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Master's Thesis
Academic Year 2025

Designing an Immersive Oceanic Sound Experience through Multi-sensory Interaction: Raising Awareness about the Consequences of Human Activities on Ocean Soundscape

Keio University
Graduate School of Media Design

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A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

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Abstract of Master's Thesis of Academic Year 2025

Designing an Immersive Oceanic Sound Experience through Multi-sensory Interaction: Raising Awareness about the Consequences of Human Activities on Ocean Soundscape

Category: Design

Summary

Due to the limitations of human perception, underwater sounds often go unnoticed. This perceptual gap makes it difficult for people to detect or recognize changes in the ocean soundscape, contributing to the growing problem of ecological silencing.

This study focuses on the ocean soundscape and expands the concept of "listening to the ocean" into the design of a multisensory experience that enables participants to feel the ocean's acoustic environment. By examining the impact of human activities on marine soundscapes, we aim to build both perceptual and emotional connections between humans and diverse underwater ecosystems.

We seek to develop multisensory experiences that integrate narrative, sensory cues, and interactive design in order to translate invisible sounds into tangible and intelligible forms. Through this approach, we aim to raise awareness about the consequences of human activity on ocean soundscapes. Ultimately, this research strives to deepen public understanding of marine acoustics, foster a stronger sense of connection with ocean ecosystems, and evoke empathy and curiosity toward the marine world and its inhabitants.

Keywords:

ocean soundscape, ecological silencing, multisensory interaction, experience design, environmental awareness

Keio University Graduate School of Media Design

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Chapter 1
Introduction

1.1. Background

1.1.1 Ocean Soundscape: An Acoustic Ecosystem

The ocean is not a quiet place; rather, it is a rich and dynamic acoustic world. Beneath its surface lies a complex soundscape composed of biological, geological, and climatic elements. The rhythmic crashing of waves, the roar of underwater volcanoes, the creaking of melting ice, and the intricate vocalizations of countless marine organisms, all create a living ocean symphony. This symphony is not merely a collection of sounds; it is an acoustic ecosystem. For marine species, sound is essential for communication, navigation, reproduction, and survival, forming the invisible threads that connect life beneath the waves.

Acoustic ecologists, notably R. Murray Schafer has emphasized the importance of the soundscape and defined it as our sonic environment and the ever-present array of noises with which we all live, in understanding environmental health [1]. Although Schafer's seminal work primarily explored terrestrial environments, the concept of the soundscape is equally vital for comprehending the unique acoustic characteristics and ecological significance of the marine environment. In fact, the sea itself is considered a main sound for maritime civilizations, highlighting its fundamental acoustic role. Within this broader soundscape framework, Bernie Krause further classifies natural sonic elements into biophony (biological sounds), geophony (non-biological natural sounds) and anthrophony (human-made sounds) [2]. Soundscapes contain acoustic cues associated with biological communities and provide information on ecological processes, vocal diversity, community composition, habitat characteristics, and overall condition [3]. When understood in this framework, the ocean soundscape can be seen as an intricate living

composition, one that reflects both the beauty and fragility of marine ecosystems.

1.1.2 Human Activities: Anthropogenic noise

With the development and exploitation of the ocean, human activities have increasingly threatened the health of marine environments, not only through chemical and plastic pollution or overfishing, but also through noise pollution. Anthropogenic noises that date back to the first seafaring people have been increasing exponentially over the past 100 years. include the sound of watercraft; offshore oil/gas exploration and production noise; sonar operation; underwater telemetry and communication for mineral exploration and research; fish bombing and other underwater explosives; offshore construction [4]. These noises alter the natural soundscape of the ocean, becoming a major conservation problem with serious impacts on marine species in all oceans. ranging from immediate auditory damage and physiological stress to significant behavioral changes such as altered migration paths, disrupted foraging, abandoned breeding grounds, and even mass strandings. Crucially, this growing acoustic disturbance can mask natural sounds, making it difficult or impossible for marine animals to communicate, navigate, find mates, or detect predators and prey, represents a relatively invisible but deeply disruptive form of ecological degradation. We must become more aware of the noise pollution that could significantly interfere with biological processes [5]. With anthropogenic noise and other sources of pollution increasing worldwide, these research gaps need to be further addressed, especially because they pertain to vulnerable ecosystems, many of which are affected by global climate change and anthropogenic influences [3].

