Monitoring Ocean Microplastics Through Citizen Science

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Abstract

The goal of this project was to develop parameters for a citizen science program through which participants utilize a web-based application to monitor ocean microplastic along New England coastlines. The proposed framework for a citizen science program prioritizes the engagement of participants to three ends: to increase public education and awareness of the problem of plastic pollution in oceans and along coastlines; to increase public advocacy for policies that address plastic pollution; and finally, to provide an important source of data on microplastics to contribute to existing datasets. Through interviews and reviews of existing citizen science programs, we identified five *Principles of Design* that every citizen science program should follow, including:

1. Simple and Repeatable - to ensure the best chance for accurate and reliable data.
2. Short Duration - to engage participants while not draining their time or energy.
3. Educational/Awareness - to increase awareness and knowledge of an issue.
4. Build Community - to create a sense of togetherness and accomplishment.
5. Engaging - to increase participant enjoyment and commitment at every step.

We then developed a framework of *Program Components* to implement these *Principles of Design*, including:

1. Outreach Materials - to garner an audience and engagement in the program.
2. Informative Materials - to educate participants on the importance of the program.
3. Data Collection Protocol - to ensure participants can collect sound data.
4. Mobile Application - to facilitate data entry and information sharing.
5. Follow-up - to retain participants and remind them of their impact.

The program framework includes a web-based application, through which participants conduct visual counts of microplastic samples using the app's displayed heat maps of high-value areas of sample need and microplastic concentrations. The project represents an innovative and effective approach to engaging citizens in scientific research and promoting environmental stewardship.

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Authorship

Iris contributed to the majority of plastic research and the main motivations for it as the center of our project. She also conducted much of the critical citizen science research and organized many of the interviews and much of the information collected from them. Iris compiled the information that was collected from document review and interviews into the Principles of Design.

Colby contributed largely to the citizen science and computer science portions of the project, conducting extensive background research in both sections. He built the web-based application in its entirety and identified the future of the project. Colby also identified the crucial Program Components of which he created the majority of.

Both Colby and Iris worked together to create the goal, objectives, methodology, and various other sections of the project. Additionally, they were each consistently reviewing the other’s contributions.

Introduction

It is hard to believe that less than a hundred years ago, there was no such thing as plastic. Today plastic pollution in our environment is prevalent and makes up much of the trash around us. There is scarcely a place in the world not contaminated with plastic trash. To show the broad range of plastic in the environment, a team of researchers set out to test biomarkers to find where in the world plastics had not contaminated nature. Because they are ubiquitous on every continent other than Antarctica, the researchers examined ants for traces of additives embedded in their skin upon first contact with plastic. At the end of several years of testing ants around the planet, including the few locations farthest from any human activity, they discovered not a single ant that did not contain traces of plastic. Likewise, an environmental health expert said of plastic pollution, that *"there is no untouched centimeter"* (Schlanger, 2019).

One place plastic always ends up is the ocean. Every year, up to 14 million tons of plastic are estimated to flow into marine waters. The majority of plastic is indirectly polluted from land while the remaining 20% of plastic is directly deposited into the oceans by marine sources (Statista, 2023). As synthetic debris accumulates in the environment, there is little chance for the plastic to become integrated into the natural environment, since much is non-recyclable, but all is non-biodegradable. Foreign to the natural environment, plastic pollution leads to environmental degradation in many ways, including habitat disruption, decreased biodiversity, and climate change. Marine ecosystems are particularly vulnerable to plastic pollution due to their inherent interconnectivity and interdependence of the living organisms residing within. It is increasingly concerning that the smallest microplastics can be traced up through trophic levels, facilitated by ingestion, resulting in devastating effects caused by chemical toxins being released from the plastic particles, as if functioning as a sponge (Le Guern, 2019). Humans are at the peak of all trophic levels as we are frequent consumers of seafood, therefore we are not safe from the impacts of ocean plastic (Mohamed Nor et al, 2021). No matter where plastic resides in the environment, there will be impacts on the surrounding area exponentially affecting the living flora, fauna, and humans that live connected to each other thanks to the environment. Therefore, it remains the job of the polluters, humanity, to rectify these impacts.

While there is increasing attention to the problem of ocean plastics, there is a persistent gap in our understanding of how ocean plastics accumulate along coastlines. Most research has focused on understanding the surface debris forming country-sized plastic islands. Researchers, however, have been struggling to explain why the influx of plastic to the entire ocean is 10 times the magnitude of plastic quantified in its surface waters. The answer to this "missing plastic issue" became clear when new data suggested that shorelines have become a common environmental sink for the majority of ocean plastic debris (Ritchie, 2019).

Citizen science is one approach to environmental problems like ocean plastics that uses crowdsourcing to collect data, and public engagement to improve awareness, understanding, and advocacy around the plastic waste problem. It is a useful approach to improving our understanding of how ocean plastics accumulate along coastlines for several reasons. First, it uses crowdsourcing to collect data that can then be contributed to databases such as NOAA's global NCEI *Marine Microplastic* mapped database (National Centers for Environmental Information, 2018). Secondly, it sparks public engagement in the issue of ocean plastics to improve awareness and education about this environmental problem. Finally, in addition to fostering awareness of the ocean pollution issue, public engagement can increase advocacy for working towards pristine beaches. Citizen science is an exciting approach to research and education in a new field of scientific study that utilizes the potential of the public to make groundbreaking discoveries with unique benefits for all involved.

The goal of this project is to develop parameters for a citizen science program through which participants utilize a web-based application to monitor ocean microplastic along New England coastlines. In order to design the citizen science program, we will work towards the following three objectives:

1. *Identify* best practices, limitations, and effective tools used for current citizen science programs.
2. *Determine* software techniques that can promote accessible, engaging, and efficient human-computer interactions in citizen science.
3. *Recommend* best practices for a citizen science ocean plastic monitoring program and provide a model derived from those recommendations.

Chapter 1: Background

Section 1 Plastic

1.1 - The Magnitude of the Ocean Plastic Issue

Since the invention of plastic in 1907, the revolutionary synthetic material has grown more rapidly and grown more widespread than any commonly used material (Eriksen et al, 2014). As a synthetic, plastic remains durable even with thousands of years of environmental exposure expanding the chance for negative impacts beyond comprehension. Plastic production worldwide was estimated to be 460 million tons in the year 2019 (Ritchie & Roser, 2022). Furthermore, “Much of this is not recycled and is disposed into the natural environment, has a long environmental residence time, and accumulates in sedimentary systems worldwide, posing a threat to important ecosystems and potentially human health” (Kane & Clare, 2019). The annual influx of new plastic into the environment has not slowed, so where is it all going? Research suggested that plastic accumulating in the ocean’s surface water had reached 5.25 trillion pieces of debris in 2014, roughly weighing 268,900 tons in total (Eriksen et al, 2014). For reference, this weight is comparable to the combined weight of an astonishing three million people, under the assumption that 10.8 average-sized people are required to weigh a single ton (CDC, 2021).

(Text Box) Where is the Plastic Coming From?

There is an undeniable ubiquitousness when it comes to plastic pollution in the environment. Plastic occurs in the environment for many reasons and through many processes. When analyzing the enormous presence of plastic in marine environments, it has been found that “the only major source of plastics to the ocean that has been estimated globally is improperly managed plastic waste generated on land” (Law, 2017). When trash and plastic pollution is deposited on land, typically into landfills, weather, erosion, and other environmental influences can dislodge plastic trash and propel it on a long journey to the ocean. Rivers play a part here too, ending at the coastal transition to the ocean, making beaches and shorelines the first stop plastic debris may make during their time in the ocean, and sometimes their last. “Factors such as climate, terrain, land use, and distance to the ocean suggest that many smaller rivers play a bigger role than we thought. It takes 1,600 of the biggest emitting rivers to account for 80% of plastic inputs to the ocean” (Ritchie & Roser, 2022).

1.2 - What Happens to Marine Plastic Debris Over Time?

Of the existing ocean plastic data, more is understood about the status of plastic pollution on the ocean’s surface but there is limited data concerning accumulation along shorelines or in the deep ocean. When thinking critically about how much plastic must have entered the oceans over the decades, the total estimate of remaining plastic, even contained to the surface, should exceed millions of tons - much more than most estimates. Researchers call this conundrum *the* *missing plastic issue* (Ritchie, 2019). Some key explanations offer potential insight into where the missing plastic has disappeared too, including deep ocean and coastal environments by accumulating in sediment and still waters. “Once introduced into coastal waters, a fraction of plastic litter is transported to offshore waters and another settles or strands on landmasses in coastal environments” (Lebreton, 2019). To visualize this flow of plastic through the global marine sections Figure 1 shows the flow of circulation through the ecosystem along with accumulation percentages.

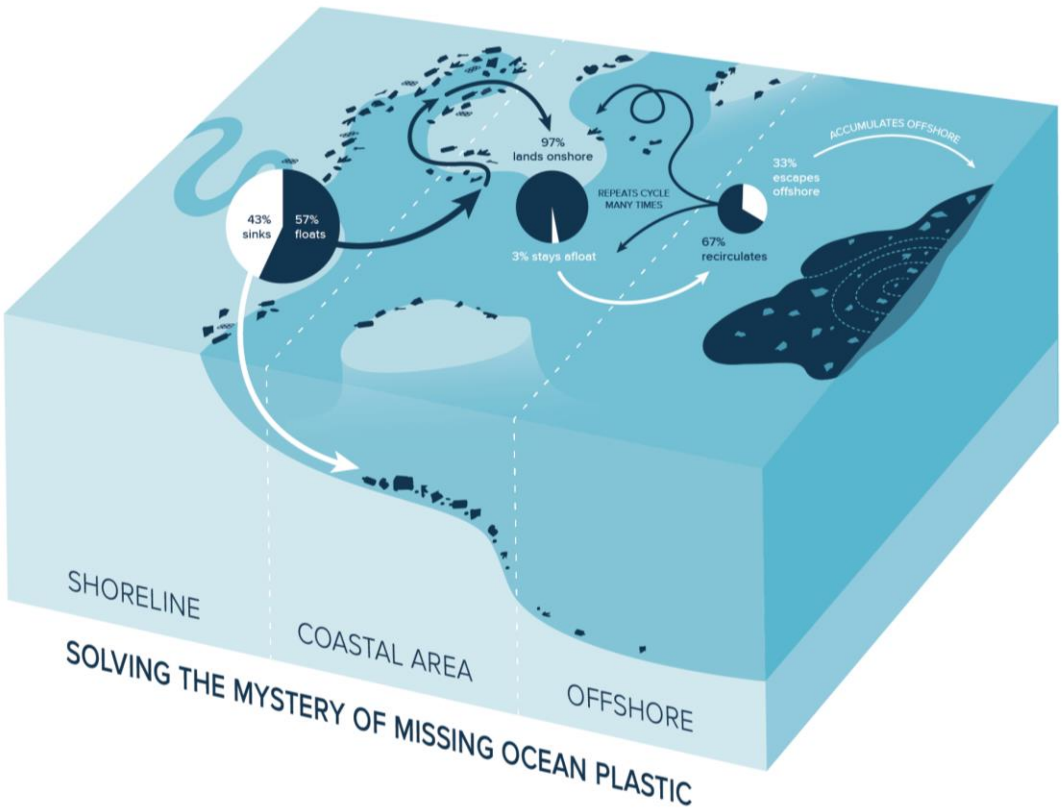


Figure 1: The Journey of Floating Ocean Plastic from Rivers to Garbage Patches

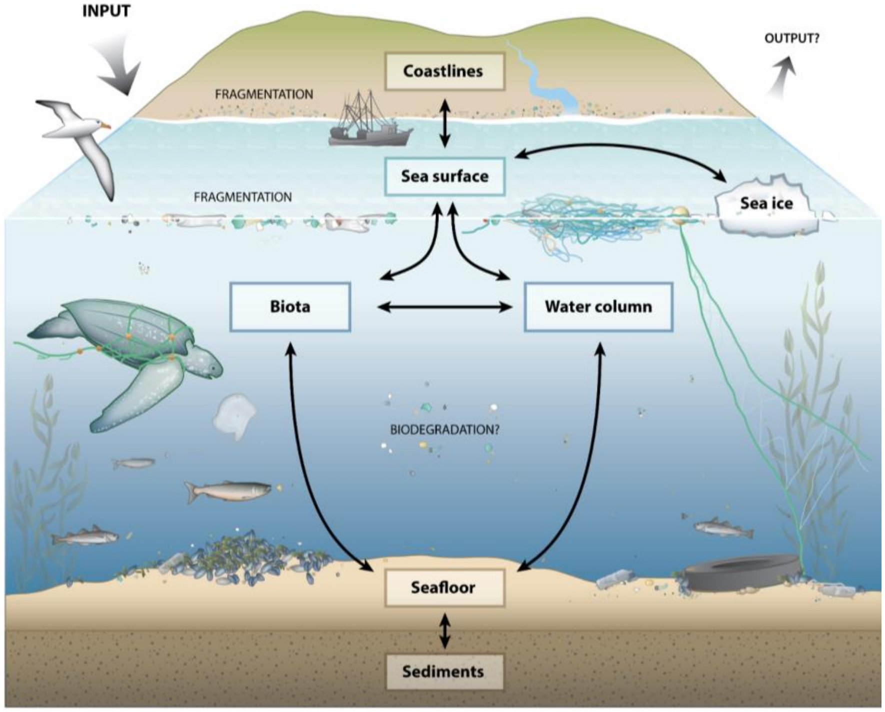
Recent research explains that “whilst we try to tally ocean inputs with the amount floating in gyres at the center of our oceans, most of it may be accumulating around the edges of the oceans” (Ritchie, 2019). This explains why most of the plastic entering the ocean ends up accumulating along shorelines and coastal areas, as “the vast majority – 82 million tonnes of macroplastics and 40 million tonnes of microplastics – is washed up, buried or resurfaced along the world’s shorelines” (Ritchie, 2019). Pollution accumulation in coastal habitats is difficult to predict and harder to quantify, but accessible to clean up. Before cleaning efforts can begin, the efforts must have a set destination, along with an understanding of the debris dispersal patterns in the different environments. Plastic will end up under the surface when it is either too heavy or too small to stay afloat. One estimate suggests that 66.7% of marine plastic has disappeared below the ocean’s surface due to high-density plastics losing buoyancy or by fragmentation creating microplastics that are too small to remain floating at the surface. Coastal beaches and shorelines have accumulated 23.4% of ocean plastic, particularly microplastics as they become combined with beach sand. Which leaves only 9.9% of all the plastic in the ocean remaining in the visible surface waters (Isobe, & Iwasaki, 2022). It is important to note that not all pollution in the ocean is plastic, it also consists of materials such as wood, paper, metal, glass, textiles, and rubber. However, plastic is the most persistent in the ocean as it is resistant to biodegradation, unlike other materials (Law, 2017).

