Small but Mighty:

Learning outcomes and impacts of microplastic focused citizen science

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LUCSUS
Lund University Centre for Sustainability Studies

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Abstract

Microplastics are a present and future threat to the sustainability of coastal socio-economic systems. Current solutions and management could be improved by developing citizen science programs to foster community engagement and knowledge generation. However, research is limited on the actual learning outcomes and impacts of citizen science. To help close this gap, this research builds upon existing studies and found strong evidence that participation in citizen science leads to an increase of specific subject content and science knowledge and contributes to individual outlooks leading to continued support for environmental action. However, there were mixed results on how participation impacts environmental behaviors or policy engagement. These learnings show that citizen science has the potential to contribute to effective management of microplastics but should be done through co-creation since desired outcomes are unique to each community.

Key Words: community science, non-profit, sustainability, impact, socio-ecological systems

Word Count: 11824

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Finally, I want to give recognition to the pre-existing work and efforts of other researchers in the field that this thesis was built upon.

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List of acronyms

Acronym	Meaning
MICS	Measuring Impact of Citizen Science
MMCSP	Microplastic Monitoring Community Science Program
PWP	Plastic Wave Project
SDGs	Sustainable Development Goals
SESs	Socio-Ecological Systems
UN	United Nations

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1.0 Introduction

1.1 Microplastics and socio-ecological systems

Plastics are now so widespread that they are considered a marker of the current epoch (Villarrubia-Gómez et al., 2018). The impacts of plastic pollution on socio-ecological systems have gained global attention inside and outside the scientific community (Horton & Barnes, 2020; Sun et al., 2023). Microplastics are of special interest due to the lack of concrete knowledge about their long term impacts, ubiquitous presence, and complexity in regard to finding effective political, social, and ecological solutions (Barboza et al., 2018; Horton & Barnes, 2020; Villarrubia-Gómez et al., 2018). The United Nations (UN) has even recognized plastics and microplastics as a challenge to 13 of the 17 sustainable development goals (SDGs) due to their compounding and far-reaching adverse impacts on ecosystems and livelihoods (Usman et al., 2022). Kramm & Völker (2018) explain that microplastics are a global risk to socio-ecological systems (SESs) due to four factors: 1) they are an unintended byproduct of the "everyday" operations of modern society; 2) they have a complex and uncertain nature regarding cause and effect; 3) they impact both natural and social systems on global and local scales; and finally, 4) they are perceived in a variety of ways leading to competing views about effective solutions (Kramm & Völker, 2018).

Even though the study of microplastics is relatively new, it has already caused great concern because these small plastic pieces are incredibly difficult to locate and remove, and can carry a variety of harmful substances through the food chain (Davison et al., 2021; Revel et al., 2018; Setälä et al., 2022). While public concern, environmental awareness, research efforts, and management tactics are improving, production and consumption of plastics are also predicted to increase globally for some time, meaning the risks related to microplastics will also continue to grow (Horton & Barnes, 2020; Kramm & Völker, 2018). Due to the potential adverse effects on environmental health, biodiversity, ecosystem services, human food security, and countless other aspects of SESs, research regarding methods to mitigate the adverse impacts of microplastics and reduce production and pollution is of great importance (Barboza et al., 2018; Horton & Barnes, 2020).

1.2 Current management of the microplastic problem

Even with all the attention, there remain many gaps in research about microplastics, especially concerning the implementation of effective management (Villarrubia-Gómez et al., 2018). To ensure consensus on strategies that minimize the creation and negative impacts of microplastic pollution, it is necessary to increase collective action and collaboration among a variety of stakeholders, including policy makers, industry leaders, and local communities (Kumar et al., 2021; You et al., 2020). Some solution pathways from scientific literature include strengthening cooperation on local and global scales, improving policies, encouraging technical advancements of greener alternatives, holding producers accountable with concrete commitments, and creating plastic-focused education and outreach (Gong & Xie, 2020; Iroegbu et al., 2021). Combined with the introduction of strict laws and the development of pre-existing management tools like recycling and alternatives, there is also a need for continuous monitoring, reduction of clean-up costs, and further research (Kumar et al., 2021). In a review of current microplastic governance, Usman et al. (2022) found that there is a need for a shift away from the reliance on specific product bans or volunteer consumer actions along with an increase in community involvement in monitoring and conservation. Overall, including diversity in the creation of knowledge about microplastics, along with the expansion of understanding and involvement, is necessary to create solutions and properly manage microplastics on local and global scales.

1.3 Citizen science as a potential part of the solution

The current conventional science and management relationship has been insufficient in addressing increasingly complex problems in SESs like microplastics (Martínez-Fernández et al., 2021). Including non-academic knowledge and public engagement is essential to identify and address these kinds of issues (Martínez-Fernández et al., 2021). Public engagement involves the exchange of ideas between the public and government officials, experts, or practitioners in the field about a particular problem or proposed solution (McKinley et al., 2015). These interactions have been increasingly viewed as integral in creating sustainable policies and management activities (McKinley et al., 2015).

Citizen science is a promising avenue to achieve this and contribute to the proposed microplastic management and solution pathways by producing knowledge, informing action, and democratizing science through genuine interactive and inclusive methods (McKinley et al., 2015; Paul et al., 2020; Riesch & Potter, 2014; Sauermann et al., 2020; Wehn, Gharesifard, et al., 2021; Wyeth et al., 2019). Local citizen science programs focused on microplastic monitoring or collection can fill gaps and complement national microplastic actions due to their ability to cover a multitude of locations and increase sample sizes (Bosker et al., 2017; Paradinas et al., 2021; Setälä et al., 2022). In fact, policy decisions about nurdles, small plastic pellets used in the production of plastic products, have been based on the results of citizen science (Tunnell et al., 2020). While training of community members and monetary investment would be needed for the success of these programs, citizen science would also be a way to lower the overall cost of microplastic monitoring around the world (Paradinas et al., 2021; Setälä et al., 2022).

All the potential benefits have led to an increased adoption of citizen science programs within nongovernmental and governmental organizations and as a strategy to contribute to the UN's SDGs (Biraghi et al., 2022; Paul et al., 2020; Somerwill & Wehn, 2022; Walker et al., 2021). Even so, citizen science papers continue to be underrepresented in academic and peer-reviewed literature, primarily due to their relative newness and the inherent challenges of integrating natural and human sciences (Tunnell et al., 2020). Even less represented are studies about the impacts of citizen science, as outcomes are often assumed, speculated about, ignored, or unreported (Bela et al., 2016; Wehn, Gharesifard, et al., 2021). Although efforts to capture and report the impacts of community science programs have increased as the aspirations of these programs grow (Wehn, Gharesifard, et al., 2021), even the major citizen science organizations like Citizen Science Association in North America and the European Citizen Science Association in the EU have minimal recommendations for measuring impacts (Citizen Science

Association, n.d.; CitizenScience.gov, n.d.; EU-Citizen.Science, n.d.; European Citizen Science Association, n.d.).

The majority of existing research on the impacts of citizen science is focused on how it affects scientific understanding, data collection, and data quality. However, there is increasing recognition that besides contributing to data, monitoring, and reducing costs, citizen science can also contribute to our understanding of how people perceive, operate, learn, and make decisions regarding challenges in SESs (Paul et al., 2020). It is unanimous that learning is an important outcome of citizen science programs, but more evidence is needed on specifically what kind of learning occurs (Bela et al., 2016; Paul et al., 2020; Sauermann et al., 2020; Schuttler et al., 2018; Toomey & Domroese, 2013). The lack of focus on measuring learning and community impacts has created a gap in citizen science research (Wehn, Gharesifard, et al., 2021). It is important to close this gap because understanding the ways citizen science fosters learning can have great repercussions on society's ability to solve and manage complicated sustainability problems like microplastics (Bela et al., 2016; Krasny & Tidball, 2009; Phillips et al., 2018; Simonsen et al., 2014). Public understanding of microplastics and their negative socio-ecological impacts is currently low (Gong & Xie, 2020), so raising awareness and comprehension about the topic is an essential part of implementing policies or creating change in SESs (McKinley et al., 2015). Citizen science can help broaden the visibility and acceptability of the scientific process and build overall knowledge about microplastics, increasing society's support for methods and policies to mitigate the socio-ecological risks (Bela et al., 2016; Phillips et al., 2018).

1.4 Research Aim

The aim of this research is to begin to close existing gaps within the fields of citizen science and microplastic research and contribute to sustainability science. To achieve this, the research aims to identify and analyze the learning outcomes resulting from community science participation, and subsequently explore how these insights can contribute to the creation of solutions and effective management of microplastics. The overarching research questions are:

What learning takes place through participation in a microplastics focused citizen science program?

How can these learnings contribute to sustainability within socio-ecological systems?

Discovering answers to these questions is relevant for sustainability science due to the socially relevant problem of microplastics, solution orientation, and its focus on understanding knowledge production and decision making outside of academia (Lang et al., 2012). The context-specific insights can then be used to inform real-world action and further research (Lang et al., 2012).

1.5 Outline

The previous section set the scene for the importance of this research. The following section, *Background*, provides detailed information about microplastics, citizen science, and the specific citizen science program of study. After *Background*, the *Methodology* section discusses the theoretical starting point, the discovery and creation of an appropriate framework to measure learning, and the methods used to collect qualitative and quantitative data. Section 4, *Results and Analysis*, then summarizes the main learnings and analyzes the data collected through interviews to answer the first research question. Next, the *Discussion* section connects findings to current literature to understand how the learning outcomes can contribute to sustainability and addresses the second research question. The *Discussion* also includes other considerations and next steps for future research. The final section, *Conclusion*, drives home the main findings and relevance of this research.

2.0 Background

2.1 Microplastics

This section will explain what microplastics are, where they come from, and where they go. It will also build upon what was previously mentioned in sections 1.1 and 1.2 and further explain how microplastics are a risk to sustainability within SESs.

2.1.1 What are microplastics?

Plastic pollution is not a new phenomenon. "Plastic particles" were already recognized as part of the plastic problem in the 1970s (Kramm & Völker, 2018). Nowadays, microplastics are defined as plastic particles less than 5mm in diameter and are found in a variety of sizes, shapes, and chemical compositions (Barboza et al., 2018; Gong & Xie, 2020). There are two types of microplastics; primary, coming directly from the petrochemical industry in the form of nurdles or plastic additives to cosmetics, and secondary, coming from the breakdown of larger plastics like water bottles, car tires, or synthetics fabrics (Barboza et al., 2018; Gong & Xie, 2020). The increasing production of plastic on a global scale combined with the lack of appropriate disposal and recycling methods has led to plastic leaking into the environment at an unprecedented rate (Kumar et al., 2021). Microplastics end up in soil, water, air, and living things through a variety of ways, including wastewater treatment, laundry, runoff, improper disposal, and accidental ingestion (Barboza et al., 2018; Gong & Xie, 2020; Revel et al., 2018). They have also been discovered in food products, including salt, sugar, bottled water, and even beer (Barboza et al., 2018). Microplastics have been found in a great number of marine species, like shellfish, seabirds, and marine mammals, but also in human bodies, placentas, and our bloodstream (Barboza et al., 2018; Davison et al., 2021; Gasperi et al., 2018; Gong & Xie, 2020; Leslie et al., 2022; Ragusa et al., 2021; Revel et al., 2018). Most recently, microplastics have been found to be capable of crossing the blood-brain barrier, adding to the growing concern about the impacts of microplastics on human health (Kopatz et al., 2023).