1.1.3 The Invisibility of Sound: Unnoticed Ocean Change

Despite the severity of these disruptions, oceanic soundscapes often remain outside the scope of public awareness. Of the many sources of biological noise in the ocean, we are probably most familiar with the songs of whales and dolphins, but there are countless other sources of biological noise in the sea [4]. However, changes in ocean sound are largely hidden beneath the waves and imperceptible to the human ear. This is largely due to the fact that humans are poorly adapted for

underwater sound [4].

As Schafer observes, noise pollution results when man does not listen carefully. Noises are the sounds we have learned to ignore [1]. This oversight stems from a fundamental difference in human and marine perception: humans are visually dominant creatures. We tend to "see" environmental change rather than "hear" it, making the sound a less intuitive and less immediate medium for environmental engagement.

This perceptual bias contributes to what some researchers describe as ecological silence, a phenomenon in which the gradual loss or distortion of natural sounds goes unnoticed. Without a conscious effort to listen, many indicators of marine stress remain unheard and unaddressed. This invisibility of sound fosters a collective lack of awareness and empathy for the auditory struggles faced by marine organisms. Ultimately, our failure to "hear" the distress of the ocean hampers public engagement and weakens support for the preservation of the soundscape and broader mitigation efforts.

1.2. Motivation

The sea is the main sound of all maritime civilizations. It is also a fertile sonic archetype [1]. Throughout history, humanity has long been captivated by the ocean, which is mysterious, vast, and constantly changing. The ocean has always symbolized the unknown, inspiring both fear and fascination. Most people consider the ocean a silent place. In fact, it is full of voices. Scientists and artists have long paid attention and listened to ocean sounds, and more and more of these sounds are being recorded and studied.However, for most members of the public, awareness of these ocean sounds remains extremely limited. Beyond the well-known songs of whales, the ocean is filled with countless other interesting and surprising sounds. Today, as advances in technology allow humanity to dive deeper and further than ever before, each new discovery encourages scientists and artists alike to further challenge "the limitations of our terrestrially evolved sense". In doing so, opportunities are open to extend ocean imaginaries beyond current understandings and reconceptualize the ways oceanic space is understood and experienced [6]. I believe that by encouraging more people to listen to these

underwater sounds, we can create new ways to perceive and imagine the ocean.

Human activities have had a great impact on the marine environment. The ocean is now facing new challenges. Although visible forms of degradation such as overfishing, plastic pollution, and sea level rise have received global attention, changes in the oceanic soundscape have been largely ignored. This silent crisis lies hidden beneath the surface, presenting itself not just as a technical issue, but fundamentally as a matter of perception and awareness. New methods of educating the public on the importance of environmental protection must be developed. The home territory of soundscape studies will be the middle ground between science, society, and the arts. My motivation comes from the belief that design, especially multisensory and experiential design, can play a crucial role in interdisciplinary collaboration. It can help build new conversations between humans and the ocean. It also offers a way to bridge this perceptual gap.

1.3. Research Question

This study is driven by the central question: How can multisensory interaction design translate ocean sounds into perceivable and emotionally resonant experiences that enhance public awareness of human impacts on the ocean soundscape?

This question guides a design-led inquiry that positions ocean sound not only as an ecological indicator, but also as a communicative medium capable of fostering environmental understanding and empathy.

1.4. Research Objective

Public awareness of ocean soundscapes remains limited, and the ecological consequences of anthropogenic noise are often overlooked. Due to human limited capacity to perceive underwater sound, we rarely listen to the ocean intentionally and often do not recognize the importance of doing so. This perceptual gap contributes to a broader disconnect between human society and the ecological realities of marine environments.