Microplastics

As these various types of pollution spend more time in the marine environment the materials decompose and disperse into the ocean. As plastic pollution decomposes it creates these small pieces of plastic, called microplastics. Microplastic is a general word often used to refer to small pieces of plastic in our environment, but they are classified by size more specifically. Ocean plastic is considered to come in four sizes as the material deteriorates. The largest macroplastics describe any plastic debris over 200 mm in size. One step down is mesoplastics which are between 4.76 to 200 mm. Then, there is the largest size of microplastics 1.01-4.76 mm, and the smallest microplastics 0.33-1.00 mm. Curiously, 94% of the pieces of plastic in the ocean are microplastics, however, the weight of all the microplastics only accounts for roughly 11% and 3% of the plastic in the ocean, at 35,540 tons (Eriksen et al, 2014). Constantly exposed to harsh weather and ocean tides, one year of friction and salt water can be enough to turn a plastic water bottle into micro-sized pieces of plastic (Eriksen et al, 2014). The behavior of microplastics in marine environments is unique to other plastic debris size categories. As a result, “The particle size distribution of plastic marine debris has not been satisfactorily measured in any marine reservoir” (Law, 2017). Future marine research focused on microplastics attempting to fill the gaps in the current knowledge would hold great value for those attempting to address the issue of marine plastic pollution through environmental cleaning.

The Movement of Plastic in the Ocean

During its time in the open waters, debris will roam until it becomes caught up in one of the typical marine systems of plastic entrapment, which include coastal ecosystems, the global ocean circulation system, ocean gyres, or the marine food chain (MacPhee, 2022). Though each of these has a different designation, every aspect of the marine system is connected. Figure 2 below visualizes the movement of ocean plastic through the interconnected marine ecosystems along with locations where plastic fragmentation typically occurs. The author originally included the following description to accompany this figure, “The large gray arrows indicate fluxes into and out of the marine environment, including potential biodegradation of plastics. The boxes indicate reservoirs of plastic debris, and the black arrows indicate fluxes into and out of the marine environment, including the potential biodegradation of plastics. The boxes indicate reservoirs of plastic debris, and the black arrows indicate potential pathways of plastics between reservoirs. Fragmentation of plastics caused by weathering and biological processes can occur in all reservoirs, especially when exposed to sunlight (at the sea surface and along coastlines)" (Law, 2017).



Law KL. 2017.
Annu. Rev. Mar. Sci. 9:205–29

Figure 2: The Mass Balance of Plastics in the Marine Environment (Law, 2017)

1.3 - The Impacts of Plastic Pollution

Toxicity

All types and sizes of plastic are harmful to the environment, marine life, and humans; however, their differences determine the severity and extent of impacts. Plastic as an unnaturally occurring material has key characteristics that intensify its ability to disrupt the natural world. Especially when introduced to water, negative impacts are exacerbated "because of plastic's inherent properties: buoyancy, durability (slow photodegradation), propensity to absorb waterborne pollutants, its ability to get fragmented in microscopic pieces, and more importantly, its proven possibility to decompose, leaching…toxins in the seawater" (Le Guern, 2019). The topic of microplastics specifically is a serious emerging issue that has yet to be globally recognized. Through an understanding of how these small particles are changing the health of the environment, and therefore human lives, there is an opportunity to educate the world on exactly why they should care. "With the continued growth of plastics production worldwide, the abundance and risks of plastics in the marine environment warrant concern and motivate research not only to quantify plastics contamination and its biological, ecological, social, and economic impacts but also to inform solutions" (Law, 2017).

Climate

The context of this issue not only concerns the ocean, but plastic is also threatening the health of the entire marine ecosystem. Affecting one key environment changes the health of the entire planet through climate change, “The sea surface also connects the ocean and the atmosphere and controls important exchanges between those two systems, including the flow of oxygen, which is an essential element for life, and the flow of carbon dioxide, one of the main gasses responsible for climate change” (Galgani & Loiselle, 2020). Therefore, the presence of plastic in oceanic systems poses more than aesthetic concerns, the disruption from plastic circulating in this environment represents a serious threat to the function of the entire ocean, the planet’s climate, and therefore all living things (Le Guern, 2019). The circulation of ocean currents is vital to the function of the entire earth’s climate system. The implication is that the failure of the ocean to properly circulate means launching the planet into another ice age. However, few may realize that an irreplaceable cog in this function is partially filled by the everyday activity of whales. Whales are the top contributor to the vertical mix of marine waters, therefore implying that their deep dives facilitate the continuous circulation of currents within the entire ocean. Shining the light on yet another way that the entire planet is threatened by the very presence of plastic debris in the ocean, is through the entanglement of whale populations (Animal Welfare Institute, 2017). Whales, however, are not the only species affected by the introduction of plastic into marine ecosystems.

Biodiversity

The main dangers that marine plastic poses to animals are ingestion and entanglement. One measure of impact was confirmed by a study, in which plastic was found to have negatively affected over 1200 marine species (5Gyres, 2021). Entanglement occurs, for example, when mile-long fishing nets floating abandoned in the sea are referred to as Ghost Nets notoriously trap fish, crabs, turtles, birds, dolphins, sharks, and whales. Lost to sea, these nets continue to work as intended: restricting the movements of animals by entanglement leading to lacerations, infection, and even suffocation for species that require the surface to breathe (Le Guern, 2019).

Accidental ingestion of marine plastic debris by animal organisms is one of the most detrimental impacts of plastic pollution in the ocean. When marine life and seabirds ingest large amounts of plastic pollution, they can become malnourished. Thousands of animals die annually from starvation due to indigestible plastic filling up their stomachs leaving no room for nutritional food to be consumed (Le Guern, 2019). The movement of plastic particles through trophic levels via ingestion by animals low on the food chain intensifies the very hazard of plastic in the environment. Researchers have proven that “plastic does soak up pollutants, acting as toxic sponge for man-made toxins present in the ocean, thus accumulating pollutants” (Le Guern, 2019) up to a point where “a single plastic microbead can be 1 million times more toxic than the water around it” (5Gyres, 2021). The ingestion of plastic by animals has the potential to poison the creature by releasing toxins trapped within the plastic material. Additionally, these toxins ascend the trophic levels within the creature's flesh through a process called bioaccumulation (Rodrigues et al, 2023). What is often left unconsidered, is that humans are at the very top of every trophic level, thus insinuating the potential of health issues as a result of consuming seafood.

Humanity

As concern for the increasing level of harmful toxic plastic pollution infiltrating the marine environment rises, more attention has been placed on compiling a scientific understanding of the risks to human health. We have established that microplastics contain toxins that become a threat once ingested, ascending until they reach the top of trophic levels, typically ending with people. When concerning the ingestion of contaminated food, there is no denying the possibility that "microplastics found in food types such as seafood and salt may have adsorbed chemicals from the environment it originated from" (Mohamed Nor et al, 2021). Conclusive research on the magnitude and impacts of human exposure to microplastics remains to be conclusively researched. "These uncertainties have resulted in many controversies regarding the potential risks that microplastics may pose to human health" (Mohamed Nor et al, 2021). It remains that humans are actively being exposed to microplastics, presenting another plastic-related topic for future scientific research.

1.4 - New England Coastlines

Historically, New England is a very important area of the world to monitor ocean plastic as it was the first location to ever be studied for the presence of ocean plastic in the 1970s. The original research article, *Polystyrene Spherules in Coastal Waters,* stated that "Polystyrene spherules averaging 0.5 millimeters in diameter (range 0.1 to 2 millimeters) are abundant in the coastal waters of southern New England" (Carpenter et al, 1972). This study spurred additional research and resulted in a fascinating area of study of plastic distribution, accumulation, and deposits in marine environments. In consideration of New England specifically, the habitats threatened by the accumulating presence of plastic in the marine ecosystem are;

- Salt Marshes
- Rocky Coastal Habitats
- Mud Flats
- Shellfish Beds
- Eelgrass Beds
- Kelp Forests
- Water Columns
- Sandy Coastal Habitats

When attempting to address the issue of plastic in these coastal New England habitats, it is important to remember that each habitat presents different levels of accessibility. Due to the unique landscapes, sodden materials, biodiversity, and physical access, there are many considerations that need to be made when planning to monitor each habitat. Public access to deep ocean locations presents a different level of accessibility in comparison to shorelines and beaches. Therefore, the most consistently safe and accessible habitat remains to be sandy beaches along the coast. Not only is a sandy beach a widely acceptable sodden soil type for the general public, but additional accessibility features such as ramps and sand mats, are common at state and town-owned beach locations (Mass.gov, 2023).

Monitoring efforts must also take into consideration what the program seeks to research, in this case, microplastics. The 5 mm or smaller pieces of microplastic exist in the environment at the mercy of natural powers of movement, creating a difficult task for outsiders to predict and trace every potential path each microplastics may take before accumulating someplace to monitor. During a conversation with interviewee Neil Blake, the Baykeeper of Port Phillip Bay in Australia, the concept of how the geography of an area reflects the number of microplastics deposited or accumulating in that environment was discussed. It was learned that in the case of coastal habitats with "shorelines with hard seawalls and things like that, generally the wave action will often hit those walls and will cause turbulence that will often carry the microplastics further away." Furthering our understanding that "You're more likely to find an accumulation of microplastics in sandy beach areas than in an area with a lot of hard substrates." Therefore, our project will focus on addressing the accumulation of ocean microplastic on the coastlines of New England, as it is the most accessible type of marine habitat for accumulation to occur that will facilitate a citizen science program that achieves our projected goals.

1.5 - Current Efforts to Address Ocean Plastic

Here we examine Organizations that currently exists to tackle ocean plastic in various ways. The assessment of their efforts and methods will guide our understanding of the people and organizations that are currently addressing the ocean plastic issue while also highlighting any gaps in what efforts exist. During our research, the information we gathered was accumulated and presented in one table, as seen in Table A found in Appendix A. The breakdown comparison between organizations related to ocean plastic data can be divided into three main categories. The groups are "Citizen Science Organizations," "Organizers of Beach Cleanups," and those who are mainly focused on "Data Collection for Storage." Within these groups, there are organizations that differ in their focus on debris type, collection method/ location, data type/storage, and some organizations that could fit into any combination of these groups. The table compares each of these areas by generally separating the organizations by their range status; Global, National, or Local.

Citizen Science Organizations

Organizations in Table A currently utilizing Citizen Science to collect data on marine pollution are The Ocean Cleanup, Adventure Scientists, and the EPA's Microplastic Beach Protocol. The approaches these three organizations use for data collection, quality, usage, and storage vary, therefore the examples they set provided this project with a range of potential decisions for these categories. What we found was that most were indeed cleaning up plastic, but no one was attempting to clean microplastics specifically through their programs. For example, The Ocean Cleanup is an organization working to “clean up 90% of floating ocean plastic,” (The Ocean Cleanup, n.d.) globally by only focusing on the ocean’s surface plastic.

Organizers of Beach Cleanups

The last category of organizations was those that specialize in beach cleanups. Table A highlights the following groups to fit into this characteristic; the globally active International Coastal Cleanup (ICC), Blue Ocean Society of Marine Conservation based in the US state of New Hampshire, Ocean Conservancy’s CoastSweep in Massachusetts, and the Maine Island Trail Association. Each organization is operated in its own way, the Blue Ocean Society of Marine Conservation is a “non-profit that protects marine life in the Gulf of Maine through research, education and inspiring action” (Blue Ocean Society for Marine Conservation, (n.d.). Specialized in beach cleanups, Blue Ocean can be hired to host and lead corporate, public, or private, cleanup events, or will help organize an event by supplying materials and instruction only. However, what never came up as part of these organizations' efforts was a method to address the accumulation of microplastics specifically, during beach cleanups or organizational efforts in house.

Data Collection for Storage

The last set of organizations interact with Ocean and Microplastic data through creation and storage using databases. These businesses range from global status, National Centers for Environmental Information (NCEI), to National, as in Scotland’s Marine Environment’s accumulated findings from its now finished citizen science program. Publicly storing collected data ensures it is fully accessible to governments, businesses, researchers, and individuals who use this information to limit or address plastic waste. The NCEI has been accumulating data on microplastics in the environment for roughly 50 years to facilitate the efforts “To improve water quality and protect the ecosystem, especially coastal ecological habitats” (National Centers for Environmental Information, 2018).

Section 2 Citizen Science

2.1 - What is Citizen Science?

Citizen Science is a process of data collection through the participation of the public in the scientific monitoring process. Citizen science **increases scientific knowledge** through public collaboration, wherein the public usually participates as unpaid volunteers. “It can function as a means of engaging the public with science on the scale of individual experiments, creating a unique position of combining participation, monitoring, and social change” (Roche et al, 2020). Within the monitoring programs, participants have the opportunity to engage in scientific activities while sharing findings in order to contribute to a larger initiative. Alternative viewpoints may highlight the potential for data to help uncover and more fully understand the issues at hand. In this regard, it should be noted that “Citizen science data are used extensively in studies of biodiversity and pollution; crowdsourced data are being used by UN operational agencies for humanitarian activities; and citizen scientists are providing data relevant to monitoring the sustainable development goals (SDGs)" (De Sherbinin et al, 2021).

According to an EU analysis of citizen science practices for environmental policy, it was determined that there are three main methods of coordination: so-called the 'contributory,' 'collaborative,' and 'co-created' methods. **Contributory** is the most common type of program "designed by scientists but enlisting the help of volunteers to collect monitoring data" (Bio Innovation Service, 2018). Recently, there has been a growing interest in public involvement, which has led to the **collaborative** type of programs that are "designed by scientists with volunteers contributing data, refining project design, analyzing data or disseminating findings" (Bio Innovation Service, 2018). The remaining projects have been named **co-creating**, as the "scientists and volunteers collaborate throughout all stages of the scientific process" making this option the most collaborative process, involving the participants in the planning process (Bio Innovation Service, 2018).

Depending on the design, **the program may be targeted** to engage any level of expertise, from the untrained public, youth, and students to amateur scientists and educators. Those involved in these programs will often incentivize their own projects by generating local ideas to advance or understand their place in the world, especially driven by local communities. In such cases, the public may seek to engage with scientists in search of leadership, advice, or program coordination (Ullrich, 2023). This results in many different ways to coordinate the work between the scientific researchers and the participants.

2.2 - Benefits of Citizen Science

The growth of citizen science over the past decade is not surprising when one considers its many benefits. These benefits include the following, each of which is discussed below;

- Scientific educational insight
- Engagement, awareness, empowerment
- Community building

Educational

By involving the public in informal and formal methods of scientific research there is an opportunity for citizen science to be used as an educational tool. As citizen science expands as its own distinct field of research, it generates new understandings and knowledge through collaboration with the public in scientific practice. With the growth of this field of study, the educational value of these programs becomes an important consideration in the planning process. Citizen science programs all have the potential to foster learning when purposeful steps are taken to integrate educational opportunities. Citizen science programs facilitate a unique opportunity for the scientific community as they are typically tailored to be completed by amateur scientific researchers. They also have the ability to "develop connections between students' everyday lives and science so that they will have tangible reasons for continuing with the lifelong learning of science" (Jenkins, 2011, p. 501). Over time, there has been progress to mindfully foster environments for learning within citizen science by the program's developers.