2.1.2 Microplastics as a risk to sustainable socio-ecological systems

Microplastics are a risk and additional burden to already vulnerable coastal SESs, causing havoc across biological, ecological, and socioeconomic dimensions (Horton & Barnes, 2020; Kumar et al., 2021; Sun et al., 2023; Villarrubia-Gómez et al., 2018). The term "socio-ecological system" refers to the complex and interconnected relationship between social and ecological dimensions of the world (Berkes et al., 2002). The separation between human systems, like governance, and ecological systems, like a beach dune ecosystem, is arbitrary, as these systems cannot truly be detached from each other (Berkes et al., 2002). The health of coastal areas specifically is incredibly dependent on the interconnections between human and ecological systems (Refulio-Coronado et al., 2021). Building sustainability within SESs, in this case, means increasing the capacity to manage risks and unexpected changes, while ensuring the functions of social and ecological processes for the future (Simonsen et al., 2014). "Risks" are defined as conditions that increase the likelihood of undesirable outcomes or irreversible damage (Kramm & Völker, 2018). Microplastics are a global risk to sustainable SESs due to the following four dimensions:

1) Microplastic pollution can be considered a "by-product" of everyday operations of modern society and has been an integral part of our lives since its development (Kramm & Völker, 2018). Plastic is an incredibly diverse and functional material that will likely continue to be an important part of society going forward (Kramm & Völker, 2018).

2) Microplastics impact both the ecological and social dimensions in SESs. They have been found to inhibit photosynthesis and reproduction in phytoplankton and limit carbon sequestration by changing the circulation of organic matter in the ocean (Horton & Barnes, 2020; Kumar et al., 2021; Shen et al., 2020). They cause physical damage by blocking digestion and chemical and biological damage by carrying toxins, pathogens, and other pollution through the food chain (Barboza et al., 2018; Gong & Xie, 2020; Revel et al., 2018). Microplastics also impact political, social, and economic dimensions, which can have compounding effects (Kramm & Völker, 2018). Studies related income loss in marine industries like fishing and tourism to the growing presence of microplastics (Kramm & Völker, 2018). The impact on human health specifically is not well understood, but has already caused concern (Barboza et al., 2018; Davison et al., 2021; Revel et al., 2018).

3) Microplastics are incredibly complex. They harm both living and nonliving things, impact global processes and combine with other environmental stressors like ocean acidification, ocean warming, and other particulate pollution leading to unpredictable physical, chemical, and biological problems (Horton & Barnes, 2020; Kumar et al., 2021; Villarrubia-Gómez et al., 2018). The extent of microplastic pollution is not entirely known, adding to the complexity of the issue (Horton & Barnes, 2020; Kumar et al., 2021). Microplastic sources, composition, shapes, and additives are incredibly diverse as well, leading to even more uncertainty about impacts (Kramm & Völker, 2018).

4) There are many differing views and priorities about microplastic policy and management (Kramm & Völker, 2018). While there has been success in narrow policies targeting a specific type or source of microplastic pollution (e.g. the Microbead-Free Water Act in the US), each country, and even state,

has individual priorities in terms of management (Kramm & Völker, 2018; Usman et al., 2022). Successful policies have resulted from cohesion and agreement from a variety of stakeholders about priorities, definitions, values, and evidence which is mostly lacking in regards to microplastics (Kramm & Völker, 2018).

Current policies and tactics have not been able to effectively manage or reduce these complex risks that microplastics pose to SESs. There are many proposed solutions, including plastic focused education, improving policies, strengthening cooperation, increasing monitoring, and involving the community in conservation (Gong & Xie, 2020; Iroegbu et al., 2021; Kumar et al., 2021). Citizen science has the potential to contribute to these solutions and discover new ideas, which will be elaborated on in the next section.

2.2 Citizen (Community) Science

As explained in section 1.3, citizen science is a promising way to build an understanding of microplastics and increase support for management policies by fostering a wide range of learning. This section provides a background of citizen science and its impacts, and expands upon the learning process and outcomes of participating.

2.2.1 What is citizen (and community) science?

The term 'citizen science' was coined by Alan Iwin in 1995 (Irwin, 1995, 2018). Irwin argued that it was well past time to consider and value knowledge generated outside of the traditional scientific field as understanding the world around us would only benefit from unique community perspectives (Irwin, 1995). While one way of knowing is not better or worse than the other, "there will be no sustainability without a greater potential for citizens to take control of their own lives, health and environment" (Irwin, 1995, p. 7). A new "citizen science" is needed to cope with environmental crises, build environmental awareness and challenge dominant ways of knowing about the world (Irwin, 1995).

Today, citizen science can be defined as a multifaceted phenomenon consisting of a collective of individuals from multiple backgrounds who gather, analyze, and monitor environmental information, usually with low cost and approachable tools, for the purpose of knowledge generation (Wehn, Gharesifard, et al., 2021; Wyeth et al., 2019). Citizen science programs are deployed in a wide range of fields including but not limited to biological conservation, astronomy, medicine, and environmental science (Sauermann et al., 2020). It comes in many different forms, led by academic institutions, concerned community members, non-governmental organizations, or other groups (Sauermann et al., 2020; Wyeth et al., 2019). One form led by community members to achieve local goals is considered 'community science' (Ballard et al., 2017; Wyeth et al., 2019). Community science programs often target social justice issues and seek to impact policy and local decision making (Ballard et al., 2017). These programs can also have an aspect of data collection, community engagement, and robust collaboration between different stakeholders (Ballard et al., 2017). Projects that intertwine involvement in science with public engagement in governance and decision-making are exactly what Irwin envisioned citizen science to be two decades ago (Bonney et al., 2016, p. 9).

2.2.2 Impact of citizen (and community) science

Scientific understanding of the impacts of citizen science is still evolving due to the emerging nature of the field. The potential benefits of citizen science programs run the gamut from contributing large quantities of data to research projects, to encouraging environmental stewardship through participation in understanding local problems (Bela et al., 2016; Sauermann et al., 2020; Schuttler et al., 2018; Walker et al., 2021). Some view citizen science as a tool to contribute to the institutional scientific field without challenging the supremacy of scientific understanding, while others view it as a way to democratize science by including local knowledge, increasing transparency, challenging scientific norms, and providing a pathway for community members to have a say in environmental decision making (Sauermann et al., 2020; Walker et al., 2021; Wyeth et al., 2019). Depending on the type of program, it can create a deeper connection to and understanding of the local environment and larger social-ecological system, contribute to social wellbeing, and enhance learning by providing a way for individuals to give back to their communities (Ballard et al., 2017; Bela et al., 2016; Haywood et al., 2016; Schuttler et al., 2018; Walker et al., 2021). Of all the types of citizen science, community science programs may have the greatest potential to influence public understanding due to the close involvement of participants in not only collecting data but also designing the protocols, interpreting the data, and displaying the results (Bonney et al., 2016).

Alongside the benefits, being realistic about what a program can achieve and having conversations about the limitations is an important part of citizen science research (Riesch & Potter, 2014). Volunteer engagement is difficult to maintain, financial compensation can cause conflicts, additional burdens to community and individual lives can be created, trust can decline when programs don't show an impact, and existing power structures and inequalities can be exacerbated (Paul et al., 2020; Walker et al., 2021). If citizens are the ones collecting data, the ethical considerations of who actually "owns" final research outcomes also arises (Riesch & Potter, 2014). Programs should be transparent with the data and information it collects, what it's used for, and keep participants updated on progress (Riesch & Potter, 2014). Finally, it's important not to paint citizen science a panacea to existing problems, but a tool that can be used alongside existing efforts to continue to build sustainability in communities and SESs (Paul et al., 2020).

2.2.3 Learning through citizen science

While there are a variety of benefits provided through citizen science programs, its ability to foster learning is especially important due to the potential impact of learning broader society and local SESs (Bela et al., 2016; Krasny & Tidball, 2009; Phillips et al., 2018; Simonsen et al., 2014). In this case, learning is defined as a dynamic and interactive process involving changing or building upon knowledge, awareness, engagement, skills, behaviors, and attitudes of individuals and communities (Phillips et al., 2018; Tidball & Krasny, 2011). Uncertainty around microplastics makes them a risk to SESs, as explained in section 2.1 (Kramm & Völker, 2018), so reducing this uncertainty through learning can help communities make informed decisions and implement effective management. The notion that knowledge about SESs should be co-produced with academic and non-academic actors (Martínez-Fernández et al., 2021) underlines the fact that citizen science is an appropriate avenue.

Participating in citizen science lays the foundation for or develops environmental learning in ways that shorter, more isolated programs do not (Ballard et al., 2017; Toomey & Domroese, 2013). The hands-on, repetitive, and localized nature of environmental citizen science programs make them well suited to influence or reinforce a wide range of learning and be a natural conduit for changing behavior (Phillips et al., 2018). Learning in social interactions or through facilitated opportunities like citizen science can create individual outcomes like a sense of responsibility, empowerment, or specific skill sets which then translate into community stewardship practices and contribute to sustainability within SESs (Krasny & Tidball, 2009). This can include support of activities or policies that promote environmental protection or day to day activities or knowledge sharing that supports an environmental goal. Individuals can also use citizen science as a chance to recognize and hone their specific roles and areas of proficiency in environmental protection, science and conservation (Ballard et al., 2017). This can then inspire more involvement with or even build careers within sustainability and environmental science.

While learning takes place at an individual level, it is also inherently systematic, going beyond into wider groups and leading to larger transformation (McKinley et al., 2015; Tidball & Krasny, 2011). An increase in localized knowledge, scientific skills, connection to community, awareness of environmental problems and causes, and understanding of SESs through citizen science have caused measurable changes in collective action and community participation (Haywood et al., 2016). Individuals and groups involved in citizen science can use their intimate knowledge of local problems to get involved with social action, like pressuring governments and companies to change practices and policies that reduce environmental harms (McKinley et al., 2015; Paul et al., 2020; Wyeth et al., 2019). Citizen science programs also often involve large, publicly available, and interactive datasets which can not only increase understanding and data interpretation skills of the volunteers, but also help other members of the public understand the problem (Phillips et al., 2018).