This research focuses on the ecological impact of human activity on ocean soundscapes. Beginning with the concept of “listening to the ocean soundscape”, it

explores how multisensory interaction design can serve as a perceptual bridge between human experience and underwater acoustic environments. Specifically, the study aims to achieve the following three objectives:

- To investigate how different combinations of sensory modalities influence perception and emotional response to ocean sounds.
- To design and develop a multisensory and interactive prototype that transforms ocean soundscapes into immersive, perceivable, and emotionally engaging experiences.
- To assess the effectiveness of multisensory experiences in improving public understanding of underwater acoustic environments and raising awareness of the ecological consequences of human activity.

Chapter 2
Literature Review

2.1. Soundscape, Environmental Perception, and Ecological Awareness

2.1.1 Ecological Awareness in the Anthropocene

Ecological awareness is broadly defined as the capacity to recognize the interconnectedness between human actions and ecological systems, encompassing both cognitive understanding and affective responsiveness to environmental change [7]. Beyond factual knowledge, it involves an ethical consciousness and emotional sensitivity toward the well-being of non-human life [8]. This form of awareness is particularly crucial in the context of the Anthropocene, where the impacts of human activity often unfold on abstract or imperceptible scales. As Plumwood contends, the promotion of ecological awareness requires more than the rational transmission of information; it must also involve the senses, emotions, and imagination of individuals [9].

2.1.2 Soundscape as Medium for Environmental Communication

The concept of soundscape, first introduced by Murray Schafer, refers to the total acoustic environment as it is perceived by humans [10]. It includes three core components: biophony (sounds produced by living organisms), geophony (natural non-biological sounds), and anthrophony (human-generated sounds) [11]. Together, these elements reflect the ecological conditions of a place and serve as a form of environmental information. In recent years, scholars have recognized the potential of soundscapes as effective tools for environmental communication. As

Dumyahn and Pijanowski noted, acoustic environments can serve as indicators of environmental change, often capturing disturbances that may not be visible [11]. Soundscape-based approaches are increasingly used to engage the public in environmental issues by offering immersive and emotionally resonant experiences. These practices cultivate sonic awareness and help translate abstract ecological dynamics into perceptible, embodied forms of engagement [12].

Listening to the soundscape is increasingly seen as a way to cultivate ecological awareness, a form of understanding that goes beyond cognitive knowledge to include emotional, sensory, and ethical dimensions [9]. This makes it a powerful tool for engaging the human sensorium and fostering attunement to the presence and change of the environment. Listening to environmental soundscapes can also foster a more relational understanding of nature. As Ross argued, acoustic media can mediate between ecological knowledge and sensory experience, enabling listeners to perceive environmental change in ways that are embodied and emotionally meaningful [13]. This makes soundscapes particularly valuable in environmental education, participatory research, and eco-acoustic art, where communication aims not only to inform, but also to affect. Thus, soundscapes function both as diagnostic tools for detecting ecological shifts and as communicative mediums that translate environmental complexity into perceptible and affective experience.

2.1.3 Environmental Perception and the Role of the Senses

Environmental perception is not merely a visual or cognitive activity. It is a multisensory and embodied process shaped by direct interaction with the surrounding world. Scholars in ecological philosophy and sensory studies emphasize that human engagement with nature is mediated through multiple sensory modalities. These include hearing, touch, smell, vision, and bodily movement [14]. Sensory input influences how individuals detect ecological change, form emotional responses, and develop connections with specific places.

Each sense contributes uniquely to environmental understanding. Hearing facilitates awareness of natural rhythms and disturbances that may not be visually evident. Touch conveys information about temperature, materiality, and texture, grounding perception in physical experience, and strengthening sensitivity to environmental variation [8]. Smell is closely related to memory and emotion; it

allows individuals to associate specific scents with seasonal cycles, place identity, or ecological transitions [15].