Such efforts, however, have not gone without their own challenges, mainly that it is difficult to infer educational values from programs that were designed with learning as an afterthought. The best way to provide opportunities for learning through participation in these programs is to be aware of it from the beginning of the planning process. Proper support is required to ensure that the integration of education and citizen science can be achieved (Roche et al, 2020). To understand what kind of support will be the most successful, a report by the US National Academies of Sciences, Engineering, and Medicine addressed its personal goal to "identify promising practices and programs that exemplify the promising practices and lay out a research agenda that can fill gaps in the current understanding of how citizen science can support science learning and enhance science education" (National Academies of Sciences, 2018, p. 2).

Engagement, Awareness, and Empowerment

Citizen science can inspire engagement, awareness, and empowerment for the advocacy of environmental issues and policies. By participating in programs through monitoring, cataloging, and surveying the environment or society, people may have new experiences that alter the way they think about what is happening in the world and to our planet and respond publicly, by advocating for policy change, and privately, by changing personal behaviors. De Rijck notes that "...citizen science is not only about collecting data and generating useful knowledge…it is also a powerful tool for raising awareness of environmental issues and policies and involving and empowering the public" (De Rijck et al, 2020, p. 4). Furthermore, "Citizen science initiatives can both benefit from and contribute to science education, and can raise environmental awareness, which in turn can lead to behavioral change" (De Rijck et al, 2020, p. 16).

Community Building

Another benefit associated with participating in citizen science programs is community building through social interactions. These programs will often bring together large groups of local community members who otherwise may not interact in their everyday lives. Through new social interactions, there is an opportunity for growing innovative new ideas that further the potential for innovative results. *'Best Practices' in citizen science for environmental monitoring*, suggest that the,

> "creation of networks and partnerships – citizen science may create new communities of interest and improve social connections and the sense of belonging. Most initiatives bring together actors and communities who would never cooperate otherwise. Thereby, they help to establish new paradigms of communication — with or without the use of new technologies" (De Rijck et al, 2020, p. 22).

An enhanced sense of community also provides more opportunities for local change by creating a community with greater influence, as voices together are stronger than solo. As one report puts it, “community-based citizen science can help answer questions of concern that are important for local management and policy but go unaddressed by professional science” (Bio Innovation Service, 2018). Building trusted working relationships between the participants and/or the researchers offers a chance for more meaningful connections to be made. These connections can be fostered into friendships or lead to networking opportunities, both unique benefits that are likely completely unrelated to the initial purpose of citizen science programs.

2.3 - Citizen Science and Plastic Pollution

Citizen science can be an effective and multifaceted tool to combat plastic pollution. First, it can help educate individuals about the importance of keeping plastic out of the environment as well as increase awareness of how plentiful plastic is in our world. Second, with increased education and awareness, citizen science can empower participants to push for policy change, regulating the use of plastic and its lifecycle. These policy changes have already begun to happen in places around the world. For example, data collected by the Great Canadian Shoreline Cleanup, a citizen science beach cleanup initiative, helped inform policy to ban plastic bags in Canada (OceanWise, 2020). Lastly, citizen science provides a valuable means of collecting data on plastic pollution. This data can be used to identify areas where plastic pollution is most concentrated and to develop targeted solutions to mitigate the problem. Through citizen science, individuals can contribute to important scientific research and become active participants in the fight against plastic pollution. Furthermore, these initiatives often provide opportunities for community engagement and collaboration, fostering a sense of shared responsibility for environmental stewardship.

2.4 - Data

Data Collection

Citizen Science can harness the power of the public to collect environmental data and fill existing data gaps, creating another benefit for these programs to productively collect new data in previously under-monitored areas. Of course, the program’s design and intention determines the quality of data. Programs that focus on environmental awareness, for example, may put less emphasis on data quality and engage a wide range and number of people to complete simple tasks. On the other hand, other programs may focus on data quality and accuracy. For example, Adventure Scientists is a citizen science organization that requires skilled individuals to participate in their projects in order to collect information from difficult-to-access locations. From their perspective, “We achieve our mission by mobilizing and training outdoor enthusiasts and local communities to collect high-quality scientific data that are difficult to access, require too large a scale, or are too costly to obtain with traditional methods” (Adventure Scientists, 2023).

In contrast, families with young children working together to do citizen science can be great, however, may result in unwanted data. While it is true that children may not have a proper understanding of the purpose of the research, can lose interest, or invalidate data, the participation of young people in citizen science is not entirely negative. Students have accounted for a large number of citizen science participants. According to a study in Research Ideas and Outcomes, over half of the data collected by children under the age of 10 is usable (Pivarsky, 2022). How the collected data is used will determine the potential changes and success of the citizen science program in the end.

Lack of training and expertise among participants of any age can also be one of the major limitations of citizen science. This means that regardless of the intent of the citizen science program, lack of training resources not only decreases engagement but can cause the program to provide poor data as well. Citizen scientists may not have the background or experience to properly collect and interpret data, leading to inaccurate or unreliable results. This can compromise the validity of the results and the overall quality of the data collected through citizen science projects.

To accommodate the challenge of data quality, proper citizen science programs should have a thorough protocol for participants to follow, however, multiple studies cite that the greatest challenge for participants is not having enough training resources (Balázs et al., 2021). Even if protocols are well thought-out and comprehensive of the needs of the program, citizen scientists still may not follow the protocol as designed. According to the researchers, simplification of the user interface is one of the best ways to improve upon protocols being accurately followed, increasing the change of sound results (Balázs et al., 2021). According to *The Science of Citizen Science*, "In many cases, volunteers stop participating in projects as they do not know how to collect data using these protocols. Other authors have reported that participants often indicate that they are less concerned about the aims of the project or are unaware of the potential end uses of project data and are only interested in participation" (Balázs et al., 2021). For citizen scientists to collect sound data, they need to know what they are collecting it for, how it will be used, and what aspects of the data are important to maintain accuracy (Balázs et al., 2021).

Filling Data Gaps

Citizen science can be used as a method to collect information for data analysis and interpretation, quality assessments, and problem-defining. Sampling spatial and temporal bias can contribute largely to citizen science program failure. The involvement of volunteers has the potential to provide key information on previously difficult study areas.

Data Representation

Another major limitation of citizen science is data representativeness, how comprehensive the data is of the truth. Data representativeness can be caused by many factors, including but not limited to; the demography of participants, the location of citizen science programs, and research location needs. Participants may tend to be of a certain age group, ethnicity, income level, or geographical area, resulting in a lack of perspective from other groups. Additionally, many citizen science programs require the use of a computer or smartphone with an internet connection, marginalizing poor or rural communities in the research opportunity. An Internet connection can also pose problems with GPS accuracy, leading to useless data (Balázs et al., 2021). The required location for the data collection can pose challenges as well, for instance, a program developer cannot assume that their public users will be able to access the open ocean to collect information on surface plastics.

Sampling Bias

Alternatively, the citizen science program developer must anticipate the ability of their users to access the necessary locations and determine such information based on the type and quality of the final desired data. While this may be able to be solved by developing the citizen science program around a target audience in some scenarios, this is not always the case. Popularly frequented locations may have more opportunities for data collection as a result of increased foot traffic, proximity to large populations, or accessibility to the area. Contrarily, locations off the beaten path, in rural or hard-to-reach areas, will have fewer opportunities for data collection. Citizen scientists need to be informed of where data is missing, both so they can contribute meaningfully, and so they can help fill in the gaps to complete a more complete picture of the issue at hand.

For a sample to be valuable, it needs a reference point, meaning other samples around it, and multiple samples in the same place over a period of time. This is one of the largest issues with data collection, as a site can be sampled once, and then never again, or too many samples all in the same area over a short time, rendering the extra data useless (Callaghan et al., 2019). These biases are often a result of too many samples taken in well-populated areas, or from a surge in engagement at the beginning of a program accompanied by a lack of continued engagement over time. Biases like these can create data analysis issues down the road (Callaghan et al., 2019).

Combating Bias

These types of biases can be improved upon by utilizing incentive techniques, like leaderboards. Rather than focusing leaderboards on the quantity of samples, leaderboards should focus on these gaps in data, and which participants contribute to filling them. The value of a sampling site can be determined and portrayed to citizen scientists based on the spatial and temporal gaps. A site that has not been sampled recently, or ever, should be signified as more valuable by the researchers to the participants, incentivizing them to fill these gaps (Callaghan et al. 2019).

Data Usage

Once data has been collected through a citizen science program, it must be used in order for it to be of value. Data is often analyzed and compiled by the organization that ran the citizen science program for publication on their public website or by other means. This data can be used by researchers, students, and other individuals that need data on the subject of the citizen science program. Additionally, data can be sent to third-party organizations such as governments or NGOs for use in policy or as a tool to advocate for policy change.

Furthermore, the data collected through citizen science programs can also be used for education and outreach purposes. By sharing the data with the public, citizen science organizations can raise awareness about environmental issues and engage individuals in scientific inquiry. The data can also be used to inform decision-making, such as land-use planning or natural resource management.

In addition to its practical applications, citizen science data can also contribute to scientific research. The data can be used to test hypotheses, generate new research questions, and provide a valuable source of information for scientific studies. By involving members of the public in data collection, citizen science programs can also increase the diversity and scale of research efforts. Data collected by citizen science projects can have multiple applications as well. For instance, citizen scientists helped generate data for Globe at Night, a citizen science project aimed to quantify light pollution. Astronomers have utilized the data to identify dark sky oases, while environmental scientists used the data set to study the effects of light pollution on bat populations (Barringer et al., 2011).

2.5 - Beyond the Scope of Citizen Science

There are some data types that simply cannot be obtained through citizen science. This can be a result of expensive, complicated, or stationary data collection techniques. Large machines required to collect samples or procedures that must be strictly followed by knowledgeable scientists can limit the possibilities of citizen science. However, this is not true for all citizen science projects. Brian Mitchell, a United States National Parks Service ecologist in Woodstock, Vermont said in *Citizen Science: Can Volunteers Do Real Research?* “if we explain to them what they should be doing and how to do it. Nothing we're doing is so difficult that volunteers can't do it if they are properly trained.” (Cohn, 2008).

Researchers studying microplastics using citizen science in the Scilly Islands, United Kingdom, were able to collect sediment in glass jars, which were later analyzed in a laboratory for its microplastic content (Nel et al., 2020). In this case, where data collection could be abstracted from data analysis, citizen science was able to be utilized. This is not always the case though, and could not be applied to real-time or sensitive data collection, such as the identification of a fungal species, where multiple fungi species with similar appearances are present. For the fungal species example, collecting each sample for identification in a laboratory could cause more harm than good. Additionally, data that needs to be collected from regions such as cliff sides or remote ocean locations are inaccessible to citizen scientists. For example, undergraduate students studying tree canopy biodiversity in Great Smoky Mountain National Park needed double-rope climbing certification in order to collect data (Keller, 2004). Therefore, some types of data will be physically inaccessible to citizen scientists, while others can be catered to citizen science. Citizen science can be extremely beneficial in locations people already frequent, such as coastlines.

Section 3 Software

3.1 - Utilizing Technology for Citizen Science

Citizen science provides an opportunity for information on a range of environmental domains to be collected at rates official monitoring could simply not achieve without substantial funding. Thus, creating a method to acquire valued data for many previously difficult-to-monitor subjects of study (De Rijck et al, 2020). A key contributing aspect that provides this ability is when programs are coupled with technology to perform data collection, such as mobile internet, applications, sensors, and other portable devices. When data collection is coupled with technology it facilitates the ability to upload and store the information almost immediately, opening up so many possibilities for sharing findings and updating existing knowledge. Technologies also provide endless ways to perform the outreach needed to acquire participants from anyone with internet access (De Rijck et al, 2020). After data collection, online databases provide storage and sharing abilities for monitoring programs through the use of visualizations or other community efforts to communicate findings (Ullrich, 2023).

Smartphones

Many citizen science programs utilize technology as the main source of data entry for the participants to use. This includes the Marine Debris Tracker[1], eBird[2], and many others that allow citizen scientists to use their mobile phones as data collectors. Some citizen science programs utilize mobile phones as the main data collection interface, utilizing sensors on the phone to collect specific data about location, orientation, or using the phone's camera to collect images. The use of mobile smartphones for citizen science has no doubt increased over the last decade due to the increase of Americans who own smartphones, with 35% of Americans owning phones in 2011, to a staggering 85% of Americans owning smartphones in 2021. (Pew Research, 2022) With such a large percentage of the population using smartphones, there should be no reason not to continue this trend and further the reach of citizen science using smartphones people already own.

3.2 - Maps Services

Integrating map services is not new to software applications by any means. Maps are an accessible, developed source of data visualization that can allow the user to see data in relation to geographical objects, locations, and coordinates.