Some existing desired learning outcomes of citizen science include specific content knowledge, interest in science or the environment, skills of science inquiry like data collection, confidence, community trust, motivation to engage with environmental issues, and place-based and global environmental stewardship (Bela et al., 2016; Bonney et al., 2016; Phillips et al., 2018). While one program may not be able to foster all of these learnings, citizen science can improve the overall knowledge base of environmental science and increase society's support for methods and policies to mitigate socio-ecological risks by improving the visibility and acceptability of the scientific process and its findings (Bela et al., 2016; Phillips et al., 2018). This is especially important in the case of microplastics due to the lack of concrete understanding and misalignment in management tactics (Kramm & Völker, 2018).

2.3 Case Background: The Microplastic Monitoring Community Science Program in New Jersey

The citizen science program of focus in this study is considered a 'community science' program. As previously mentioned, community science is a type of citizen science developed and led by community members and not attached to an academic or governmental institution (Ballard et al., 2017; Wyeth et al., 2019). The Microplastic Monitoring Community Science Program (MMCSP) was developed and is currently run by three non-profit organizations based in New Jersey; Plastic Wave Project, Save Coastal Wildlife and Save Barnegat Bay. Plastic Wave Project (PWP) is the lead organization of the program responsible for communicating and organizing volunteers. PWP is a grassroots nonprofit with the mission to educate the public about the harmful impacts of plastic pollution to help create healthy, plastic free waters and communities (Plastic Wave Project, n.d.-b). I helped create PWP in 2018 and have been involved with the development and management of the community science program since its inception. This personal involvement is one of the driving forces behind the research.

The MMCSP began in December 2019 and is currently in its fourth year of data collection (Plastic Wave Project, n.d.-a) (Image 1). The goal of the program is to discover when and where microplastics congregate on the New Jersey shore while also providing an approachable way for local people of all backgrounds and ages to learn about microplastics and science. Volunteers who participate in the program choose a location at any beach, inlet, or shoreline of any kind four times a year when the seasons change (winter, spring, summer, and fall). Volunteers sift through samples of sand along the profile of their chosen location in a systematic way and report the number of microplastics they find. Volunteers also provide insights like recent weather events, temperature, water action, and other observations. They are guided by video and text instructions and are recommended to visit the same location each time they sample. However, there is no requirement to participate every season. The program currently has around 200 listed volunteers, but the number of individuals or groups who submit data varies from 20 to 60 each season. PWP recently released a New Jersey Microplastic Map (Image 2), an interactive map for public use displaying all the data collected since December 2019. The purpose of the map is to continue to spread awareness about the local presence of microplastics and hopefully eventually influence and inform local policy.

Image 1. Program training session.
Volunteers sifting through sand and looking for microplastics during a training session in September 2022 in Highlands, NJ. Photos by Gavin Shwahla.

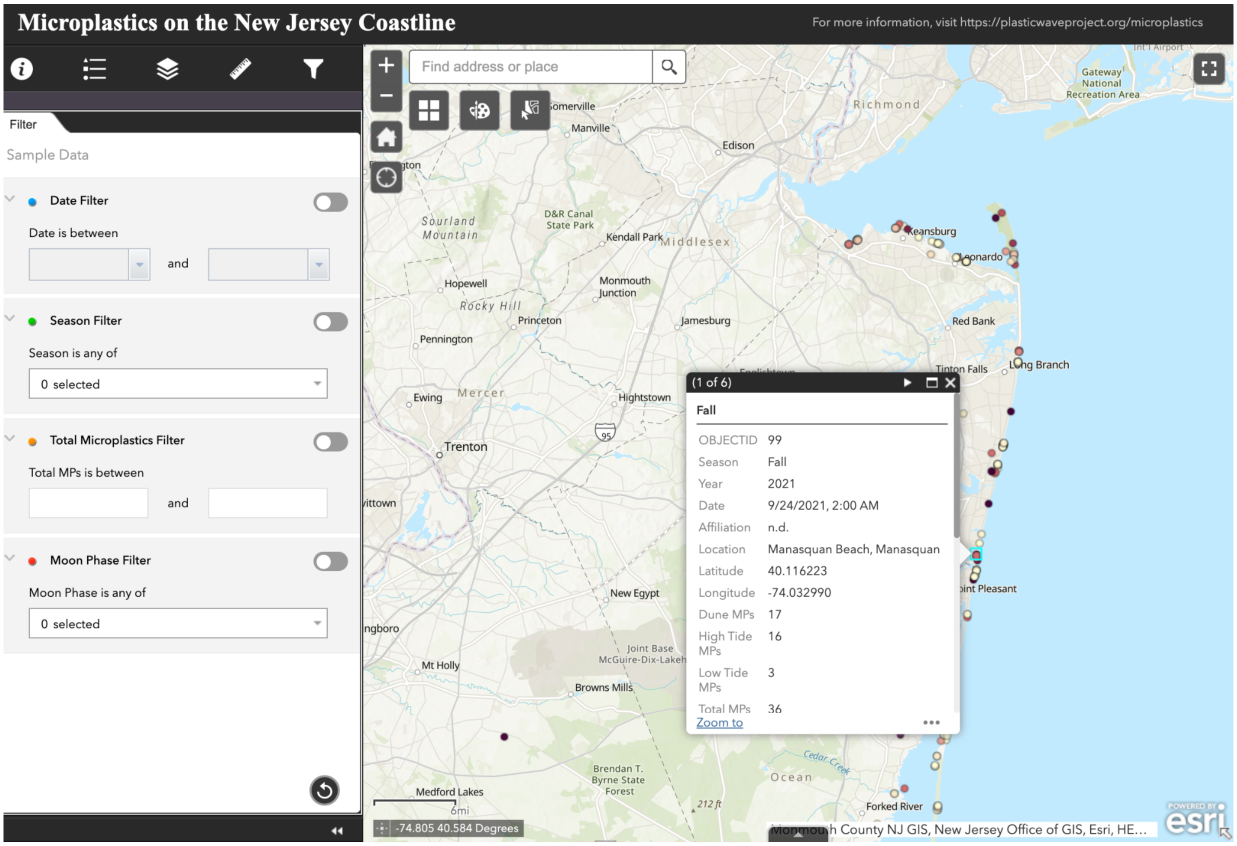

Image 2. New Jersey Microplastic Map.
Screenshot taken April 28th, 2023 of the map produced by PWP. One sample location has been clicked to illustrate how the map displays the data (Plastic Wave Project, 2023).

3.0 Methodology

The previous two sections provided justification for the research and background information about microplastics, citizen science, and the MMCSP. Citizen science has the potential to provide the necessary learnings to create more effective solutions and management of microplastics, but the specific learnings that arise from participation in a microplastic focused citizen science program have, up until now, yet to be discovered. This section explains my overall research process in finding an appropriate way to discover the learning outcomes of participation. It includes the overarching theoretical approach, the development of a framework to measure learning outcomes based on previous literature, and the resulting data collection and interview process.

3.1 A post-positivist theoretical approach

A post-positivist approach informs my research design, methods, and assumptions. This view of knowledge generation builds on the positivist idea that people can know about objects or society independently of individual or social conceptions of reality (Hicks, 2018). Absolute objective truths about the world, however, do not exist because an understanding of the world is inherently value laden based on individual experiences, biases, world views, and cultures (Cooper, 1997; Fox, 2008; Hicks, 2018; Trochim, 2007). By using multiple measures and types of observations, along with being reflexive about positionality, error can be reduced to create context specific generalizations (Cooper, 1997; Fox, 2008; Hicks, 2018; Ryan, 2006). It’s important to use a mix of quantitative and qualitative methods to strengthen findings while understanding that the tools used to gain information are subject to the researcher’s own positionality (Fox, 2008; Panhwar et al., 2017) These generalizations can then be falsified or built upon with further investigation (Cooper, 1997; Fox, 2008; Hicks, 2018). Post-positivist research also reflects on the ethical aspects, purpose, and impact of the research itself and comes from a place of learning with subjects instead of studying them (Fox, 2008; Ryan, 2006).

3.2 Creating a framework to measure learning outcomes

The overarching post-positivist methodological approach corresponds to the chosen mix of qualitative and quantitative methods which will be explained in this section (3.2) and the next section, 3.3. Learning outcome categories are pre-defined based on previous research, but the presence of other impacts is also considered. The information collected can be used to create context-specific generalizations, while understanding the limitations of the ways in which knowledge is accessed. Lastly, by using existing applicable frameworks, this research lends itself to be built upon and either corroborated or falsified through further research. This is especially important in the field of citizen science in order for impact to become a driving force for how programs are designed (Kieslinger et al., 2018).

3.2.1 Background of citizen science impact measurement

Organized and structured methods of measuring the impacts of citizen science are relatively recent developments in the field due to the lack of specific ontology for describing and understanding citizen science and its impacts (Kieslinger et al., 2018; Wehn, Gharesifard, et al., 2021). Scholars in the field have begun to develop customizable frameworks and general guiding principles for impact assessment and evaluation (Jordan et al., 2012; Kieslinger et al., 2018). Assessments should be balanced between social and science outcomes, multi-scalar and comprehensive, adaptable, and easy to understand by people of many backgrounds (Jordan et al., 2012; Somerwill & Wehn, 2022). They should also be grounded in social theories and consider the needs of the citizen scientists, not just the data (Druschke & Seltzer, 2012; Somerwill & Wehn, 2022). (Wehn, Gharesifard, et al., 2021, p. 1696) add six general guiding principles for evaluating citizen science: “1) acknowledging that there are a variety of purposes for citizen science impact assessment; 2) conceptualizing non-linear of impact journeys to overcome impact silos; 3) adopting comprehensive impact assessment data collection methods and information sources (qualitative as well as quantitative); 4) moving beyond absolute impact to include relative impact; 5) fostering comparison of impact assessment results across citizen science projects; and 6) cumulative enhancing the framework over time”. It’s also essential to also consider the barriers to and negative impacts citizen science could have on a community, which are currently incredibly underreported (Walker et al., 2021). One way to ensure an accurate assessment is to use or build upon an existing framework that is informed by previous research.

3.2.2 Using relevant resources to form a framework for this case

Using a framework is important because it contributes to the professionalization of citizen science, fosters funding and support, recognises desired outcomes, and enables for further research (Kieslinger et al., 2018). To find potentially relevant frameworks, I examined resources from organizations dedicated to expanding the relevance and understanding of citizen science including the Citizen Science Association, the European Citizen Science Association, and the Measuring Impact of Citizen Science (MICS) platform (Citizen Science Association, n.d.; CitizenScience.gov, n.d.; EU-Citizen.Science, n.d.; European Citizen Science Association, n.d.; MICS Project, n.d., 2020; Somerwill & Wehn, 2022). While resources specifically addressing the measurement of learning impacts were limited, three relevant sources were used to develop the framework for this study: 1) The Open Framework for Evaluating Citizen Science Activities by Kieslinger et al. (2018) (Table A1); 2) The Framework for Articulating and Measuring Individual Learning Outcomes from Participation in Citizen Science by Phillips et al. (2018) (Figure A1); and 3) the Co-Evaluation Tool by Woods et al. (2020) (Figure A2). These sources were most relevant because they had a focus on learning outcomes and were meant to be tailored and modified to a specific program.