When multiple senses are activated in combination, they offer a more comprehensive and emotionally resonant experience of the environment. Research in virtual nature contexts shows that the integration of auditory, visual, tactile and olfactory stimuli significantly improves emotional engagement and physiological recovery compared to audio-visual input alone [16]. Similarly, in urban environments, multisensory elements, such as sounds, smells, and tactile qualities, significantly influence how people perceive space and engage in public activities. These sensory inputs shape both the spatial experience and the behavioral responses [17].

This growing body of research suggests that the senses do more than receive information. They actively shape how people attend to the environment, interpret ecological signals, and relate to non-human life. Through sensory engagement, individuals become more aware of subtle environmental cues, experience interdependence, and respond with greater care. Multisensory perception, therefore, plays a central role in the formation of ecological consciousness and in the support of a more relational and ethical connection to the natural world.

2.1.4 Narrative, Imagination, and Ecological Consciousness

Narrative plays a pivotal role in cultivating ecological awareness by enabling emotional and ethical engagement with complex environmental challenges. As Dahlstrom emphasizes, storytelling offers a compelling means of conveying scientific knowledge in ways that are not only more accessible but also more emotionally resonant and persuasive [18].

Perspective-taking is an important narrative strategy. It invites individuals to view the world from the viewpoint of non-human beings, helping to build empathy and concern for environmental issues that are often distant or difficult to perceive [19]. Speculative narratives as explored in Haraway's concept of speculative fabulation envision multispecies kinship and forms of world-making that challenge anthropocentric norms. These stories invite audiences to imagine alternative ecological futures, cultivate multispecies responsibility, and support long-term ethical reflection rooted in material and embodied co-existence [20]. Participatory storytelling also contributes to deeper engagement. When people are involved in

creating narratives that include non-human perspectives and ecological processes, they often develop a stronger sense of responsibility. Talgorn and Ullerup describe this as "planet-centered empathy", which shifts the ethical focus from individual choices to collective and more-than-human futures [21].

Narrative does not simply inform; it shapes how people feel, imagine, and act in relation to ecological systems. By embedding scientific and ecological content within emotionally meaningful and morally resonant frames, narrative fosters deeper engagement with environmental issues and supports the development of ecological consciousness that is situated, empathetic, and future-oriented.

2.2. Multisensory Experience Design

The multisensory experience is defined precisely as the incorporation of two or more sensory modalities in a coordinated way, aiming to enrich the sensory experience, thus improving aspects of the user's emotion and overall experience [22]. This approach recognizes that each sense has strengths and weaknesses: for example, sound alone can convey temporal patterns and distant events, but adding visual elements can give spatial context or form; adding touch can give a sense of physical presence, and scent can trigger memory or mood. By blending modalities, we can communicate information more efficiently and holistically and also provoke stronger emotional responses.

2.2.1 Making the Inaudible Perceivable

A key reason for multisensory interaction is that many critical aspects of the ocean soundscape are literally invisible or inaudible to humans under normal circumstances. Multisensory design allows us to translate those imperceptible aspects into forms that we can perceive. In multisensory ocean design, we often substitute visuals for sound or vice versa. This principle is often called sensory substitution or augmentation, using one sense to represent data originally meant for another. Multisensory techniques are crucial for making the invisible visible and the inaudible audible. They allow designers to reuse scientific data, whether sonar readings, seismic acoustics, or water quality, into sensory stimuli that humans can directly experience, thus demystifying the hidden processes of the ocean.

2.2.2 Enhancing Presence and Immersion

In addition, the involvement of multiple senses tends to significantly enhance the feeling of presence and immersion, which is vital to creating a convincing ocean experience. Presence is the subjective sensation of "being there" in a simulated or remote environment, and has been found to increase when more senses are congruently stimulated [23]. In virtual reality research, Gao and Spence emphasize that adding tactile feedback to the usual audiovisual setup can greatly strengthen the sense of presence [24]. When someone feels "present" in an underwater soundscape, they are more likely to emotionally connect with that environment and understand the stakes. As Gallace and Spence (2014) observed, touch and other senses can anchor a person's experience, making it less like watching a distant issue and more like living it. In designing ocean sound experiences, achieving a high degree of presence means the difference between an engaging journey versus a forgettable demo.