Heatmaps

As mentioned above, citizen science projects can lead to temporal and spatial biases in data. In order to combat these biases, heatmaps can be used. Heatmaps vary in color to show different

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[1] https://debristracker.org/
[2] https://ebird.org/home

“temperatures” based on a given value. Heatmaps offer an effective and easy-to-understand way to visualize numerous types of data. Heatmap colors contain a gradient from a “cold” or lower value to a “hot” or higher value. Color gradients should be chosen based on the desired effect, colorblind awareness, and variability to display the granularity of data. (Few, 2008)

Different types of heatmaps exist to fulfill different purposes, with geographic scale and range of data contributing largely to their use cases. Density heatmaps (or hot spot maps) offer great aspects of lots of types of heatmaps, allowing for granularity in data, from low values to high values being shown as colored blobs. Geographic location is conveyed by overlaying the heatmap over a map and altering the size of the blob, allowing users to see the specificity of the data. Finally, hot spot maps are not contained by any geographic area, such as a state or county boundary, and can show data that may flow between these (such as microplastic) (Maptive, 2021)

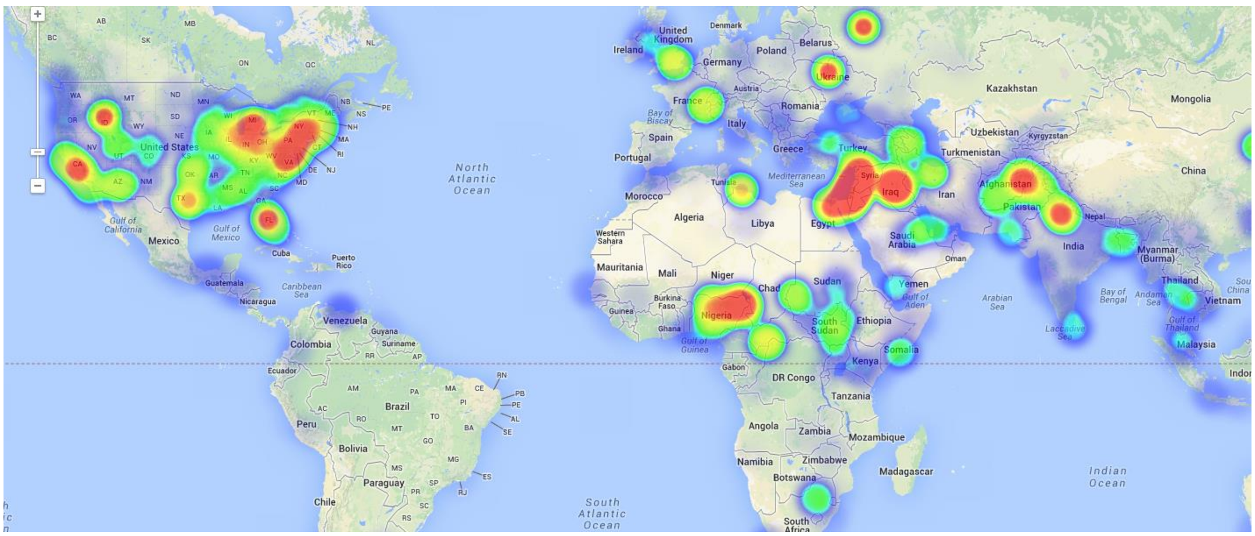

Figure 3: Example Heat Map (The GDELT Project, 2014)

Chapter 2: Methods

The goal of this project was to develop parameters for a citizen science program through which participants utilize a web-based application to monitor ocean microplastic along New England coastlines.

Objectives

1. Identify best practices, limitations, and effective tools used for current citizen science programs.
2. Determine software techniques that can promote accessible, engaging, and efficient human-computer interactions in citizen science.
3. Recommend best practices for a citizen science ocean plastic monitoring program and provide a model derived from those recommendations.

Objective 1

To determine the best practices of citizen science we will conduct an in-depth analysis of the information gathered through various methods, including:

- Detailed document review
- Comparison of current citizen science programs
- Interviews

Document review was used to inform us of general trends in citizen science programs backed by peer-reviewed research, such as incentivization and engagement practices. Documents included scientific research journal articles, news articles, and publications by citizen science programs. It also provided a framework for the types of data that can be collected and the benefits and limitations of using citizen science to collect said data.

To determine which stakeholder organizations, have valuable information on coordinating beach plastic cleanup efforts and plastic debris management, **a comparison table** was created. The table compared aspects of organizations based on their outreach level; global, national, or local to New England. In order to efficiently grasp the differences between the stakeholder organizations, comparisons were made between their mission, collaborating organizations, the debris type of focus, methodology, current program/event status, and data framework including collection, storage, and usage. The visualization offers an easy comparison of the alternate methods stakeholders are using to address the ocean plastic issue (See **Appendix A)**. Based on the analysis of the information collected, we were able to identify which of the organizations would be most fitting to interview for this project.

Interviews were conducted with members of organizations focused on ocean plastic through beach cleanups and citizen science programs. Speaking directly with professionals allowed us to understand the common situations of citizen science and beach cleanups from a first-person perspective. These conversations resulted in a list of design principles for citizen science programs as well as an understanding of the components required to create said program.

Objective 2

In order to create a user-friendly and efficient website, modern software design and architecture design techniques were investigated. Research into efficient human-computer interaction was investigated to develop an understanding of how participants can efficiently interact with the program, even if they have little computer or mobile experience. This increases participation in programs as participants who become frustrated may not want to be involved in citizen science in the future. To reduce the impact on the environment wherever possible, the environmental impact of cloud computing services was examined. This allows for a holistic approach to the program, ensuring that we do not contribute negatively to one environmental issue while attempting to improve another. This research informed us of the general structure of the application and informed us of the technologies that are available to be used for our project. By comparing and contrasting different software design paradigms and software technologies, we were able to identify those that would be easiest to implement given past experience.

After determining the appropriate technologies for the application, we focused on deciding what features to include. Our research involved analyzing various citizen science mobile applications, listed in the table included in Appendix A, to gain insights into how to structure the application and what functionalities to incorporate. By examining applications from various projects, not just limited to ocean plastic, we were able to identify similarities and differences that improved or detracted from the application's function. This allowed us to determine the features to include, such as user accounts, administrator pages, and map services, and those to exclude altogether.

In addition, we interviewed several citizen science project administrators to identify which aspects of the project should be incorporated into the application. Many of these conversations revolved around the target audience of the application, which helped guide the design process to prioritize usability and consider that not all users may be familiar with technology. Thus, the application's focus was on simplicity, ensuring that anyone could use it with minimal guidance. Simplicity also drove the decision to create a single application that would cater to both researchers and participants, streamlining the development process and ensuring data consistency across all instances of the application. Our interviews with experts also informed us of the importance of checks and balances within the application to ensure data quality. These conversations influenced our data entry, visualization, and management techniques throughout the development of our application.

Scalability and future usage were in the forethought of the application, with its structure focused on the ability to implement for any citizen science program and further development. Clean code structure, abstracting, and generics allow for the application to be adapted in the future while also allowing room for new features to be added.

Objective 3

Using all the information we collect from research, interviews, and user studies, we will be able to develop a framework for a citizen science program including recommendations for future programs. Research on existing citizen science programs and beach cleanups gave us a perspective on the field to recommend possible improvements through our findings. Evaluating the environmental impact of various website services will ensure we are not proposing recommendations that can cause more harm than good. Investigating studies that have analyzed citizen science allowed us to implement techniques that may help us achieve our decided goals. Interviews with professional experts in citizen science and beach cleanups provided us with key inside tips as well as provide us an understanding of common shortcomings from a first-person perspective.

Chapter 3: Results

Throughout this project's efforts, the accumulated findings and research have resulted in a clear understanding of this project's focus followed by result sections corresponding to the objectives. Each result section is based on the background document review and expert interviews. To influence program decisions, a list of key design principles was created to ensure every step of the program works to achieve the project goal. Next are the results of an analysis of traditional program components, which facilitate the application of the *Principles of Design* as the most critical parameters for an effective citizen science program when applied to the *Program's Components*. In each program component we have included an example of that component.

Result 1: Principles of Design

Through analysis of our interviews with key Citizen Science experts and stakeholders, and review of documents including *Choosing and Using Citizen Science*: A Guide to When and How to Use Citizen Science to Monitor Biodiversity and the Environment by UK Centre for Ecology & Hydrology (Pocock, 2014), and the research article *Citizen Science, Important Tool for Researchers* by Keyles, 2018. We identified five main design principles which should be considered in the development of Citizen Science programs. We call these 'Principles of Design'. Through document review and expert interviews, we have determined the following *Principles of Design* to be the most critical parameters for an effective citizen science program when applied to the *Program's Components* presented in the next section:

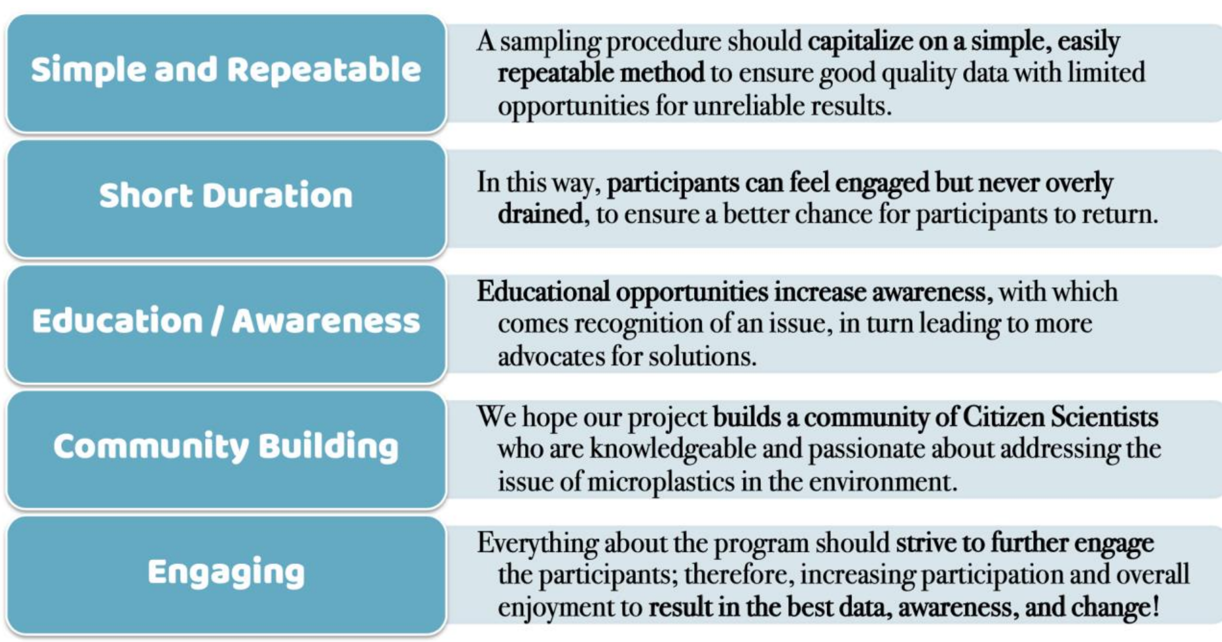

Figure 4: Principles of Design

1.1 Simple and Repeatable

"When trying to broach the subject of microplastics... ensure the method is simple and can be repeated," was the first definitive guidance we received from Neil Blake, the Baykeeper of Port Phillip Bay in Australia. Blake stressed the importance of these design principles to ensure the citizen science protocol is easy for participants to follow and engage with. Based on his expertise, the sampling procedure altered directions to capitalize on a simple, inexpensive, easily repeatable method to ensure good quality data with limited opportunities for unreliable data. In this experiment, the sampling method will only require visual observation by the participant of the sampling frame for 5 mins minimum to count and remove every microplastic identified on the surface. Relying on visual observation as opposed to collecting a soil sample that needs to be sent off for lab evaluation alleviates many potential complications, such as funding and engagement while ensuring "quality control or rigor" Blake pointed out. The feasibility of acquiring accurate microplastic sampling by visual observation was confirmed through an interview with Dr. Kara Lavender Law, an expert in the field of the ocean's circulation and the degradation of marine plastic debris. During the interview, Dr. Kara Lavender Law recounted her experiences sampling ocean plastic with plankton nets, "students pick out the plastics they can see, that are visible by eye, and most of those are microplastics."

1.2 Short Duration

Based on Neil Blake's personal experience with monitoring microplastics through a Citizen Science program, a complex scientific protocol that takes hours to complete is what must be avoided to ensure high rates of involvement along with completed sampling efforts. From this conversation, we felt it was important to design a protocol that can be completed in 1 hour from start to finish by simplifying everything possible for the participants. *In this way, participants can feel engaged but never overly drained, so as to ensure a better chance for returning participants.*

1.3 Educational/Awareness

During our conversation, Neil Blake explains, "The phrase that's been used by some management agencies is that 'Microplastics is an emerging issue.' It's almost like it's still not validated in the minds of people…and the only reason they are still emerging is because not enough people are actually paying attention." Leaving a sense of urgency and importance for always including educational information in projects relating to the issue of microplastics and marine plastic debris, in order to facilitate the growth of awareness. With awareness comes recognition of an issue, in turn leading to more advocates for solutions, clean-up events, and changes in personal and societal norms, all in hope of true positive regulation and policy change to stop the sources of the issue in general.

1.4 Build Community

“Citizen science attracts a specific type of person” stated Neil Blake, setting no expectation of who may be a part of the community to be built. Common returning volunteers will often become “friends” in the literal sense with the researchers, strengthening their connection with the people and the cause. We hope our project builds a community of Citizen Scientists who are knowledgeable and passionate about the advocacy for solutions to address the issue of microplastics in the environment. Some ways that citizen science programs will facilitate the creation of community is through the in-person group efforts, online social media communications, and collaboration with local groups, schools, and social movement organizations (Pocock, 2014).

1.5 Engaging

Everything about the program should strive to further engage the participants. Engagement increases participation and overall enjoyment which results in the best data, awareness, and change! To ensure there is a continued inflow of data, the program will strive to have high engagement and retention levels of participants. As each of these *Principles of Design* has benefits for increasing engagement, one additional method will focus on engaging participants through the program’s initial outreach.

Outreach is the first opportunity to engage with potential participants, so we conducted interviews with experts in the field to gain advice and insight. As a volunteer coordinator for the Blue Ocean Society in New Hampshire which organizes, hosts, and sets up beach cleanup events, Danielle Kamberalis has first-hand experience in outreach. New volunteers need to be “convinced” of the value of the project, why, where, and how to carry it out. All of this requires extensive material to encourage the new volunteers to get involved with the project, so we must spread engaging outreach materials. Additionally, participants’ engagement may benefit from incentivizing outreach materials to convince them to come back. This means that outreach materials could change in importance depending on who the target audience is. One benefit of repeat volunteers is that there is less need for outreach materials, meaning program organizers can redistribute their time to engage them in the project.

Result 2: Program Components

In following the Principles of Design, we have identified the following to be the most critical components of a citizen science program:

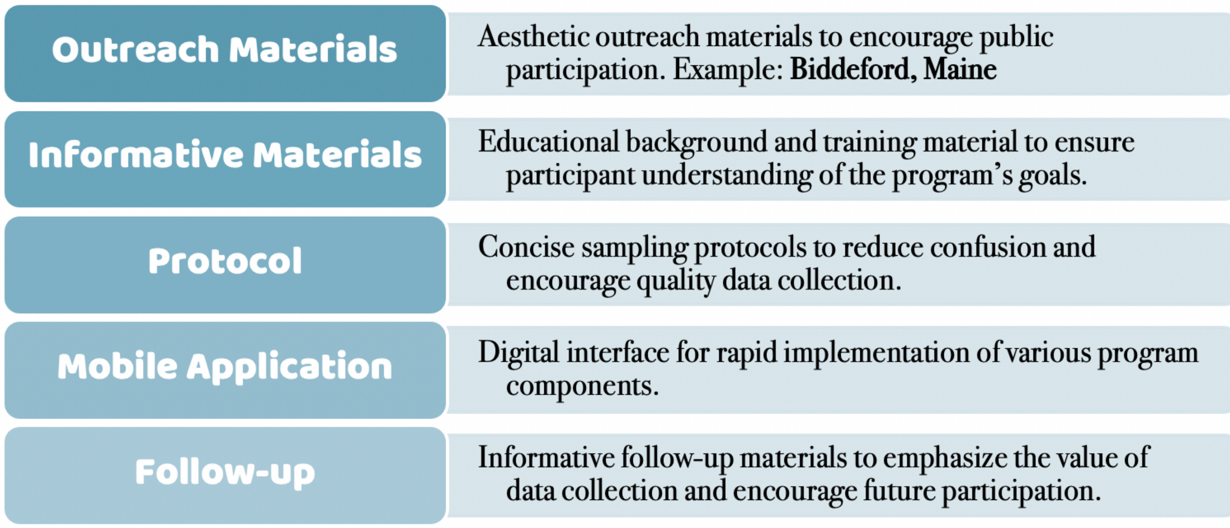

Figure 5: Program Components

2.1 Outreach Materials

Aesthetic outreach materials attract and sustain a steady stream of participants for a citizen science project. Providing engaging and informative outreach materials encourages crucial public participation. These materials may take the form of physical or digital publications and should be diverse to cater to a broad range of potential users. Social media posts can help to target younger audiences, while printed materials are suitable for older demographics. It's essential to create visually captivating components that capture the user's attention, while also providing relevant information about the project's significance.

