tag each question with its category and we define the interaction type of each question (open, option, star, checkbox, emoji, slider) and the corresponding possible answers.

As an example, here is the excel compiled for TESS-photometer survey https://drive.google.com/open?id=17BAN5W4UaueaVmflvxEydxsI09rIJ-c0 .

Step 3: survey creation

Once all the questions have been defined, we used the *Coney Create* tool to design the final survey. In this phase the "storytelling" is added to the survey, by defining the survey as a sequence of questions and conversational elements (text, images and gif) to make the survey more enjoyable and to help personalizing the conversation flow. In addition different branches can be created to customize the conversation according to the answer given by the user.

To guide users during the survey filling, we adopt the storytelling to contextualize groups of similar questions and to give to users feedbacks about the survey completion status.

The analysis of the results of this questionnaire will be included in deliverable D5.6.

5 Initial Guidelines

Here, we outline initial guidelines inferred from our typology, identified challenges and work carried out so far.

1. **Consider volunteer participation patterns**
   Pollution is an ever-present concern, yet some forms of pollution are invisible or otherwise hard to recognise. Asking volunteers to simply record pollution may bias results, yet more ubiquitous methods of data collection - such as sensors or smartphone applications - risk distancing volunteers from the scientific process. Consider the level of activity expected of volunteers, the context in which they will gather data and what tools and materials they will have with them at the time.
2. **Consider project aims when defining volunteer engagement**
   Even otherwise very similar projects can have very different aims. A project which aims to raise awareness and promote education is much less likely to be concerned with the validity of gathered results than an investigative, research-driven project. At the same time, educating volunteers may be much more easily achievable in restricted, one-on-one or small group sessions than remotely.
3. **Match task types to expected crowd size**
   Some citizen science tasks can be completed much more quickly, easily and rapidly than others and require much fewer participants. If a project aims to simply gather examples of plastic pollution in a small area, then a simple cataloguing task is fine. On the other hand, if the project requires information which volunteers may be unfamiliar with, then a more supplementary-based methodology may be necessary, in which case the size of crowd may become unmanageable. For every volunteer contributing images or records, an equal number of volunteers describing those records is required. Carefully consider the types of task and activity that will be carried out and how these might align with the size of the crowd involved.

4. Diversify input devices
   If citizen science projects are to be truly accessible, then they must be open and welcoming to all volunteers. Underprivileged groups, more elderly participants or those with disabilities may have considerable difficulty with contributing through certain devices, tools and methods -- such as expensive sensors or devices. Where possible, offer multiple input devices or consider how the input mechanisms can be adapted or made accessible for other stakeholder groups.

5. Open up the scientific process
   Participants can offer potentially vital knowledge and experiences which project administrators have overlooked. Moreover, allowing volunteers to participate in multiple stages of the scientific process promotes learning and can strengthen volunteers' intrinsic

motivations to participate in a project, leading to increased contributions and appreciation of both the project and scientific research.

6 Conclusions and Future Work

This deliverable outlined a typology of the characteristics affordances and requirements of citizen science tasks, with a particular focus on those within the domain of pollution. We clustered projects according to commonalities in terms of the tasks requested of volunteers, the project aims and the expected outputs, identifying strengths, weaknesses and requirements of these tasks. We further provided a sample of 81 pollution-related citizen science projects, drawn from Wikipedia, SciStarter and contributions from stakeholders in the domains of citizen science and pollution. Based on this work, we identified 5 key areas for research surrounding the design and implementation of tasks, while outlining preliminary research which we have conducted in each of these areas.

In future work, we will develop this sample further, building upon the preliminary research and provisional typology to develop guidelines for task design, accounting for differences in task-types, input affordances, assets and domain.

7 References

Baker, Gretchen M., et al. "The bioblitz: Good science, good outreach, good fun." *Park Science* 31.1 (2014): 39-45.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977-984.

Boutsis, I., & Kalogeraki, V. (2014, June). On task assignment for real-time reliable crowdsourcing. In *2014 IEEE 34th International Conference on Distributed Computing Systems* (pp. 1-10). IEEE.

Curtis, V. (2018). *Online citizen science and the widening of academia: distributed engagement with research and knowledge production*. Springer.

De Lellis, P., Nakayama, S., & Porfiri, M. (2019). Using demographics toward efficient data classification in citizen science: a Bayesian approach. *PeerJ Computer Science*, *5*, e239.

Foster, M. A., Muller, L. I., Dykes, S. A., Wyatt, R. P., & Gray, M. J. (2013). Efficacy of BioBlitz surveys with implications for sampling nongame species. *Journal of the Tennessee Academy of Science*, *88*(3-4), 56-62.

Haklay, M. (2013). Citizen science and volunteered geographic information: Overview and typology of participation. In *Crowdsourcing geographic knowledge* (pp. 105-122). Springer, Dordrecht.

Kim, J. S., Greene, M. J., Zlateski, A., Lee, K., Richardson, M., Turaga, S. C., ... & Campos, M. (2014). Space–time wiring specificity supports direction selectivity in the retina. *Nature*, *509*(7500), 331-336.

Mugar, G., Østerlund, C., Hassman, K. D., Crowston, K., & Jackson, C. B. (2014, February). Planet hunters and seafloor explorers: legitimate peripheral participation through practice proxies in online citizen science. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing* (pp. 109-119).

Nakayama, S., Diner, D., Holland, J. G., Bloch, G., Porfiri, M., & Nov, O. (2018). The influence of social information and self-expertise on emergent task allocation in virtual groups. *Frontiers in Ecology and Evolution*, *6*, 16.

Richter, A., Hauck, J., Feldmann, R., Kühn, E., Harpke, A., Hirneisen, N., ... & Bonn, A. (2018). The social fabric of citizen science—drivers for long-term engagement in the German butterfly monitoring scheme. *Journal of insect conservation*, *22*(5-6), 731-743.

Sauermann, H., & Franzoni, C. (2015). Crowd science user contribution patterns and their implications. *Proceedings of the national academy of sciences*, *112*(3), 679-684.

Schäfer, T., & Kieslinger, B. (2016). Supporting emerging forms of citizen science: A plea for diversity, creativity and social innovation. *Journal of Science Communication*, *15*(2), Y02.

Schwartz, S. H. (2012). An Overview of the Schwartz Theory of Basic Values. Online Readings in Psychology and Culture, 2(1). https://doi.org/10.9707/2307-0919.1116

Wiggins, A., Newman, G., Stevenson, R. D., & Crowston, K. (2011, December). Mechanisms for data quality and validation in citizen science. In *2011 IEEE Seventh International Conference on e-Science Workshops* (pp. 14-19). IEEE.

Wiggins, A., & Crowston, K. (2012, January). Goals and tasks: Two typologies of citizen science projects. In *2012 45th Hawaii International Conference on System Sciences* (pp. 3426-3435). IEEE.