The Open Framework by Kieslinger et al. (2018) is an extensive list of open ended evaluation questions, including one category specific to outcome and impact. Relevant questions that informed the interview questions in this study are listed in Table A1. The framework by Phillips et al. (2018) proposed six learning outcome categories and influenced the learning categories used in this research (Figure A1). Both of these resources were meant to be translated into a more practical assessment through a mix of qualitative and quantitative data gained through online surveys, interviews, or focus groups (Kieslinger et al., 2018; Phillips et al., 2018). To transform the questions and learning categories into a practical assessment, the Co-Evaluation Tool from the MICS served as inspiration. The Co-Evaluation Tool is used to document the impact of citizen science participation on knowledge, practices, and interest in science and the environment (Woods et al., 2020). The tool produces qualitative and qualitative information through open-ended questions and overall impact rating though a 0 to 7 Likert-style scale (Woods et al., 2020).

Following the guidelines and structure of the aforementioned literature, I created a framework of eight categories of learning to measure: 1) Engaging with science; 2) Understanding microplastics; 3) Environmental behavior; 4) Engaging with policy; 5) Identity and ownership; 6) Sustaining action; 7) Community building; and 8) Barriers to participation (Figure 1). The framework also includes a “gap” between “Engaging with science” and “Barriers to participation” to represent the learning areas that are not specifically assessed in this study but could be an outcome of participation.

Figure 1. Learning outcome categories.

3.3 Interview and data collection methods

As recommended in the literature, a combination of qualitative and quantitative methods were used to measure learning outcomes of participation. To collect qualitative data, I used structured interviews with predetermined questions and a specific sequence, ensuring that each interviewee provided responses for all eight learning categories (Stuckey, 2013) (Table 1). Each category consisted of two to three open-ended questions, drawing from the three relevant sources discussed in section 3.2.2. Follow-up questions were asked in real-time based on the interviewee's responses, but to ensure consistency, all the listed questions in Table I were asked in every interview (Stuckey, 2013).

After the open ended questions in each category, the interviewee was asked to give an overall impact score from 0 to 7. The inclusion of an overall score in the form of a Likert-style scale ranging from 0 to 7, was based on the Co-Evaluation Tool and added the quantitative dimension. This kind of rating style is used to measure the absence or presence of a specific item (Höhne et al., 2021). A score of “0” corresponded to “no impact” and a score of “7” corresponded to “the most impact”. Labels were given only to the endpoints of the scale, rather than for every integer, to align with the labeling approach used in the Co-Evaluation Tool. Furthermore, assigning labels to every integer this study would impede the comparability of answers to future studies which use the same framework (Höhne et al., 2021; Woods et al., 2020).

Table 1. Interview questions and order.

Interview Questions
Engaging with science
How has your knowledge about science in general changed after participating in the program? (ex. collecting and interpreting data, investigating problems, creating explanations)
How has participating impacted the way you view science and its role in society?
On a scale from 0-7, to what extent has participating in the program impacted how you engage with science?
Understanding microplastics
How has your knowledge about the presence of microplastics and their impacts in New Jersey (or the world) changed after participation?
How has your concern about microplastics been impacted by participating?
On a scale from 0-7, to what extent has participating in the program impacted your understanding of microplastics?
Environmental behavior
How have your everyday behaviors around plastic use changed after participating in this program?
How has your motivation to start or try other environmentally friendly behaviors been impacted since participating?
On a scale from 0-7, to what extent has participating in the program impacted your environmentally friendly behaviors?
Engaging with policy
How has participating in the program impacted how you engage with policy regarding microplastic pollution?
Since participating, what local policy problems, if any, have you been able to identify regarding microplastics or other environmental issues?
On a scale from 0-7, to what extent has participating in the program impacted how you engage with environmental policy?
Identity and ownership
How has your sense of responsibility for the environment been impacted by participating in the program?
How has participating impacted the degree to which you see yourself as a scientist or someone who knows about, uses, and contributes to science?
How has participating impacted the level of confidence you have in your own abilities or the sense of ownership you have?
On a scale from 0-7, to what extent has participating in the program impacted your identity?

Sustaining action
What other microplastic issues or different environmental issues have you gotten involved in outside of the program, if any?
How has participating impacted the way you feel about getting involved with environmental issues?
On a scale from 0-7, to what extent has participating in the program encouraged you to stay involved in environmental or social action?
Community building
How has participation impacted your feeling of connection towards other community members?
How has your opinion about community based activities been impacted by participating?
On a scale from 0-7, to what extent has participating in the program impacted your sense of community?
Barriers to participation
How do you feel about the time and effort you have put into the program?
Did the program include requirements that were difficult to meet?
On a scale from 0-7, 0 meaning there were no barriers and 7 meaning there were the most barriers, how difficult was participating in the program?
Other impacts
Are there any other impacts, thoughts, learnings or feelings you would like to share with me that we did not cover?

A pilot interview was completed on March 13th with one of the founders of Plastic Wave Project before reaching out to volunteers. At the time of this research, the program had 213 members on its roster with 82 active volunteers, or volunteers who participated in the program at least one time. Of the 82, 12 were not contacted because they either had no email on file or were under 18 years old. In total, I contacted 70 volunteers by email on March 13th, 2023 and 11 volunteers agreed to an interview. I conducted the 11 interviews between March 20th and April 5th (Table 2). Each interview was recorded with permission of the volunteer and then transcribed using the AI transcription tool Otter.ai. The transcripts were then analyzed using deductive methods to find common themes within each of the eight predetermined categories of learning in an organized and rigorous way (Bingham & Witkowsky, 2022).

3.4 Limitations of methods

While interviews provide comprehensive and in-depth qualitative data, the one limitation to consider is the types of volunteers who are not represented. Volunteers who had a negative or neutral experience may not feel comfortable speaking directly to someone in the form of an interview. Additionally, because interviews are relatively time intensive compared to a survey, it is likely that volunteers who are already quite engaged in environmental issues will be more willing to participate than ones who might have a different level of engagement. An anonymous survey was considered as an alternative data collection method, which could have provided individuals with limited time or less positive experiences a greater sense of ease in sharing their thoughts. In spite of that, a survey may not have provided an accurate representation of learnings due to the small sample size of participants. The benefits of conducting qualitative interviews, which allow for follow-up questions, outweigh the limitations in this case.

My own positionality as an interviewer could be both a limitation and a benefit. On one hand, my intimate knowledge of the program and community enabled me to relate to and understand volunteer responses. On the other hand, this means I could have made assumptions without realizing. My existing role within the Plastic Wave Project could have influenced how volunteers responded to the questions. As an inexperienced interviewer, the phrasing of questions, their order, and the types of follow-up questions I asked may have affected the quality and relevance of the information shared by volunteers.

Table 2. Interview overview.

Volunteer	Number of times volunteer participated in the program	Interview Platform	Interview Length
V1	4	Zoom	34 min
V2	1	Zoom	40 min
V3	10	Zoom	34 min
V4	12	Zoom	36 min
V5	6	Zoom	27 min
V6	7	Zoom	36 min
V7	12	Phone Call	21 min
V8	2	Zoom	41 min
V9	1	Zoom	23 min
V10	8	Zoom	35 min
V11	2	Zoom	1 hr 46 min

4.0 Results and Analysis

4.1 Overall impact scores

In general, participation in the program fostered learning in every single category, albeit to differing extents depending on the individual volunteer's background and interests. The categories receiving the highest average overall impacts score include "Sustaining action" (6.00) followed by "Understanding microplastics" and "Community building" (both 5.18). Two categories, "Identity and ownership" and "Sustaining action", received a score of 7 more than any other score. This indicates that this particular program created the most learning about the specific content of microplastics along with contributing to positive views of and increased motivation to continue environmental action. The low average score in "Barriers to participation" (1.3) suggests that the content is digestible and the structure of the program makes it relatively easy to participate. The relationship between quantitative scores and qualitative data will be explained further in the following subsections. Overall, the scores appeared to align well with volunteer responses, although some scores seemed slightly higher than expected based on qualitative insights.

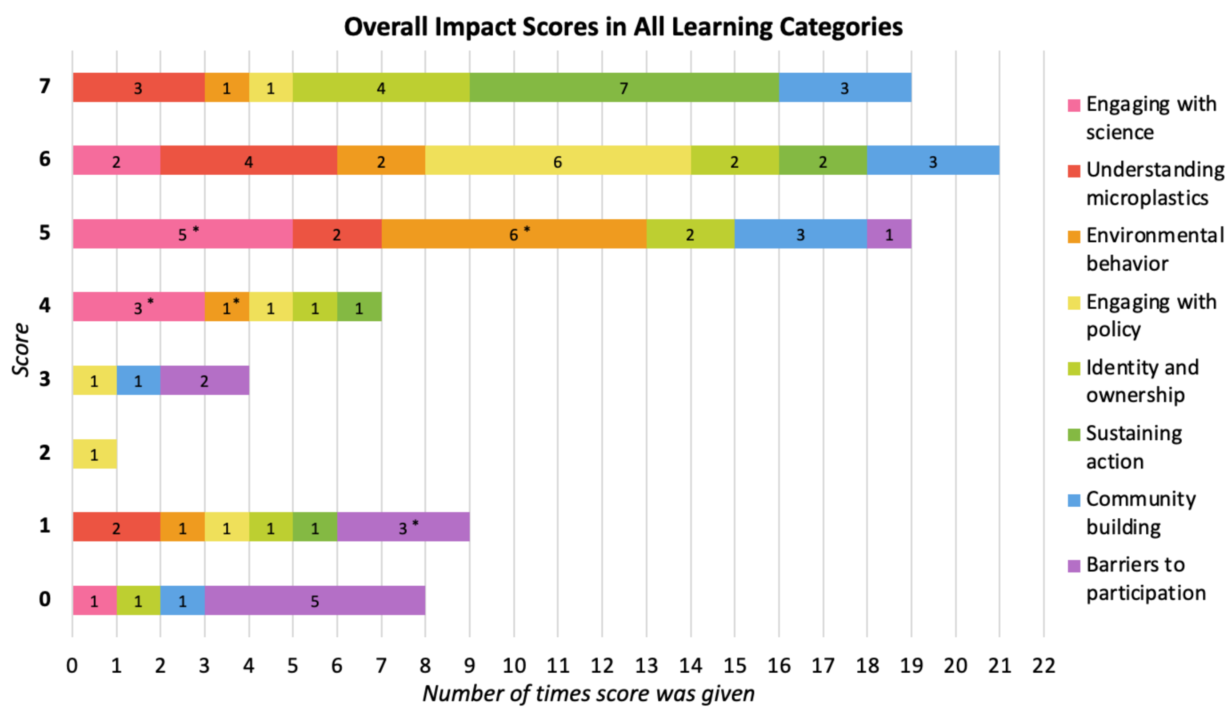

Figure 2. Overall Impact Scores in All Learning Categories.
The Likert-style score is 0 = "no impact" and 7 = "the most impact". Numbers within the stacked bars indicate the number of times the score was given in that category. A " * " means the number of times includes one score 0.5 higher than displayed. "Engaging with science" and "Environmental behavior" received one 4.5 and one 5.5 which were rounded to 4 and 5 respectively. "Barriers to participation" received one 1.5 which was rounded to 1. These were rounded down for ease of data visualization.