Kamberalis advised that our outreach materials and locations must be carefully chosen to be efficient in attracting citizens that are likely to participate in earth-cleaning efforts. Example locations to post outreach materials include beaches, community bulletins, Chamber of Commerce notice boards, libraries, gyms, and college clubs. A fascinating suggestion by Kamberalis was to time outreach efforts along with Earth-centric holidays. Around Earth Day in April, she noticed a huge increase in people's interest in offering their time to help the planet.

An important aspect of outreach materials is to outline the physical requirements of the program. Projects may require physical components such as walking, climbing, bending down, or kneeling. Outreach materials should explain these limitations to avoid wasting the time of participants who may be physically unable to participate.

To effectively implement the essential elements of the outreach materials, we identified Biddeford, Maine, a coastal New England town, as an ideal location to generate example materials for. Our decision to focus on Biddeford was driven by its proximity to the ocean and its diverse community and built environment. With multiple grocery stores, supercenters, a library, a university, and other distinct areas, Biddeford provided a variety of potential outreach locations to appeal to a wide range of participants.

To facilitate engagement with the project, one of the core Principles of Design, we recommend the establishment of a project-wide Instagram account (@microplasticsWPI) that can collaborate with local environmentally conscious organizations in Biddeford. Through this platform, the project can reach its target audience, many of whom may already follow these groups on Instagram. To maximize its effectiveness, Instagram posts should be brief yet visually appealing and informative, enabling interested participants to quickly access the project and sign up.

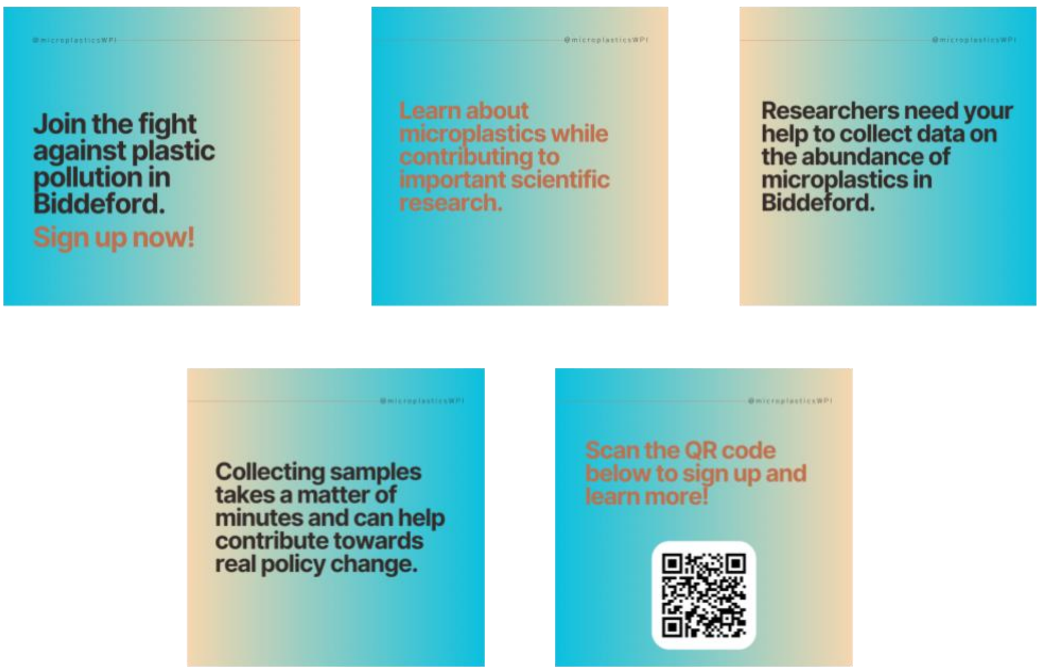

Figure 6: Sample Media Post Outreach Materials

We also recommend the creation of outreach materials to target older residents or those who do not use social media. Kamberalis informed us that cleanup events are most commonly made up of retired or older citizens. The age of participants will influence many aspects of the design and function of the program. One tip Kamberalis recommended was the addition of accessibility notices to accompany any outreach for the program. By fully explaining all the physical requirements associated with each sampling location we can better guarantee the safety and expectations of every participant.

Outreach to elder participants can be done through flyers. These flyers should be visually appealing and offer a direct way to access the project. Here, we use a QR code and provide contact information for the researchers. Flyers should contain more information than a social media post, while remaining brief and visually appealing. Flyers can be posted in Biddeford in areas like Hannaford Supermarket, McArthur Library, the post office, and around the University of New England, all of which are only miles from the ocean.

Figure 7: Sample Outreach Flyer

2.2 Informative Materials

To ensure that participants are fully informed about the citizen science project, researchers should provide background information that strikes a balance between scientific detail and accessibility. These materials should provide a clear explanation of the project's goals and objectives, as well as an overview of the scientific concepts and methodologies underlying the data collection process, as can be seen in the above materials. Additionally, these are outlined in the application developed for this project.

In addition to outlining the scientific aspects of the project, the background information should also clearly explain the motivations behind using citizen science as the chosen form of data collection. These will likely be unique insights and contributions that citizen scientists can provide to the project, as well as the potential impact of the data on broader scientific and societal issues.

By providing comprehensive yet accessible background information, researchers can ensure that participants are fully engaged and motivated to contribute to the project. Moreover, such information can foster a sense of ownership and pride among participants, leading to a more committed and involved community of citizen scientists.

2.3 Data Collection Protocol

To ensure the accurate collection of data in citizen science projects, it is imperative that citizen scientists meticulously follow the protocols crafted by the researchers. These protocols should provide a clear outline of the steps involved in collecting data and include details on any nuances or obstacles that may arise. To keep participant engagement levels high, protocols must strike a balance between being comprehensive yet concise, while also being user-friendly and easy to follow. It is essential to avoid using technical jargon or unfamiliar terminology that may alienate participants and hinder their ability to carry out the tasks effectively. Reiterating the protocol, or guiding citizen scientists through it, step by step, may also help keep engagement and ensure data accuracy.

To ensure that the protocols are effective, it may be useful to pilot test them with a small group of participants before launching the project more broadly. This can help identify any problems or confusion that may arise and allow researchers to make adjustments before larger-scale data collection begins.

Another important aspect of creating effective protocols for citizen science projects is ensuring that they are accessible to a wide range of participants. This may involve providing alternative formats for people with different learning styles or accessibility needs, or offering translations for people who speak different languages.

To establish an example protocol for our microplastics monitoring citizen science project, we took into account the aspects described in the Principles of Design. First and foremost, the protocol was iterated over multiple times to ensure it had the greatest efficacy. Second, the protocol was kept brief but informative, ensuring citizen scientists can follow along easily without losing interest. Protocol steps were created to outline how to register for the program as well as how to take a sample. Much of our protocol was inspired by interviews with Neil Blake, and adjusted to fit the needs of our citizen science project. Our full sampling protocol can be found in **Appendix B**. Below is a table outlining the various aspects of our sampling protocol:

Protocol Component	Final Decision	The Value	Idea Source
Sample Survey method	Visual Observation	Simple/Repeatable	Neil Blake Kara Lavender Law
Sampling Frame	Square meter sample area	Accessible Simple/Repeatable	Neil Blake What3Words
Sample Focus	Microplastics <5mm	Awareness	Neil Blake Kara Lavender Law
Sampling Location	Heatmap within App depicts most valued sample location	Data Accuracy Education	Document Review
Sampling Materials	Zip-Loc Bag, Sharpie, mobile phone with a camera	Accessible Data Accuracy Simple/Repeatable	Neil Blake

Table 1: Protocol Decisions

2.4 Mobile Application

A mobile app can serve as a critical tool for numerous components of a citizen science project. By integrating a mobile app, citizen scientists can access background and educational materials in the same platform that they use to collect data. Furthermore, mobile applications enable real-time tracking of citizen science data collection, allowing participants to monitor and appreciate the impact of their contributions to the project.

One of the most advantageous aspects of using a mobile application for a citizen science project is its ability to enable rapid implementation and modification of program components. In contrast, printed protocols that contain errors may be difficult to correct. With mobile applications, however, changes to various elements of the project, such as data entry or protocols, can be quickly implemented.

Mobile applications are also crucial for efficient and accurate data entry. Modern software development allows citizen science projects to guide participants through the process of collecting, reviewing, and storing data. Background information can be easily displayed, and guided protocols can ensure that participants are collecting and entering the right data. Furthermore, different technologies can support the data collection process, including timers, weather data, and location services, which can minimize errors in data collection and reduce the workload for participants, thereby increasing their engagement.

A full description of the design and implementation of our application can be found in *Chapter 4: Mobile Application.*

2.5 Follow-up

The final stage of a citizen science program involves providing follow-up materials to maintain the participants' interest and motivate them to contribute in the future. These materials can include various types of information, and the specific objectives of the citizen science project will determine the format of the follow-up materials.

For projects aimed at informing policy, regular emails can be used to keep participants up to date on policy developments related to the project. Alternatively, for projects focused solely on collecting data or for which the ultimate use of the data is not yet clear, follow-up materials may consist largely of visualizations of the collected data.

By providing informative and engaging follow-up materials, citizen science projects can foster a sense of accomplishment and involvement among participants, thereby increasing the likelihood of their continued engagement and future contributions.

Below is an example follow-up email for the example town of Biddeford, Maine can be found below in **Appendix C**. These follow-up materials were created for residents of Biddeford, to educate them about where their data is helping the issue, and to encourage participants to contribute in the future. Follow-up materials are intended to be sent via email, or through the application.

Chapter 4: Mobile Application

Section 1: Application Design

1.1 Determining Software Platform

Once the decision to make a citizen science application was made, we needed to decide what software platform was best. The benefits and drawbacks of native mobile applications and websites were considered. Mobile applications, made to run directly on the device rather than in a web browser, offer a number of advantages over websites. Native mobile apps are designed specifically for the device they run on, which means they can take full advantage of the device's hardware and software to provide better performance and a smoother user experience. This access to hardware allows for a wide range of device features allowing for more sophisticated functionality and user interactions. The most notable of these benefits was offline mode. Native apps can often function without an internet connection, allowing users to access content and features even when they don't have access to a network. This was valuable to the program as citizen scientists may not have a cellular connection on some parts of the New England coastline. However, there are also some drawbacks to native mobile apps such as high development costs, the need for updates to fix bugs, add new features, and maintain compatibility, and app store restrictions.

By creating a web app, many of these issues could be avoided. Web apps are accessed through a web browser and do not require users to download and install software on their devices. This means that web apps can be developed once and accessed on multiple platforms, including desktop and mobile devices. Web apps can also be updated and maintained more easily, without the need for users to download and install updates. Ultimately, for simplification it was assumed that citizen scientists would have a persistent connection to the internet, removing the need for offline mode. Additionally, the hardware and operations needed from the host device were determined to not be intensive enough that a web app would be infeasible.

With the hopes of future work creating a native app to gather more precise data, and allow a smoother user experience, the decision was made to move forward with a web app.

1.2 Determining Software Stack

In order to create a modern web app, many software stacks should be considered. To do so, a list of possible technologies was created. These technologies were split into categories for the following: Frontend, Backend, Database, and Authentication. The following sections explain the motivations for each technology that was chosen with a full list of considered technologies in **Appendix D**.

Front End

When deciding on a front-end software to build the app from, the following technologies were considered:

HTML/CSS/JavaScript: HTML is the markup language used to structure content on a web page, while CSS is used to style and visually enhance the content. JavaScript is a programming language used to add interactivity and dynamic effects to a web page. It's often used in combination with HTML and CSS to create modern and responsive web designs. This stack I was most familiar with and thus, would provide the least amount of learning outcomes for myself.

Bootstrap: Bootstrap is a popular CSS framework that provides pre-designed UI components and templates to build responsive and mobile-first websites. I had no experience in building with Bootstrap but strongly considered using HTML/CSS/JavaScript with Bootstrap for its ease of creating UI elements. It was ultimately decided against as I wanted to work in a new software stack.

jQuery: jQuery is a lightweight JavaScript library that simplifies the process of manipulating HTML documents, handling events, and creating animations. jQuery was considered for its ease to learn and simplification of code, especially for the future of the project. However, its limitations and relation to JavaScript and common markup languages caused it to not be chosen.

React: React is a popular JavaScript library used for building user interfaces. It's commonly used to create single-page applications and mobile applications. React was the most enticing of the options but was ultimately decided against for its lack of skills I would learn from using it.

Flutter: Flutter is a mobile app SDK that allows for building high-performance, visually appealing, and responsive mobile applications for both iOS and Android platforms using a single codebase. Flutter can also be used to build web applications using the same codebase, which makes it a versatile option for building applications across different platforms. Flutter was chosen for its ability to be easily transferred to a native mobile application in the future, and as it would provide the most learning outcomes.

Databases

When deciding on a database technology to use for the app, the following options were considered:

Amazon Web Services (AWS): AWS is a comprehensive cloud computing platform that offers a wide range of services, including databases, storage, computers, and security. It includes popular database services like Amazon RDS, Amazon DynamoDB, and Amazon Aurora. AWS was decided against for its lack of environmental sustainability and personal disdain for Amazon's business model.

NoSQL Databases: NoSQL databases are designed to handle unstructured data and can be more flexible in their structure. They include document-oriented databases like MongoDB, key-value databases like Redis, and graph databases like Neo4j. NoSQL databases were considered for their flexibility and scalability but were ultimately decided against due to the complexity of querying data and the lack of familiarity with these databases.

Firebase: Firebase is a popular cloud-based platform that offers a suite of tools for building mobile and web applications. It includes real-time database, authentication, hosting, and analytics. Firebase was chosen for its ease of use, real-time updates, and seamless integration with other Google services like Flutter. Firebase also provides a simple and intuitive interface for managing and querying data, making it an attractive choice for small to medium-sized applications.