4.2 Analysis of each learning category

The following nine subsections will highlight the primary themes in each learning category that emerged from the interviews. The relationships between the qualitative and quantitative data will also be analyzed. Everything discussed in the interviews could not be included due to the scope of this research, so instead the focus is on the most common and relevant learnings in relation to the existing academic literature. Due to the interrelated nature of the questions, answers provided by the volunteers often addressed multiple categories. As a result, the information presented in the following nine sections encompasses the entirety of the interviews, rather than being limited to the specific questions pertaining to each category. Direct quotes from interviews have been included in italics and are attributed to the volunteers as listed in Table 2.

4.2.1 Engaging with science

The questions in this category aimed to understand the impact of participation on volunteers' scientific skills and their perception of science. The average score of 4.44 means the program had a medium impact on how volunteers engage with science (Figure 3).

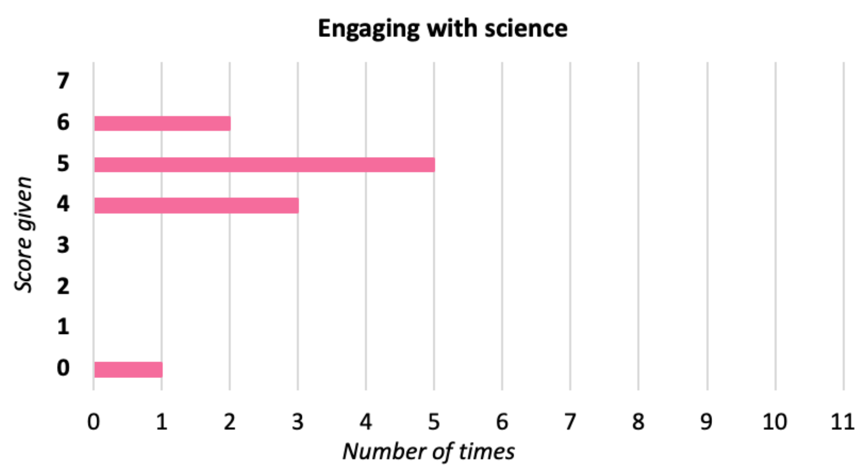

Figure 3. Distribution of scores given to the “Engaging with science” category.

The volunteer responses aligned with their scores and revealed four key aspects. First, the data collection factor of the program seemed to contribute to learning the most, either as a totally new experience or a way to build on an existing skill set. Many volunteers enjoyed data collection in the field not only as a way to learn, but also as an outdoor activity. One volunteer mentioned that the use of “elementary'' scientific concepts during data collection, like making observations or counting what you see, kept them engaged and contributed to their understanding of the scientific process due to the clear role they had in the research.

Second, many volunteers said participating contributed to their view of science being important in order to solve problems and understand the world. Quite a few volunteers also spoke about the importance of citizen science programs, as they bring science to the “average” person and allow people outside of the traditional scientific field to feel like they are contributing. As shown by the following quote, some volunteers mentioned that the program provided an opportunity to reconnect to their passions of science outside of their professional lives.

> *V6: "Citizen science has been a really important way for me to tie back to a passion of mine…[it] connected me back to science and allowed me to feel like I was contributing, where I don't contribute to it in my profession."*

Third, less than half of the volunteers mentioned that the program did not have a strong impact on their knowledge of science or their view of science in general. However, many of these volunteers already had scientific or academic backgrounds and held positive views of science prior to participating in the program.

> *V11: "I wouldn't say that participating…drastically impacted my worldview of science or anything like that, but I think it helped engage me in it and helped me think about why we're doing these things and get me a little bit more excited about participating in other related citizen science projects, or just other research projects."*

Finally, a few volunteers mentioned being introduced to the concept of citizen science through participation. Even if their view of science in general was not changed, their view of citizen science specifically was impacted positively. A couple added that they believe citizen science is a valuable avenue for learning science, collecting data, and engaging the community.

4.2.2 Understanding microplastics

This category focused on awareness and understanding of the specific content of microplastics. The average score given in this category was 5.18, which is the second highest average score tied with "Community building" (Figure 4). This indicates the program had a moderately high impact on how volunteers understand microplastics.

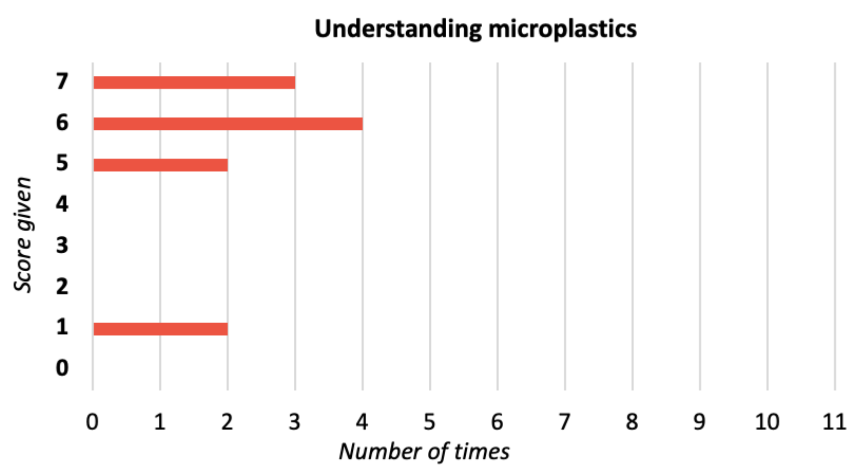

Figure 4. Distribution of scores given to the "Understanding microplastics" category.

The distribution of scores in this category seemed to align with the insights gathered from the interviews, as almost every volunteer mentioned an increased understanding of microplastics. Three main insights were discovered through the interviews. First, knowledge about the presence of microplastics increased. A few volunteers were not aware of the problem of microplastics at all before the program, so participation taught them something new. Other volunteers who already had some knowledge said participation supplemented what they already knew. Five volunteers mentioned being introduced to the term 'nurdles', which prompted critical thinking about the various sources of microplastics.

Second, participation increased concern about microplastics in most volunteers. As highlighted in the following quotes, several volunteers emphasized the significant impact of witnessing the problem firsthand, which increased their awareness, concern, and understanding of microplastics.

> *V5: "I knew it was the small pieces, but really not to what extent. So that has changed tremendously…it makes me think twice about what I use…that definitely had a big impact…when you do something hands on and you see it firsthand, it does make a difference."*

> *V8: "It's certainly changed my attitude toward plastics. And it's made me conscious of microplastics and plastics and the impact… if you know that you ingest a credit card of plastic every week...it scares the life out of me. I'm worried"*

Volunteers expressed specific concerns about the impacts of microplastics on both sea life and human health. Only one volunteer felt more positive after finding no microplastics at their location. Two volunteers expressed the opposite sentiment, where finding microplastics actually created a feeling of sadness and could ruin their experience at the beach.

Finally, four volunteers explicitly mentioned wanting to learn more about microplastics and their impacts. This is important to note when considering motivation to continue with environmental action is a desirable learning outcome as well.

4.2.3 Environmental behavior

Questions in this category aimed to understand if participating in the program inspired plastic reduction or other environmentally friendly behaviors in volunteers' day-to-day lives. The average score of 5.00 means that participation had a moderately high impact on volunteers' environmental behaviors. Due to the high amount of motivation and the existence of environmentally friendly behaviors in volunteers before participating in this program, the average score is slightly higher than expected (Figure 5).

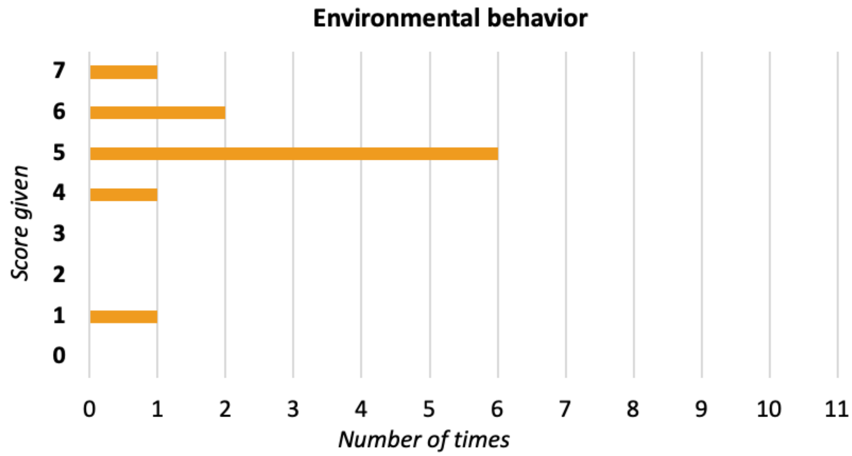

Figure 5. Distribution of scores given to the “Environmental behavior” category.

Two main insights came to light through the interviews. First, many volunteers do incorporate specific behaviors to reduce plastic use and are motivated to try other environmentally friendly behaviors, but these behaviors were not necessarily caused by participation in the program on its own. In fact, multiple volunteers said they were already actively incorporating sustainable behaviors into their daily lives before participation in the program. Pinpointing a singular cause for this shift was challenging, and instead, behavior changes were a culmination of many experiences over several years.

> *V4: “It's coincidental with, but it amplifies everything that that I kind of was doing…[participating is] a good reminder [that] this doesn't come free, you know, this comes with a burden.”*

A few added that they also educate people in their lives about microplastics and advocate for environmentally friendly behaviors. One volunteer shared that participation in this program, along with others like it, inspired a family member to pursue higher education in environmental science.

A second interesting theme that emerged from the conversations was an awareness of the impacts of plastic use and the efforts to limit it, while also acknowledging the barriers to implementing these behaviors. Several volunteers highlighted the systemic problems associated with plastic production and consumption and the lack of choice around using plastic or not, as illustrated in the following quote.

> *V10: “I'm not like the anti-plastic person. I know we need plastics…I don't get to choose if my iced tea is going to be in a glass container or a plastic container, and if I do, it's rare now, right?...You don't have a choice, or if you do have a choice, it’s a hard one, or it's an expensive one, you can't afford to make that choice.”*

Less than half of the volunteers said they have not tried new behaviors but are more aware and engaged in the potential to change behaviors if accessible to them. Additionally, witnessing the problem first hand through participation reminded many volunteers of the importance of practicing environmentally friendly behaviors.

4.2.4 Engaging with policy

Discussions in this category aimed to understand if participation changed the way volunteers thought about or participated in policy regarding microplastics or other environmental issues. The average score in this category was 4.82, indicating that the program had a slightly higher than medium impact on how participants engage with policy (Figure 6).

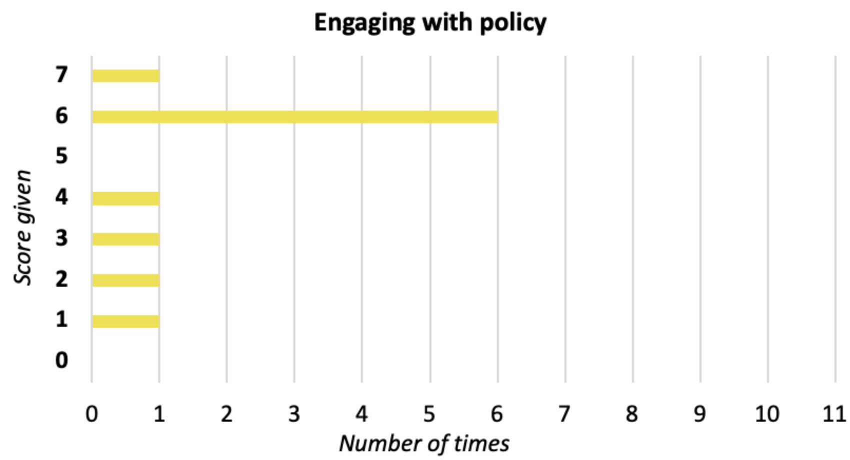

Figure 6. Distribution of scores given to the "Engaging with policy" category.

There are three noteworthy aspects about the interview data here. First, the quantitative scores did not always correspond to the interview data. A few volunteers gave scores of 6 or more, even though they did not directly engage with policy or learn about policy through the program. These scores were justified by saying they are more aware, interested, or willing to engage in environmental policy, even though they might not actively seek out political participation. Around half of the volunteers mentioned that they sign petitions or write letters whenever requested by an organization.

Second, the interview data demonstrates the challenge of solely attributing policy engagement to participation in the program. Many volunteers were able to identify multiple local environmental policy problems, but as the following quote demonstrates, this ability may not be a direct learning outcome.

> *V11: "I'd like to think that regardless of participating in the program that I would support policies to reduce plastic use or encourage or require environmentally biodegradable plastic use"*

Finally, the data shows that policy engagement and opinions are complex and unique to individual experiences. A few volunteers expressed a negative view of engaging with policy and frustration around ineffective policies like straw bans and bag bans. However, other volunteers credited their use of fewer plastic bags to the same local plastic bag ban.

4.2.5 Identity and ownership

Questions here aimed to understand how participation impacted volunteers' overall confidence, sense of responsibility, and self identity. This category received an average score of 5.00, but received a score of 7 more frequently than other scores (Figure 7). This implies the program had a moderately high impact on volunteers' identities.

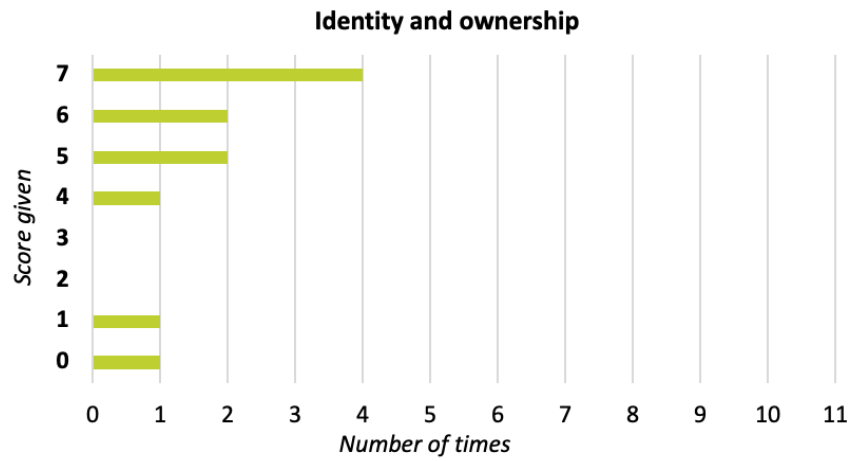

Figure 7. Distribution of scores given to the "Identity and ownership" category.

The distribution of scores corresponded well to the qualitative answers of each volunteer and three themes are noteworthy. First, all but one volunteer said that participating increased their sense of responsibility for the environment. Some volunteers already felt responsible for the environment and participation built upon it. One mentioned concern for their grandchildren's future as an important aspect of what makes them feel responsible for environmental protection.

Second, about two thirds of the volunteers said participating increased their overall confidence and sense of ownership, especially around being able to learn and try new things. A few commented on feeling proud of their participation and their role in helping to make a difference, as shown in the quotes below. About a third of the volunteers said the program did not impact their overall confidence, with many mentioning that they already felt confident in their own abilities or had a high sense of ownership.

> *V2: "I kind of feel proud of myself, that I'm helping to maybe make a little bit of a difference. And I like that. I want to do things with my time that are going to make a difference…It does help me be more confident when I mean, not just doing whatever you're doing, but like reading about the issues that come through from the different organizations."*

> *V9: "I felt a little more confident in my ability as a single person to do studies and maybe effect change. You know, studying marine biology, I kind of have a sort of grim outlook with climate change in the world and in general right now. So it felt kind of like I could make change as an individual."*

Finally, about half of the volunteers felt that participation made them view themselves as being someone who knows about and contributes to science. A few also spoke about how this experience allowed them to reconnect to their pre-existing passion for science, as previously mentioned in section 4.2.1. About a third of the volunteers mentioned how the experience contributed to their professional development, adding to their credibility, building their resume, or providing a valuable addition to their existing careers. Only a couple of volunteers said they didn't see themselves as scientists, one saying they see themselves as an activist instead.

4.2.6 Sustaining action

The questions here aimed to discover how motivation to participate in other environmental action was impacted by participation. This category received the highest average score, 6.00, and the most scores of 7 (Figure 8). This high impact score indicates that participation had a very high impact on encouraging volunteers to stay involved with environmental action.

Figure 8. Distribution of scores given to the "Sustaining action" category.

This high score is confirmed through qualitative insights. There are three things to note from the interview data. First, almost all of the volunteers had an increased interest in participation in environmental programs and viewed them as valuable. While around half of the volunteers were already involved in other community programs or environmental action before, most of these volunteers mentioned that this program added to their motivation and increased their positive view of community programs, as seen in the following quote.

> *V11: "Maybe I would have done [a different program] without having done…the microplastic research, but I think it kind of helped open that door for me and make me think more [about] how can I get involved in these types of activities...I definitely think that this project was almost like the gateway into engaging in more community science and citizen science activities."*

Second, the learnings in this category seemed to overlap a bit with "Identity and ownership" and "Community building". As the following quote shows, having a positive opinion of participation in programs that provide an opportunity to contribute to the community can lead to increased engagement in other environmental activities.

> *V6: "[Participating] made me feel like it's a place where I can help. So I think it definitely has increased my chances of getting involved in other things in the future"*

Finally, conversations showed that environmental action is unique to each individual and their own interest and skills. A few volunteers said they were not currently engaged with other organized environmental activities, but instead practice environmental advocacy through public speaking, their formal education or careers, or they focus on taking action as an individual though beach clean ups. Motivation in these activities are not necessarily linked to participation in the program, but is interesting to note because it shows the diversity of the volunteers' views of environmental action.

4.2.7 Community building

Questions in this category focused on how participation impacted volunteers' feeling of community and opinion of community activities. This category received an average score of 5.18, the second highest average score tied with "Understanding microplastics" (Figure 9). This means participation had a moderately high impact on volunteers' sense of community.

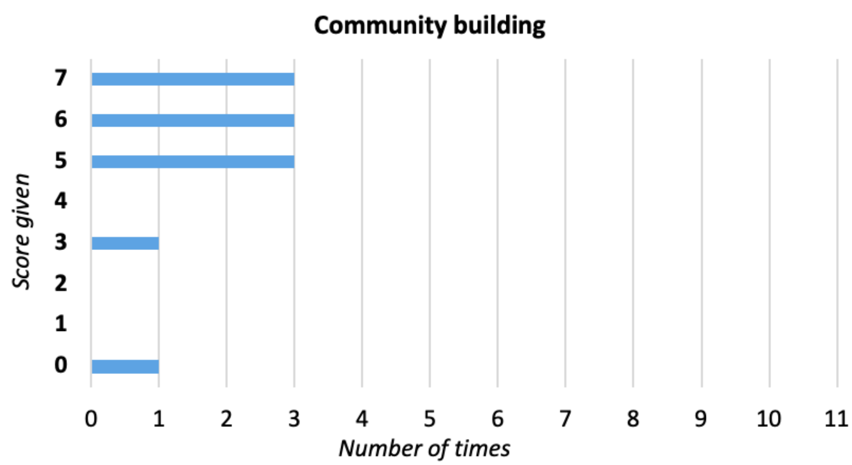

Figure 9. Distribution of scores given to the "Community building" category.

Three overall insights came to light from the interview data. First, the quantitative scores seem a bit high because there were mixed qualitative results about participation's impact on volunteers' sense of community. The skew could be due to the overarching positive opinion of community programs, which many times was already mentioned by this point of the interview.

Second, about half of the volunteers felt more connected to their community through participation while the other half felt that participating did not have much of an impact on their sense of community. A few volunteers noted that witnessing others working towards a shared goal evokes a positive feeling as it reinforces the understanding that they are not alone in their concern for the issue. Just under half of the volunteers spoke about working in groups while sampling, which either strengthened existing relationships or created new ones.

> *V4: "It was one of the few things that we could do at one point during COVID… I don't know if I would call it community building, but you know, friendship and like minded people"*

The volunteers who said participating did not have much of an impact on their sense of community were still generally positive about the program. One volunteer even gave a suggestion to improve the program and add a community focus, as shown in the quote below.

> *V6: "I didn't really get much [community building] from the program…because I didn't really ever come across anyone who was running the studies and maybe that's…a social aspect to the program that could be [added]...connecting people who are doing studies very close to each other, something like that…maybe there could be more of a more of a community driven approach to it…like a meet up for a certain town or the Jersey Shore in general"*

Finally, most volunteers expressed a belief that these types of programs are important and beneficial, with one volunteer adding that they feel more optimistic about solving environmental problems due to the existence of citizen science. Those who were introduced to citizen science for the first time also spoke about the multiple kinds of benefits, like collecting data and involving community members who might not have "traditional" science experience, as previously mentioned in section 4.2.1.