Backend and Authentication

By deciding to use Flutter and Firebase, there is no need for separate backend or authentication services. Cloud Firestore, Firebase's mobile database is hosted in GCP. GCP (Google Cloud Platform) is a cloud computing platform that provides a wide range of services and tools for building and managing applications. It is neither a database, front-end nor back-end technology, but rather a comprehensive platform for hosting and deploying applications. GCP was chosen for its relationship to other technologies from Google in this project, but also for its commitment to sustainability. Google reports that GCP utilizes "100% renewable energy for all cloud regions "(Google Cloud, 2023). AWS reports that they will strive for 100% renewable energy by 2025 but have not reached this yet at the time of writing (AWS, 2023). Since starting with GCP, I have been quite pleased with the interface, introductory credits, and integration with other services under one platform. If backend services are needed for the future of the application, GCP would be an obvious choice.

1.3 Firebase - Database and Authentication

Firebase is Google's mobile database platform, specifically Cloud Firestore, that I have had experience working with through internships and personal projects. One of the key benefits of Firebase is its simplicity in setting up a database, as much of the background work is already taken care of for you. This makes adding to the database a straightforward process. Additionally, since Firebase is billed and hosted by GCP, there is no need for additional accounts. Cloud Firestore, the cloud-hosted NoSQL database within Firebase, allows for live synchronization and offline support for mobile devices. The integration between Flutter and Cloud Firestore further simplifies data management, reducing the need for backend management of data.

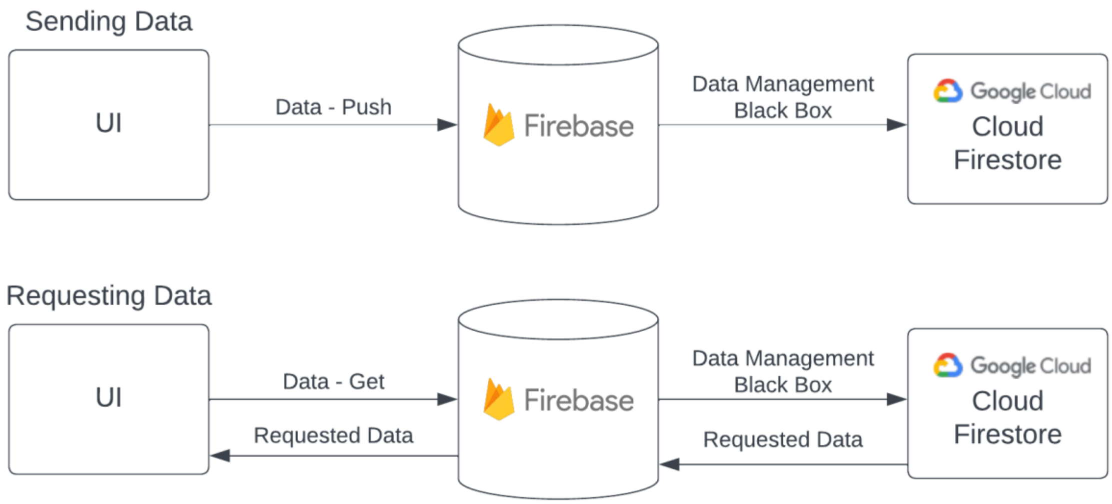

Figure 8: Interaction with Cloud Firestore

Firebase's services also include authentication providers, allowing the website to accommodate multiple forms of login for a simple authentication setup. Authentication of users to the website is critical to its success, as a user should be able to maintain their samplings independently of others. Firebase authentication offers a fast and easy solution to allow users to authenticate with many types of logins (Google, Facebook, Apple, etc.) without the need to develop an authentication service of my own.

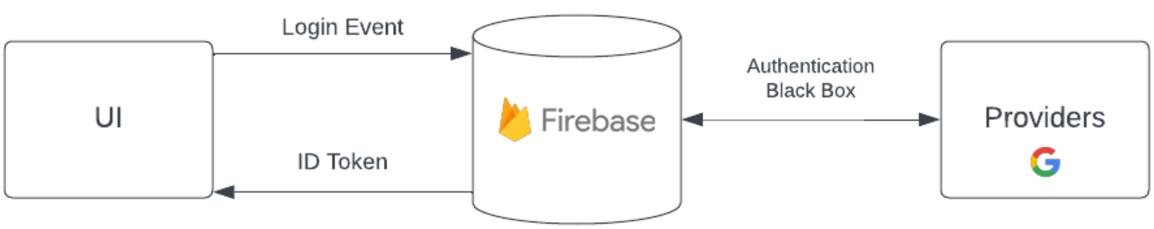

Figure 9: Firebase Authentication with Providers

1.4 Flutter

The application for this project was created entirely using Flutter, an open-source UI development kit developed by Google that runs on Dart, a free and open-source programming language also created by Google. The decision to use Flutter was based on its ability to create aesthetically pleasing UIs with minimal boilerplate code. Furthermore, Flutter code can be compiled across multiple operating systems, including Android, iOS, and web platforms, making it a reasonable choice for this citizen science project. It can later be developed into a full-fledged mobile application that runs natively on the device's operating system, rather than simply as a web page.

Another major factor that motivated the choice of Flutter is that it is written in Dart, a language that shares many similarities with Kotlin, which I use for my work and is also developed by Google. Both languages have comparable syntax, null safety, and development architecture, making it easy for me to transition from Kotlin to Dart. In addition, while Flutter code is powerful on its own, its capabilities are greatly enhanced by packages that allow for easier development and even less boilerplate code. For this project, the following packages were utilized:

- Flutter_material - The base components from Flutter
- Google_maps_flutter - To create the embedded Google Map
  - Rexios - custom heatmap plugin - To add heatmap functionality to the map
- Firebase_core - The base package for all Firebase utilities
- Cloud_Firestore - To interact with the Cloud Firestore Database
- What3Words - To localize coordinates in way that is more human friendly
- Geolocator - To retrieve the user's location from the device
- Firebase_auth - To enable authentication in the application
- Firebase_ui_auth - To add prefab Authorization UI components
- Google_fonts - To stylize the text in the application
- Circular_countdown_timer - To implement the timing function for samples
- Weather - To gather weather data for a sample

Section 2: User Flow

2.1 Login Page

Upon accessing the website, users are greeted with a title screen featuring a Login button, which launches Google Authentication services and serves as the initial gateway for accessing the data collection interface. This setup effectively mitigates the risk of incorrect data being entered, as users must first login before gaining access to the project's data entry system. Although some citizen science projects may offer "Guest" entries to streamline the registration process, this approach would not be feasible for this project, as data can only be collected at specific locations via the heatmap.

By utilizing Google's authentication provider, the risk of invalid accounts is minimized, given the widespread use of Google's services. This makes it a logical choice as the sole authentication provider for this project. However, other authentication providers or email/password authentication could be added at a later stage, depending on the preferences of the participants. The user's logged-in status is persisted across different sessions, allowing the **Login** page to be skipped if the user has previously logged in.

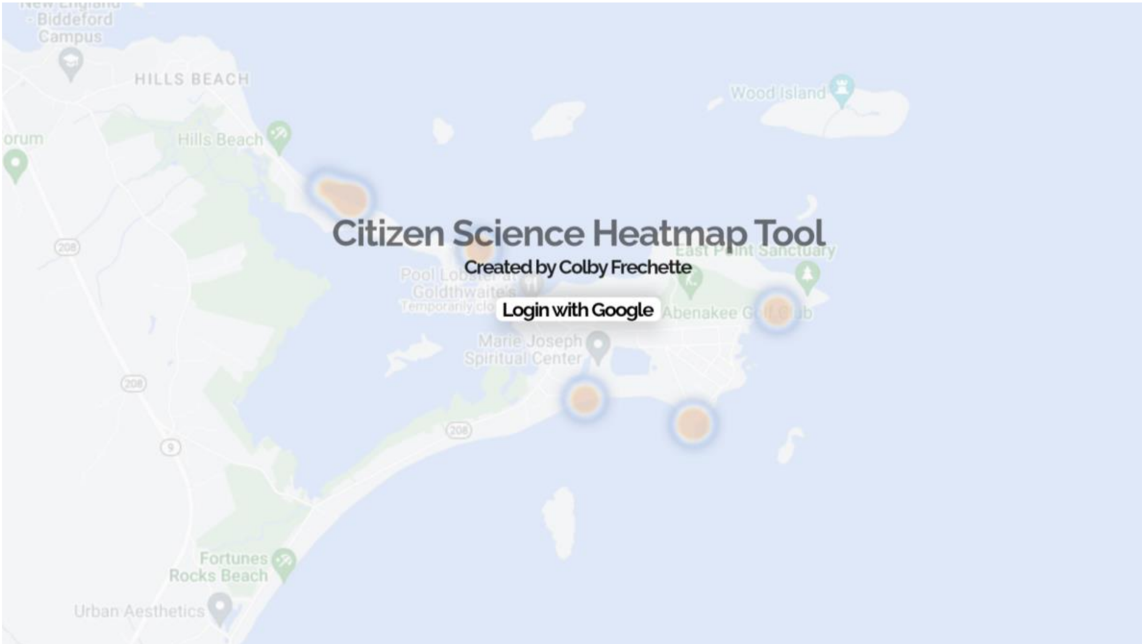

Figure 10: Application Landing Page/Login Screen

2.2 Home Page

Once the user has logged in, they are automatically redirected to the website's **Home** page. The **Home** page contains a navigation rail that allows for navigation among the various website components.

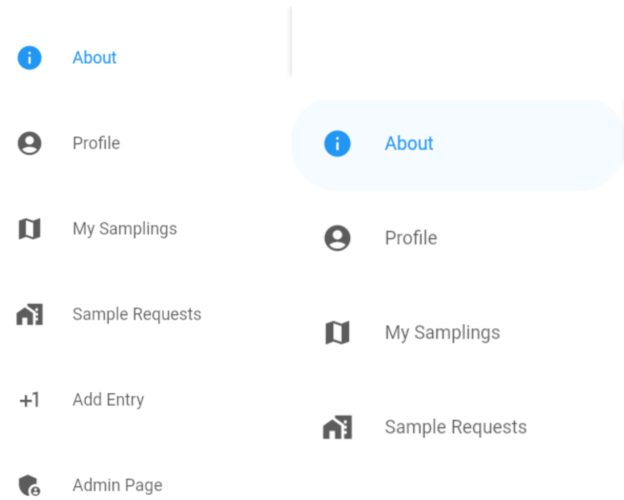

Figure 11: Admin vs Non-Admin Navigation Rails

After the user logs in, they are automatically redirected to the **Home** page of the website, which features a navigation rail for easy access to various components. By default, the **About** page is displayed, providing comprehensive information about the project's background, creators, and contact details. This page can be customized to suit the requirements of different citizen science projects for which the web-based application is utilized.

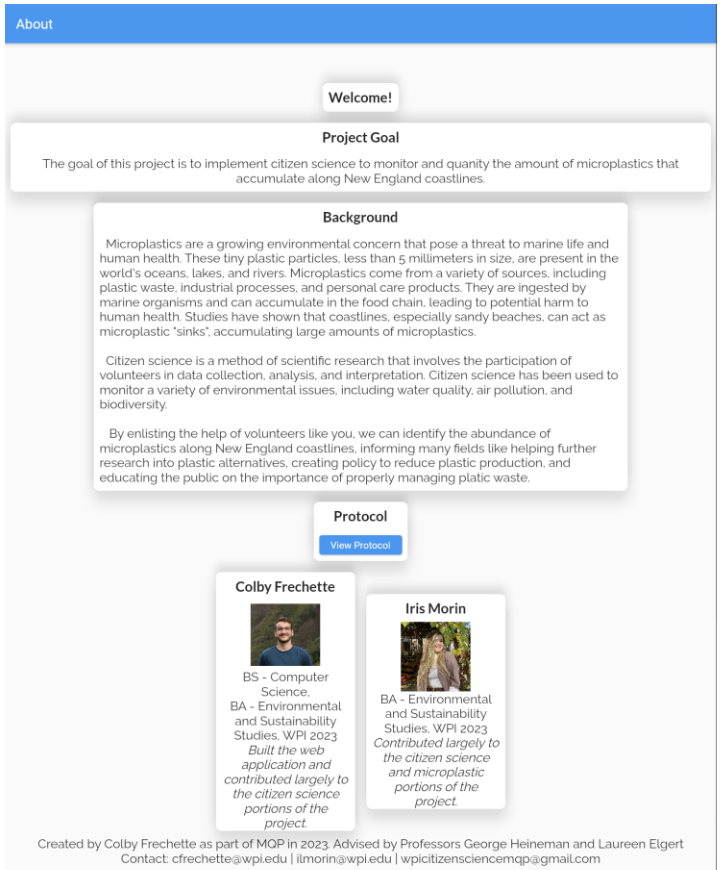

Figure 12: About Page

The **Profile** page displays the user's profile information and provides a convenient sign-out option. The **Sample Requests** page features a heatmap displaying the required samples that researchers are requesting to be taken. Heatmaps on this page indicate the value of the sample to researchers. Samples are deemed higher value based on the aspects described in **Chapter 1, Section 3.2**. First, samples that are not in close proximity to other samples receive higher value to combat the spatial bias. Second, sample areas that have not been sampled recently, or ever, receive higher value to combat the temporal bias. Currently, sample request value is calculated outside of the application, however, plans to implement automatic valuation are described in **Section 3** of this chapter. The **Sample Requests** page also includes a side drawer element to display the sample requests as a list (as seen in Figure 12). Users can easily identify the most valuable samples based on the intensity values of the heatmap and proximity to their location, encouraging their contributions to have the highest impact.