4.2.8 Barriers to participation

This category focused on understanding how difficult volunteers found participating in the program. The average score was 1.3, suggesting the program was not very difficult to participate in and that there were very few barriers (Figure 10).

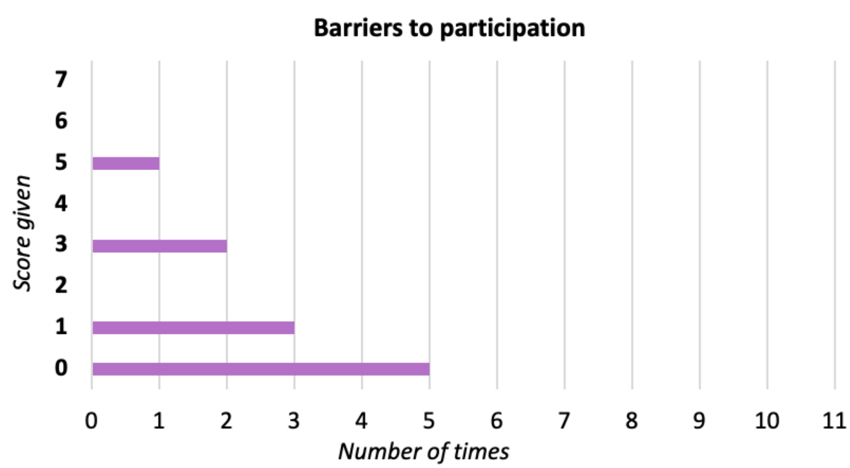

Figure 10. Distribution of scores given to the "Barriers to participation" category.

The distribution of scores reflects the qualitative data well as all volunteers had a positive view about the time and effort needed to participate in the program with some variation. Two main themes came through the interviews. First, while certain aspects do take time, like sorting out microplastics from the samples, most volunteers said it was time well spent. Only one volunteer said it was a little too much time. This volunteer acknowledged that they only participated once early on, and has seen that changes have been made since then.

Second, all volunteers said no requirements were too difficult to meet and there were few to no barriers. The only common barrier noted by more than one volunteer was that it was sometimes difficult to make it out during the two week sampling window. However, others mentioned the window was plenty of time. Some other barriers noted by individual volunteers include the amount of information to be read being too lengthy, the format of the New Jersey Microplastics Map being difficult to use, and noting there are certain physical capabilities that are necessary to participate in the program. Multiple volunteers mentioned ideas about how the program could improve during this part of the interview. This shows that barriers are different for every participant and asking about barriers can inform program improvements.

4.2.9 Other impacts

At the end of each interview, space was given for the volunteers to reflect on any other impacts or learnings that the questions did not cover. Most volunteers did not have additional learnings, but the majority offered positive feedback and reiterated the importance of the program. One topic that was not specifically addressed in the questions, but many volunteers spoke about, was the impact of the New Jersey Microplastic Map. Seeing the map allowed for individual exploration of the data, made volunteers feel like they were contributing even if they didn't find any microplastics, and fostered a sense of transparency between the volunteers and the organization. This is in agreement with previous research stating the importance of an accessible and open data display (Phillips et al., 2018). It also sparked questions about what could be done with the data and how the program could grow to cover more areas in New Jersey.

5.0 Discussion

The qualitative interviews provide insights into the kinds of learning gained by participating in the MMCSP, and quantitative rankings help contextualize which areas of learning were the most impactful. Overall, the results confirm previous research that participation in citizen science contributes to a wide range of learning. In this case, the most impactful categories were "Sustaining action", "Understanding microplastics" and "Community building". While learning is a dynamic and unique process for each individual, participation in citizen science can create a deeper understanding of specific topics and motivate and inspire further environmental engagement regardless of preexisting knowledge and backgrounds. These learning outcomes not only drive personal change but also hold the potential to contribute to overall sustainability within SESs.

5.1 How do the learning outcomes contribute to sustainability within socio-ecological systems?

Building sustainability within SESs means increasing the capacity to manage risks and unexpected changes, while ensuring the functions of social and ecological processes for the future (Simonsen et al., 2014). The eight categories of learning measured in this study did tend to overlap with each other, leading to three main takeaways when considering how learnings from citizen science can impact overall sustainability in coastal SESs in the face of microplastics: 1) an increase of content and scientific knowledge; 2) mixed results about the extent of impact on behavior changes and policy engagement; and 3) the contribution of participation to individual outlooks leading to continued support for environmental action.

5.1.1 Increase in content knowledge about microplastics

First, citizen science can increase content and scientific knowledge. As explained in sections 4.2.1 and 4.2.2, and in agreement with previous research by Phillips et al. (2018), the MMCSP effectively increased specific content knowledge, influenced data collection skills, and created a positive view of science. This is important for building sustainability because it increases the capacity to learn about and understand complex problems within SESs (Simonsen et al., 2014). Concern about the socio-ecological impacts of microplastics also increased, which can encourage individuals to take stewardship actions though policy engagement, personal changes, or advocacy (Haywood et al., 2016). The increase in understanding of microplastics found in this study is important because one of the proposed ways to help manage microplastics is specific plastic focused education (Iroegbu et al., 2021). Individual knowledge and concern about microplastics in combination with an understanding of science can reduce overall uncertainty and equip the public with the ability to make informed decisions about behaviors or management tactics (Martínez-Fernández et al., 2021).

Conversations with volunteers also provided insight into how people learn (Bonney et al., 2016). Many volunteers commented on the large impact of seeing the problem firsthand, contributing to their understanding, concern, or motivation to continue environmental actions. This insight could serve as a valuable recommendation for future citizen science programs, highlighting the importance of incorporating localized aspects that foster enhanced learning experiences. When hands-on elements are combined with transparent results, like the New Jersey Microplastic Map, another dimension of learning is added. Not only does seeing the data displayed have positive benefits for the participants, but open source public data can be used by other members of the community and contribute to the democratization of science. Overall, this suggests that local, transparent, and hands-on microplastic citizen science programs could be one avenue to foster the knowledge generation needed to build effective solutions. Creating more understanding, both scientifically and in the general public, can then translate into increased certainty about microplastics and therefore reduce the overall risk of microplastics to SESs (Kramm & Völker, 2018).

5.1.2 Mixed impact on behavior and policy engagement

Second, the results showed somewhat mixed and inconclusive results regarding behavior changes and policy engagement. Behavior and policy both contribute to the sustainability of SESs (Simonsen et al., 2014), so understanding what motivates people to act a certain way is important. While behavior change is one of the most sought after impacts of citizen science programs (Phillips et al., 2018), this study revealed that pinpointing the exact reasons behind individual behavior changes aimed at reducing plastic use was challenging. Furthermore, as stated in section 4.2.3, more awareness or motivation to try environmentally friendly behaviors does not mean they can be incorporated into daily life due to other factors like the availability and accessibility of plastic free alternatives. One of the current limitations to effective microplastic management is that there is too much reliance on individual voluntary actions (Usman et al., 2022). All this begs the question; how large of a role should individual behavior change around plastic consumption really play in managing microplastics? While individual actions should continue to be a part of the solution, a stronger focus on holding producers accountable for reducing production and managing pollution could be a way forward to build sustainability within SESs (Iroegbu et al., 2021).

One specific behavior previously stated as an outcome of participation in citizen science is equipping community members to engage in the political process and use their knowledge to create change (McKinley et al., 2015; Paul et al., 2020; Wyeth et al., 2019). The mixed results in how engaged volunteers were in policy after participating could indicate that this benefit is more of an assumption than a guarantee. If policy engagement is a goal, then programs may need to include specific action items for volunteers, like signing petitions or asking them to attend meetings. Understanding individual ability and desire to participate in the political process is an important first step before assuming volunteers will automatically be engaged. Because of the current lack of cohesion and community involvement in creating microplastic policies (Kramm & Völker, 2018; Usman et al., 2022), figuring out ways to encourage community engagement in policy participation around microplastics should be a focus of future research.

While this was not a trend in the data, a few comments were made about frustration with policy or the true ability to make a difference with individual behaviors. This is important to consider because there is a risk of individuals becoming less motivated to engage with science, policy, or environmental actions if the data from programs do not contribute to meaningful results (Walker et al., 2021). This means organizations running citizen science programs should make their goals clear and update volunteers on progress, like PWP has done with the New Jersey Microplastic Map, to reduce potential negative repercussions. It also shows the importance of connecting with the volunteers and getting their feedback to make sure the programs are providing appropriate resources and results.

5.1.3 Individual outlooks and motivation to continue environmental action

Third, participating in the program increased individual confidence, an overall sense of responsibility for the environment, and motivation to continue environmental action. It also increased positive opinions of community programs like citizen science. A couple volunteers mentioned that the existence of citizen science programs in and of themselves gave them a more positive outlook about society's ability to solve environmental issues. Additionally, volunteers spoke about taking different roles in environmental action based on their interests or skills (Ballard et al., 2017), including other community programs, public speaking, or individual actions. All these leanings are somewhat of a feedback loop because self efficacy and perceived importance impact choice, effort, and persistence (Haywood et al., 2016; Phillips et al., 2018). Like Schuttler et al. (2018) and Haywood et al., (2016) mention, many volunteers commented on their desire to participate in programs that made them feel like they were contributing to something bigger and giving back to the community. All of these learning outcomes are important when building overall sustainability within SESs because it increases diversity of engagement and knowledge, which can lead to more robust solutions and management ideas (Martínez-Fernández et al., 2021; Sauermann et al., 2020).

The results of this study indicate that citizen science can be an effective mechanism to bring individuals and communities into microplastic monitoring which is currently lacking (Usman et al., 2022). Increasing public engagement and willingness to work toward environmental goals is important for not only solving the microplastic problem, but for increasing sustainability within SESs in general (McKinley et al., 2015). However, it is important to consider that around half of the volunteers I spoke to were already quite engaged in environmental issues or other citizen science programs, so further research is needed on understanding the motivations and more detailed learning outcomes specifically of individuals without prior knowledge or experience with environmental topics.

While opinions of community programs were positive, the mixed results about the program fostering a deeper sense of community in general along with the desire for volunteers to feel like they are contributing underlines the importance of co-creating programs with the participants and the community. By doing so, community needs and desired outcomes are prioritized, potentially resulting in heightened community connections, trust, and increased engagement fostered by a shared sense of responsibility. When learning outcomes are embedded into citizen science projects from the start, the programs will have the most impact on individual and institutional scales (Bela et al., 2016; Jordan et al., 2012; Somerwill & Wehn, 2022). Desired learning can then become not only an outcome, but a driving force for creating successful citizen science programs that meet social and ecological goals (Jordan et al., 2012).

5.2 Other considerations

This section will touch upon some overall considerations about this study because reflexivity and positionality are important parts of post-positivist and sustainability research (Fox, 2008; Lang et al., 2012; Panhwar et al., 2017). While the entire thesis is informed by previous literature, it is also subject to my own bias as the author. I chose certain questions, used certain frameworks, and came up with certain takeaways which were all impacted by my own knowledge. My involvement with PWP is a potential benefit because these learnings can easily be translated into action and direct improvement of the program. But, this also means the analysis is lacking a true “3rd party” perspective which could have brought other insights to light.

It's important to note that citizen science represents only one potential avenue for contributing to the proposed solution pathways to address microplastics. Other mechanisms, like roundtables or conferences, have also been shown to allow citizens to help direct research and have a voice in environmental decision making (Sauermann et al., 2020). It takes much more than just education to create the changes needed to manage threats to SESs, but education is a part of it. While the results of this study did not bring to light many of the potential negative impacts of citizen science like decreased trust, conflicts, or additional burdens (Paul et al., 2020; Walker et al., 2021), negative impacts are important to consider before implementing a program. This even further stresses the importance of program co-creation and development.

This study focused on learning outcomes and not the scientific outcomes of the data provided or the methodology used in the MMCSP. Alongside learning outcomes, it would be interesting to see how the monitoring data provided through this program impacts overall scientific understanding and if the methodology can contribute to standardizing methodology for microplastic monitoring (Gong & Xie, 2020). Just because individuals are more aware of the problem, does not mean it can translate to effective management if the problem is not properly quantified. I did consider including these ideas early on in the research process, but eventually decided it was outside of the scope. Scientific outcomes should be considered for future research because other solution pathways include increasing monitoring to provide more in depth local information about the extent of the problem (Kumar et al., 2021; Setälä et al., 2022; Sun et al., 2023).

6.0 Conclusion

Microplastics are an ever-present threat to SESs because they are a by-product of current societal operations, they persist in the environment and cause complex negative impacts, there is uncertainty regarding these impacts, and a lack of clarity about appropriate solutions. This research builds upon a limited amount of existing studies measuring learning outcomes and impacts of citizen science. The results suggest that citizen science could be one mechanism to foster the learning necessary to build sustainability within SESs, inform solution creation, and manage the risks of microplastics. The Microplastic Monitoring Community Science Program in New Jersey created a variety of learnings, including building content knowledge about microplastics, creating more positive opinions about community programs, and increasing motivation to participate in environmental action. There were mixed results about how participation impacts behaviors and policy engagement, which offers insight into ways management tactics and citizen science programs could be improved. The research also highlights the importance of involving communities from the initial creation of citizen science to set and then achieve goals. Further research is necessary to create a deeper understanding of the impacts of learning through citizen science so it can be used in ways that create the most benefits for society and the environment.

Appendix

Table A1. Outcome and Impact Guiding Questions.
Questions by Kieslinger et al. (2018) that inspired the interview questions in this study. This is not all the questions listed in the literature, but only the ones directly related to "Outcome and Impact" and the learning categories of measurement in this study.

Outcome and Impact Questions:
1. What are the learning outcomes with regards to new knowledge, skills? 2. Does the project contribute to a better understanding of science? 3. Does the project contribute to a better understanding of the scientific topic? 4. Does the project foster ownership amongst participants? 5. Does the project contribute to facilitating personal change in behavior or political citizenship? 6. Does the project raise motivation, self-esteem and empowerment amongst participants? 7. Are participants motivated to continue the project or involve in similar activities? 8. Does the project contribute to the collective capacity of the participants in achieving common goals? 9. Does the project include objectives that protect and enhance natural resources and/or foster environmental protection? 10. Does the project contribute to higher awareness, knowledge and responsibility for the natural environment? 11. Does the project contribute to a better understanding of science in society? 12. Does the project stimulate political participation? 13. Does the project impact policy processes and decision-making (e.g., through agenda-setting or data contribution for policy evaluation)? 14. Does the project foster the use or development of new technologies? 15. Does the project consider sustainability (environmental impact or sustained social relations) as part of the project plan? 16. Are the project results transferable to other contexts or organizations? 17. Does the project contribute to social, technical or political innovation? 18. Does the project generate any economic impact or competitive advantages, (e.g., cost reduction, new job creation, new business models, etc.)?

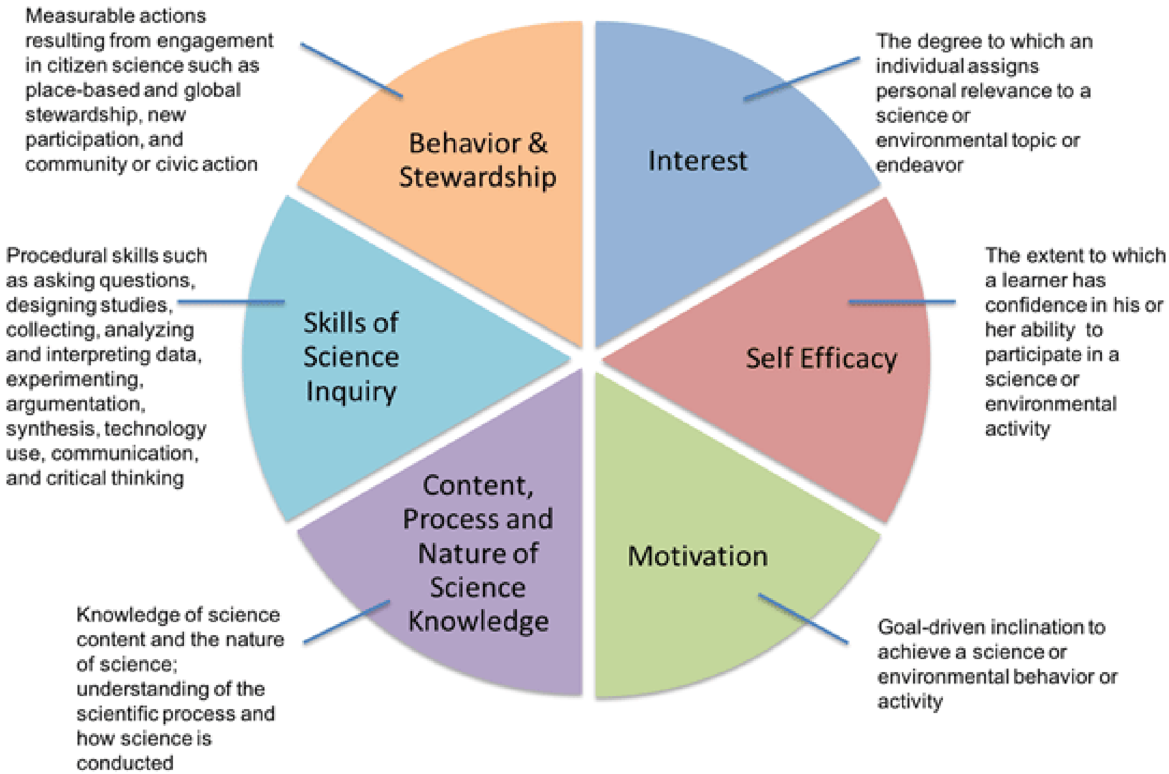

Figure A1. Learning Outcome Framework.
The Framework for Articulating and Measuring Individual Learning Outcomes from Participation in Citizen Science proposed by (Phillips et al., 2018). The categories themselves and the way they are disp;ayed inspired the framework used in this study.

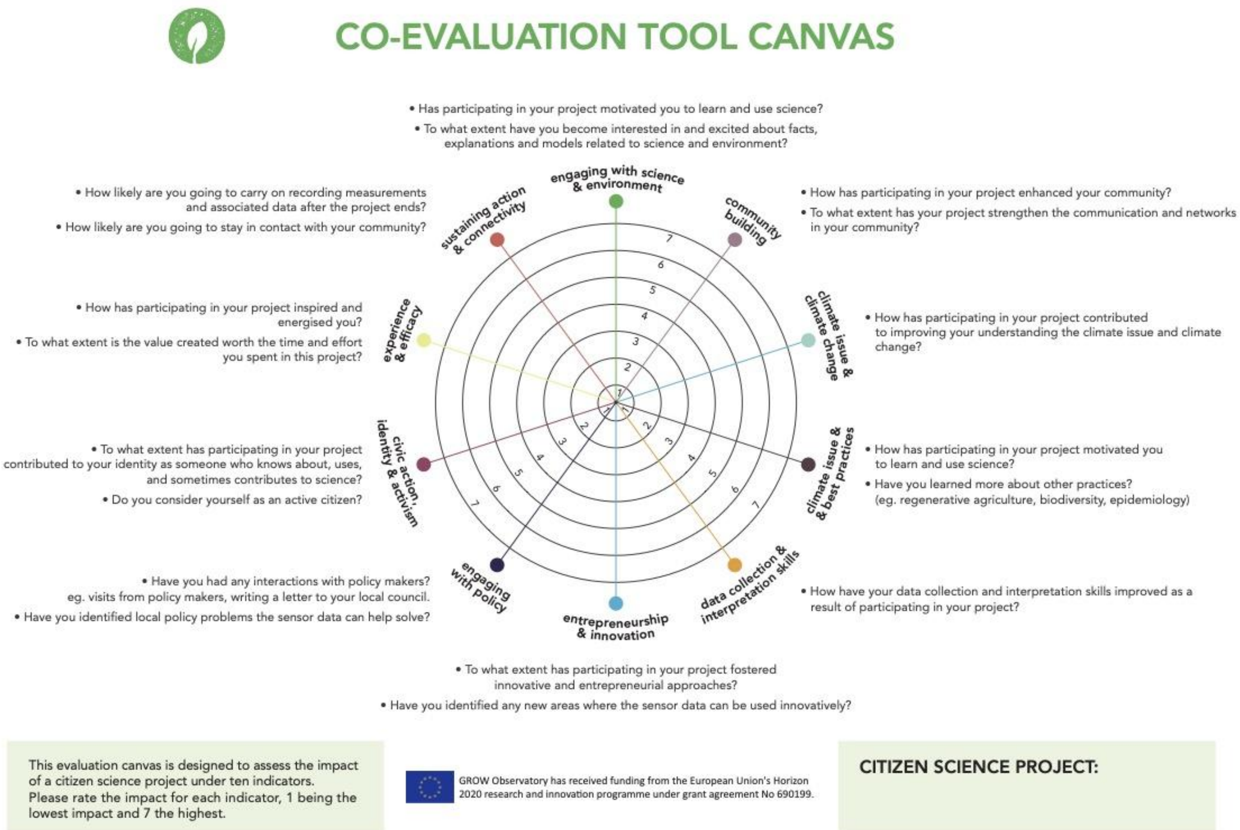

Figure A2. Co-Evaluation Tool.
Condensed structure of the Co-Evaluation tool by Woods et al. (2020) which infomed the structure of data collection.

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