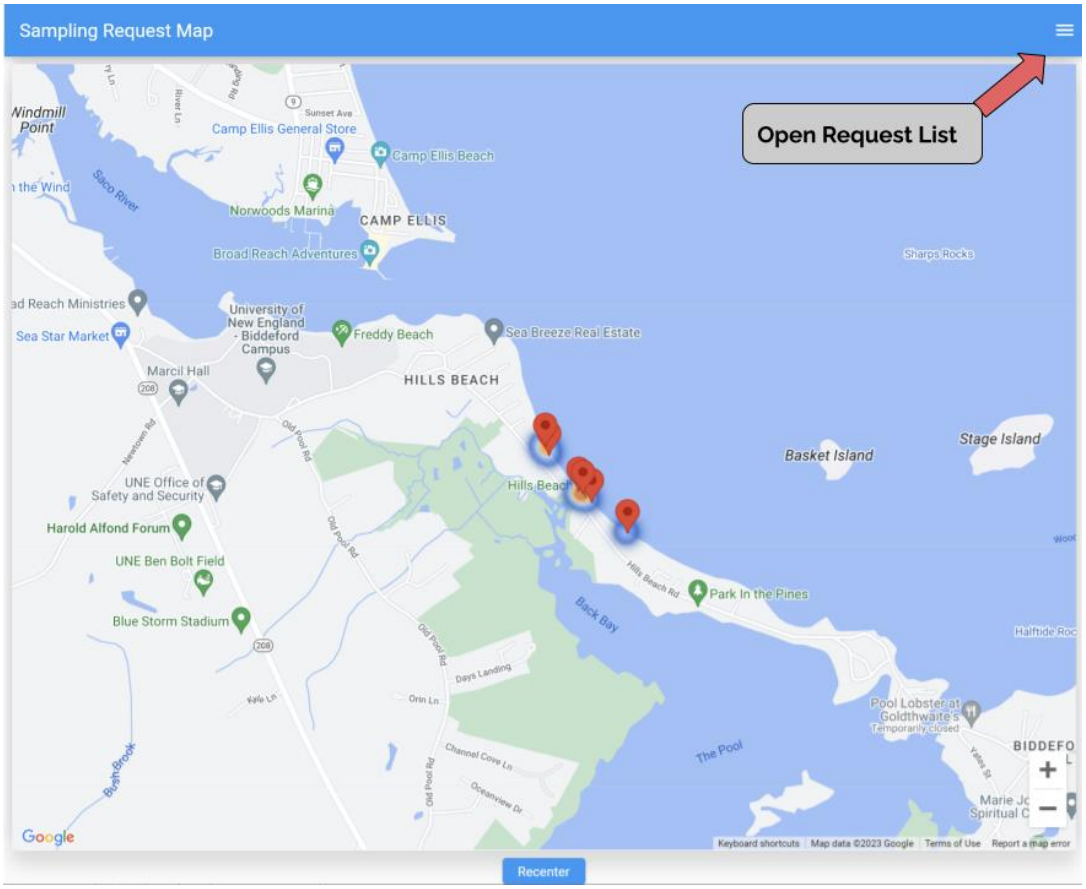

Figure 13: Sample Request Map

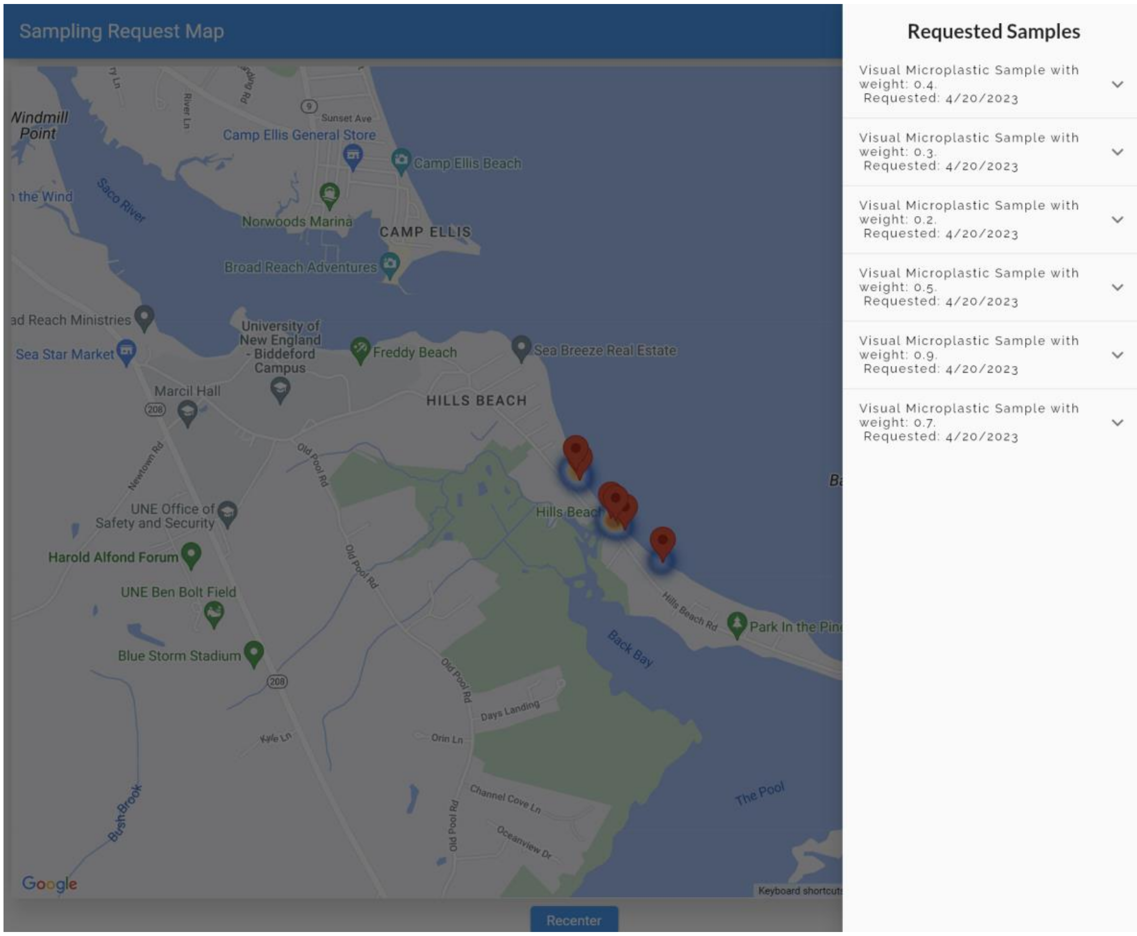

Figure 14: Sample Request List

Upon selecting a sample to take from the list, users are directed to the **Add a New Sampling** page, which offers a zoomed-in map view of the selected samples' intended location, with a satellite view to help users locate themselves accurately. As seen in Figure 14, users can use objects like dune grass, rocks, jetties, or others to triangulate the intended location of the sample. **Section 3** of this chapter describes plans to use the phone's built-in compass to navigate to the sampling location to further improve accuracy. The page also includes a timer set to a 5-minute duration for this project, allowing participants to follow the protocol within the same app without the need to switch programs. Once the sampling timer has finished, participants are prompted to enter the number of microplastics they counted. This "guided" protocol can ensure data quality and reduce confusion for participants. The **Add a Sampling Page** is built in blocks similar to the **About** page, facilitating the addition of new blocks as required for future citizen science projects.

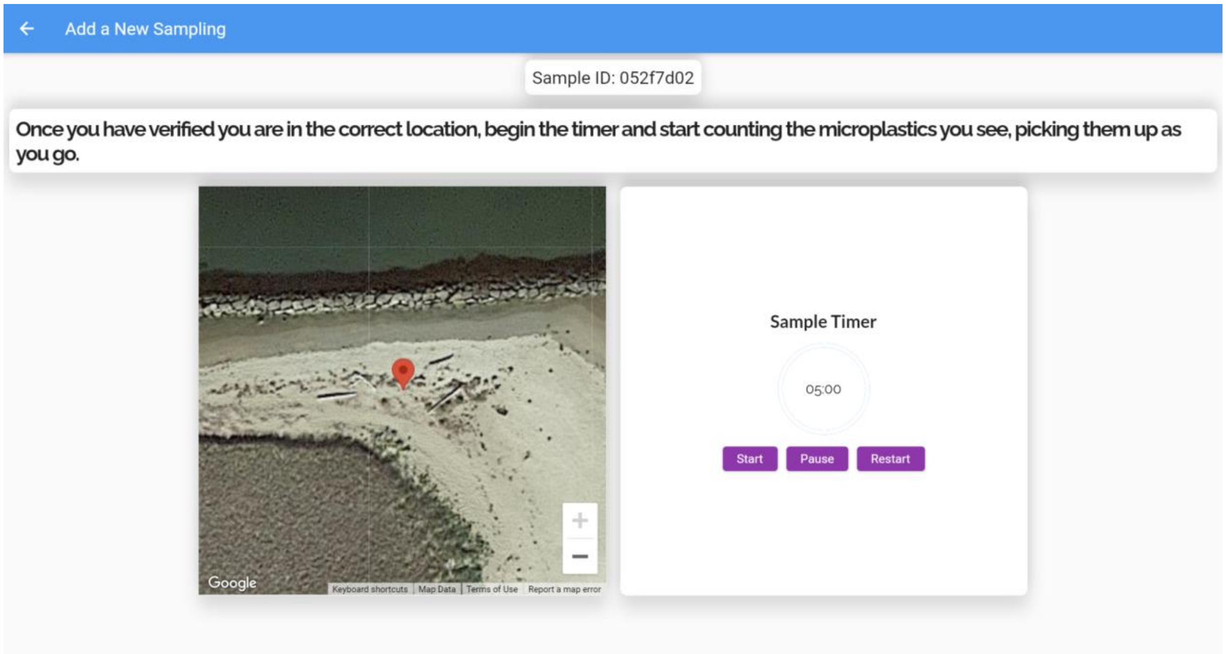

Figure 15: Add a New Sampling Screen

The **My Samplings** page serves a dual purpose, allowing users to view any sample they have participated in, regardless of whether or not it has been submitted to the researchers. Submitted samples are displayed as blue whereas unsubmitted samples are displayed as red, helping a participant see if they have samples that need to be reviewed. Additionally, if a user has unsubmitted samples, they are prompted with a floating action button to review them. Once users have reviewed their samples, they can view the impact they have made personally over the course of the project, as it remains in the **My Samples** map. On this page, the heatmap indicates the number of microplastics they counted in their sample. This, along with raw data, can help visualize the density of microplastics in an area.

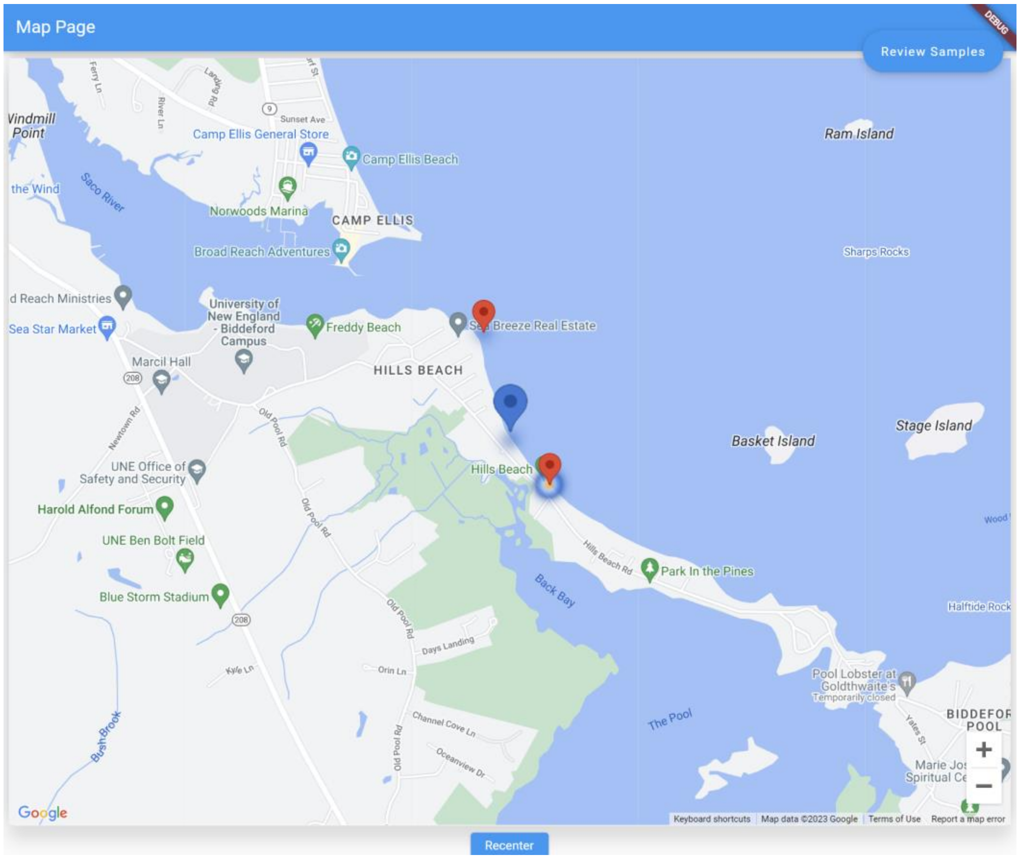

Figure 16: My Samplings

The **Review** page is a crucial feature that offers users an additional step to review their collected data before submission, minimizing the possibility of incorrect or invalid data. Users must review samples before they can be submitted, as depicted in Figure 16.

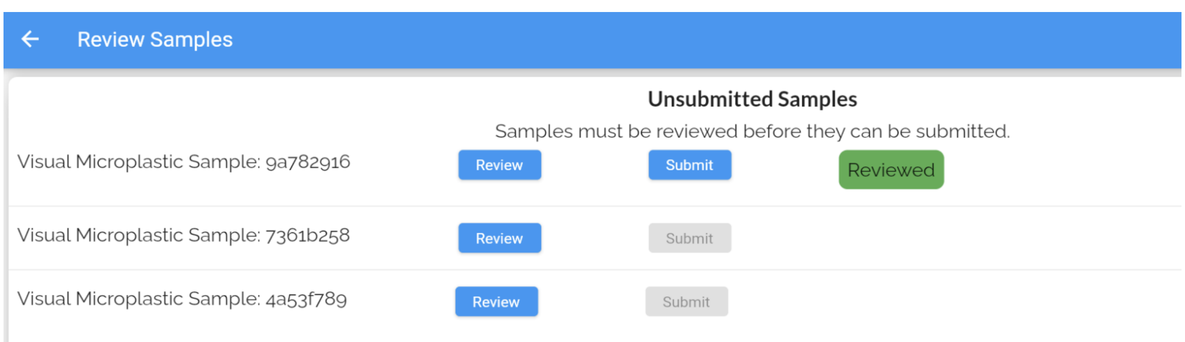

Figure 17: Review Page

2.3 Admin Settings

Researchers are granted administrator accounts that provide access to the **Admin Page**, which enables them to view and manage all collected samples. In addition, administrators can compile and export all samples as a CSV file for use in other platforms or for data analysis purposes. To prioritize the implementation of participant-focused features, certain administrative functions, such as sample deletion, editing, and review tools, were deprioritized due to time constraints. These functions are further discussed in **Section 3, Application Design**.

Section 3: Elements for Further App Development

Due to certain time constraints, Colby had to prioritize certain features and functionality of the application while sacrificing others. Despite these constraints, he was able to deliver a functional and user-friendly web application that met the project goals within the given timeframe. Various assumptions, shortcuts, and areas for further application development are as described below:

Internet Connectivity

The first and foremost assumption made about the state of the citizen scientists was that they would have constant internet connection through cellular data. This assumption allowed for the creation of the application without the need for restrictions such as local data and app store fees. App store fees can total multiple hundreds of dollars and thus creating a web application with internet connectivity was chosen. The drawbacks of this limitation were mitigated, however, with the application's development in Flutter. Flutter allows for cross-platform development, allowing the source code to be compiled for iOS and Android devices if app store fees are funded in the future of the project. Additionally, with the state of internet coverage, there are few coastal areas in New England without cellular reception and thus cellular data. This access to the internet allows users to instantly upload data to the database and mitigates the potential loss of data, such as dropping a mobile device in the ocean.

Range and Scalability

With citizen science driving the software development, it was decided that whenever possible, the application would be designed and developed to support a diverse range of citizen science projects. This means that the application should be built in a way that it can be developed beyond the scope of microplastics on New England shorelines. This would both provide the project longevity and provide means for scalability in the future. Given the time restraint of the project, certain areas of the application have not been developed entirely following these guidelines, and some features will need to be retrofitted if the project is to be utilized in other citizen science projects. The use of Firebase and GCP for backend services allows for an easy transition to other types and sizes of citizen science projects.

Application Design

Due to the tight timeline of the project, the application's design process had to take a backseat compared to other aspects such as research and software development. For instance, some features that would have enhanced the overall user experience had to be deprioritized or completely omitted. The team had to make some sacrifices in terms of aesthetics and visual appeal to focus on core functionalities and ensure that the application was functional and met the project goals within the given timeframe. Despite the limitations, Colby still made an effort to create a user-friendly interface and streamline the data entry process. However, the overall design of the application may not be as polished or visually appealing as it could have been if more time had been allocated to the design process.

Possible considered features for the future of this project's application are as follows:

- Bounding Box Sample Requests - Administrators/researchers should have the ability to define a bounding box of coordinates and a granularity parameter for which the application will generate a series of SampleRequests in the given area, spaced apart by the granularity parameter. A possible granularity could be a What3words grid section (3 square meters).
- Heatmap Value Computations - As the application currently stands, administrators/researchers need to enter the value of a SampleRequest when it is created. While this is practical, the application should dynamically allocate the value of a SampleRequest based on its proximity to other samples, how long it has been since the area has been sampled, and various other factors that the researchers define.
- Migration to Mobile Device Platforms - The web application is currently just that and could offer many more features if migrated to a native application. With proper funding, migration to the iOS and Android platforms would be simpler with Flutter. Migration would allow for additional features such as local data storage, increased performance, and access to device hardware.
- Leaderboards - To ensure that participants are staying involved with the project, a leaderboard can be implemented as an incentive with friendly competition. By showing leaderboards of various attributes (most samples, highest values of samples, regional leaderboards, etc.) participants can be incentivized to participate in the program.
- Unit Testing - As the application is developed and becomes increasingly complex with algorithms as described above, unit testing should be a critical aspect of the project. Unit tests would allow for easier and more robust development, especially as the application is utilized and developed for a range of citizen science projects.
- Firebase Database Security Rules - Proper Firebase security rules should be implemented as a way to prevent attacks. While the data may not be valuable or worth stealing, it should be protected from tampering or misuse. This will become increasingly important as the application gains traction and is used by more citizen science projects.
- Rigorous User Testing - As the development period was short, so too was the testing period. While some user tests were performed, a wider range of users, locations, and operations should be analyzed. This will offer a diverse range of errors, situations, and shortcomings of the app to ensure it is more robust and accessible.
- Accessibility - Ultimately one of the most important aspects of the project is accessibility. Citizen science is determinant on anyone being able to participate and without proper software accessibility support, the value of this project is undermined. As with the

shortcomings of the design aspect, physical and visual accessibility resources were deprioritized. However, if the project is to be continued, these settings and resources should be of high importance.

Conclusion

Throughout the course of this project, we became increasingly aware of the vast number of nuances that a citizen science program includes. Citizen science programs can be a great way to collect large amounts of data, to educate the public on the importance of environmental issues, and to empower them to become advocates for increased environmental policy. These benefits come from multiple principles of citizen science programs that are required to get a program off the ground and keep it running. To keep participants engaged, citizen science programs should include short and repeatable data collection protocols and be short in duration. Each of these various principles can be conveyed through different program components, of which we have identified outreach, informative, and follow-up materials, concise data collection protocols, and in the case of this project, an accessible mobile application to be the most critical. The program components strive to further the principles of a quality citizen science program in a way that benefits participants, researchers, and policy.

One of the most shocking elements of citizen science programs is their versatility. Citizen science programs that do not collect sound data can still have a multitude of benefits, and when they do collect sound data, can increase the scientific understanding of our planet significantly. These programs offer benefits for all ages of the population. Retirees who want to contribute to the environmental crisis we currently live in can offer their time to further science. Young people who participate in these programs become educated on environmental issues which will have a lasting impact on the future of our planet.

By creating a mobile application for this project, we were introduced to the technological side of citizen science programs as well. Technological progress can often be perceived as detracting from our environment, however, when it is coupled with citizen science it can have the opposite effect. Our application provides improved data collection protocols, simpler information sharing from researchers to participants, and increased engagement through aesthetic visualizations of data. Each of these benefits increase those garnered from the principles of citizen science programs we identified to be the most crucial.

The scope of this project was focused on microplastic monitoring along New England coastlines. However, each of the principles of design and program components we identified can be applied to any citizen science program that can contribute to any environmental issue. With little work, a microplastic monitoring program could be created in almost any location using our data collection protocol.

In conclusion, citizen science programs offer a powerful way to engage the public in environmental issues, and their benefits extend beyond just data collection. Our mobile application has shown how technology can enhance the effectiveness and engagement of citizen science programs. We hope that our work can inspire and inform the development of future citizen science programs aimed at addressing a range of environmental issues. By harnessing the power of citizen science, we can make progress towards a more sustainable future.

Appendix A

Table A: Organization Comparison

Global	National	Local to New England

Organization Name	Ocean Cleanup	International Coastal Cleanup (ICC)	National Centers for Environmental Information (NCEI)	Adventure Scientists
Mission	“We aim to clean up 90% of floating ocean plastic”	“The International Coastal Cleanup® (ICC) engages people to remove trash from the world’s beaches and waterways.”	“This database collates microplastic data from across the globe… 1972- Present”	“We ensure the availability of critical field data that accelerates conservation and climate solutions” Source
Partnering Departments/ Organizations	Self: Non-profit Organization based in the Netherlands	Ocean Conservancy (Owner/ App developer)	NOAA (Owner/ Data Distributor)	Self: Non-profit Organization based in Bozeman, USA Many partners
Debris Type Focus	Macro marine debris	Coastal marine debris	Marine microplastic	Marine and freshwater microplastic
Citizen Science	Active	Volunteer Opportunities	None	Active
CS outreach Method	Application	Application	N/A	
Tracker App/Sample Kit	The Ocean Cleanup Survey App	The Ocean Conservancy's "Clean Swell" App	N/A	Microplastics Toolkit Request Site
Data Collection	Open water data collection (ocean surface/ river/stream/canal).	Coastal marine debris hand collected and tallied.	Collection methods included in the database.	Open water data collection (ocean surface/ freshwater).
Data Storage	Citizen Science Map	ICC's Annual Cleanup Reports	Marine Microplastic Database	Microplastic Data Map Request-a- Dataset
Data Usage	To mobilize Cleanup teams based on the types, quantities, and location data of the pollution.	To engage people around the world to remove trash from the world’s waterways, identify sources of debris, and change behaviors.	“To improve water quality and protect the ecosystem, especially coastal ecological habitats.”	“These data are being used by businesses, governments, and individuals to limit plastic waste.”
Collaboration?	Beach Cleanup?	Beach Cleanup or data recipient	Data recipient	Unlikely
Contact Info	Contact Us	All Contacts International Coastal Cleanup: cleanup@oceanconservancy.org	Dataset Point Contact: Ebenezer Nyadjro ebenezer.nyadjro@noaa.gov	Organization Info: info@adventurescientists.org 406.624.3320

Website	[Citizen Scientist]	[Trash Free Seas]	[Global Marine Microplastic]	[Global Microplastic Initiative]

Organization Name	**EPA Microplastic Beach Protocol**	**Scotland's Marine Environment**	**Blue Ocean Society of Marine Conservation**	**Ocean Conservancy's CoastSweep**	**Maine Island Trail Association**
Mission	Where community scientists collect microplastic pollution data that can be used to characterize current levels and look for local, regional, and global trends.	"A New Collection Tool-Kit to Sample Microplastics from the Marine Environment Using Citizen Science."	"We are a 501(c)(3) non-profit that protects marine life in the Gulf of Maine through research, education and inspiring action."	COASTSWEEP is "the statewide beach cleanup organized each fall by the Massachusetts Office of Coastal Zone Management (CZM)"	"To advance a model of thoughtful use and volunteer stewardship of Maine's wild islands, creating an inspiring recreational water trail that is cared for by the people who use it."
Partnering Departments/ Organizations	5 Gyres Institute (Original Developer) Dr. Margaret Murphy (App Developer) National Geographic (App Sponsor)	Natural Environment Research Council (NERC)	University of New Hampshire Cooperative Extension and New Hampshire Sea Grant	Part of the International Coastal Cleanup as organized by Ocean Conservancy, based in Washington, DC.	Membership based with Strong Sponsor support
Debris Type Focus	Marine and freshwater plastic debris	Marine and Coastal Microplastic (Sediment, Seawater, and Biota)	Coastal marine plastic debris, macro and micro in New England	Marine and coastal plastic/trash/ fishing debris.	Marine and coastal plastic debris
Citizen Science	Active	Not Active	Volunteer opportunities	Volunteer opportunities	Volunteer opportunities
CS outreach Method	Application	Unclear	NA	NA	NA
Tracker App/ Sample Kit	[Marine Debris Tracker app]	Collection Tool-Kit needs locating	[Digital Cleanup Kit]	None	None
Data Collection	Coastal and inland freshwater shorelines distribution data by category.	"A New Collection Tool-Kit to Sample Microplastics from the Marine Environment (Sediment, Seawater, and Biota) Using Citizen Science"	Beach Cleanups that are public, private, or personal events using Debris Tracker App. Microplastic samples from beach experiments.	"Volunteers… collect marine debris—trash, fishing line, and any other human-made items—and categorize and tally what they find."	Island Cleanups that are for public volunteers, no data collection.
Data Storage	[Debris Tracker Database]	Project website lost.	- [2021 Cleanup Results (ME, NH, MA)]	All data collected is logged through and stored in the Ocean Conservancy's	NA

			- New Hampshire 2019 Cleanup Results - All Cleanups (NH, ME, MA) 2019 Results	International Coastal Cleanup Program	
Data Usage	Publicly accessible database to be used by all interested organizations. Data usage shared as News.	"Protecting our seas and marine biodiversity by conducting surveys to contribute to gaps in knowledge and explore responses to environmental change."	"We collect data at all Blue Ocean Society beach cleanups which contributes to our long-term marine debris monitoring research"	Data is used to discover the sources of marine debris.	NA
Collaboration?	CS App collaboration?	Unlikely, unless involved with other Specific Investigations	Beach cleanup or app users	Beach cleanup or app users	Beach cleanup or app users
Contact Info	Citizen Science App info: debristracker101@gmail.com		info@blueoceansociety.org programs@blueoceansociety.org	Cleanup Coordinators: coastsweep@mass.gov Cleanup logistics: robin.lacey@mass.gov	Cleanup Contact: stewards@mita.org
Website	EPA's Microplastic Beach Protocol	EU Capturing Our Coast	Blue Ocean Society of Marine Conservation	Mass Gov. COASTSWEEP	MITA Join a Cleanup

Appendix B

The following is an example sampling protocol for the microplastics citizen science project:

Signing Up for the first time

1. Create an account on the **Login** page.
2. Review **About** page to understand the motivations for this project.
3. Review **Protocol** page to become familiar with the materials required and the sampling process.
    a. What You Will Need (Material list)
        i. Meter stick or tape measure
        ii. Marker to write on collection vessel
        iii. Collection vessel (Ex. Zip-lock bag)
        iv. Tweezers (optional)
        v. Prepaid Shipping Envelope
    b. Instructions for using the Heat Map feature to identify sampling locations.

Collecting a Sample

1. Navigate to the **Sample Requests** page in the app.
2. Press **Go To** on the sample you would like to take.
3. Once you have navigated to the sample location, press **Take Sample.**
4. Ensure you are at the correct location via the satellite map provided in the app, as well as landmarks around you such as rocks, trees, or sand dunes.
5. Measure sample space.
    a. Using the meter stick to measure, mark a square meter in the sand using your finger or a stick.
6. Obtain the Sample ID from the app.
7. Prepare your Ziploc bag by writing the Sample ID and Today’s Date on the bag and then opening it.
8. Take your sample!
    a. Begin the 5-minute timer on your device.
    b. Count the microplastics that are visible on the surface, picking them up (with tweezers if available) and placing them in the Ziploc bag as you go. Don’t worry about sand or other things you may pick up, as long as the microplastics end up in the bag, you’re all set!
    c. Additional instructions for the sampling may be provided in the app, be sure to check these as they will change from sample to sample!
    d. Click **Save Progress.**
9. Navigate to the **My Samples** page to view the sample you just took.

10. Click **Review Samples**. (Before reviewing your samples, make sure you are at a safe location).

Data Review and Validation for Collected Samples

1. Review each sample you have collected.
    a. Each sample should have a sample ID, follow the specific parameters for the sample type, and include information about your location.
    b. Thoroughly review each field and make sure it is correct.
2. Submit!
3. Once you have submitted all your samples, place the bags in the provided prepaid shipping envelope and send it to us!

Appendix C

Follow-up example email to be sent to each participant of the Citizen Science program after microplastics were monitored:

Hi Citizen Scientist!

Your incredible efforts have made a positive impact to address Microplastics!

With your help, we have collected over **1,000+ microplastic samples** along the New England Coast!

How are samples being used, you ask?

With each sample comes a clearer understanding of the complex issue of Microplastics accumulating in coastal marine habits. With this information, **researchers, policymakers, and marine debris cleanup organizations** will be better prepared to address the issue of ocean plastic!

For Example:

The findings of this project have the great potential to influence the efforts of NOAA's.
Regional Collaboration to Address Marine Debris in the Gulf of Maine.

In which, "Partners across the Gulf of Maine are working together to prevent and remove marine debris by engaging volunteers, local businesses, coastal communities, fishing industries, and environmental justice populations in learning about the impact of marine debris on natural resources and taking action to make a difference."
https://marinedebris.noaa.gov/prevention/regional-collaboration-address-marine-debris-gulf-maine

Remember, just as every **Microplastic** is important to remove from the environment, so too is every person's **effort** to make a positive change, no matter how Micro!

Thank You Citizen Scientist, for making a difference in the battle for plastic-free Seas!

- *Team Monitoring Microplastics*

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