2.2.3 Evoking Emotion and Memory

Another benefit of multisensory interaction is its ability to evoke emotion and memory through cross-modal associations. Each sense can trigger emotional responses, but together they can amplify each other. Scent cues are a great example: smell is strongly related to emotion and memory in the human brain. A whiff of a particular scent can instantly bring back a feeling or memory. Designers have begun to incorporate scent into ocean-related experiences to leverage this. Gardoni et al. report on a multisensory augmented reality exhibit in which a custom ocean scent was spread to complement the visuals and sounds of a coral reef scene [25]. Emotional arousal and the formation of long-term memories are closely tied; experiences that engage multiple senses are more likely to be stored in memory with multiple retrieval cues (sound, sight, smell recall, all reinforcing the memory). For an awareness campaign, this is gold: you want the public to remember the message and the feeling associated with it. By designing multisensory experiences, we effectively "write" the importance of ocean soundscapes in people's minds in several ways at the same time.

2.3. Multisensory Design Practices in Ocean Sound Experience

2.3.1 Sensory Modalities: Audio-Visual Translations

At the core of ocean sound experience design is the pairing of auditory and visual stimuli to translate acoustic phenomena into human-perceivable form. Sound itself is obviously a key medium, many projects leverage actual underwater recordings played through speakers or headphones to allow audiences to hear the ocean [26]. However, hearing alone may not fully convey patterns or scale, so designers often integrate visualizations to complement the audio. A notable example is a science-art collaboration by Ren et al., which converts seismic and hydroacoustic data into immersive digital artworks, revealing the hidden realm of the ocean soundscape. The team sonified ocean data and simultaneously visualized them as dynamic images, providing the general public with a multisensory way to experience scientific observations [27]. Presented in exhibitions, these audiovisual pieces allowed audiences to see and hear phenomena normally inaccessible. This project highlights the potential for creative representations of scientific information to engage lay people. By making data perceptible and aesthetically intriguing, audio-visual design bridges the gap between specialized research and intuitive public understanding. In essence, visualization amplifies the impact of underwater acoustics by engaging our dominant sense (sight) in concert with hearing, thus overcoming the abstractness of sound alone.

2.3.2 Sensory Modalities: Haptic Listening

Touch is a powerful but underutilized sense in environmental communication. In ocean sound design, haptic feedback can add a visceral dimension to acoustic experiences. Translating ocean sounds into vibrations that humans can feel helps convey the physical presence of underwater sounds. For example, the “Sounds of the Ocean” travel experience partners with a company that provides an “Embodied Sound” system that combines auditory and physical sensations in real time. Audience members might wear special vests or sit in equipped seats that pulse in tandem with ocean audio, whether it’s the rumble of distant thunder over the sea

or the sonar ping of a dolphin [28]. This multisensory approach is meant to deepen immersion and even promote wellness, letting people literally feel the sound of nature. The tactile element not only grabs attention, but also communicates aspects of ocean noise (intensity or vibration) that pure audio cannot.

2.3.3 Sensory Modalities: Olfactory Immersion

Although sound and sight dominate most experience designs, some projects have expanded into the chemical senses to enrich realism and memory. Scent in particular is known for its strong ties to emotion and memory [29]. A prime example is the installation "Scented Shores" at the La Cité de l'Océan museum in France, which offers a playful and interactive olfactory experience of marine aromas. In this installation, visitors gather around an organically shaped "scent table" whose topography evokes ocean waves. Embedded in the table are ten stations, each with a dispenser that releases a specific ocean-related scent at the push of a button. By actively engaging their sense of smell, museum visitors immerse themselves in the sensory richness of the sea, exploring facets of the ocean environment that sound alone might overlook [30]. This kind of multisensory layering can reinforce the educational message, create a holistic impression of the ocean that is far more vivid than any one sense alone. Olfactory elements are also being used in virtual reality simulations of nature, where scent generators release odors keyed to virtual ocean scenes to heighten immersion. Although the use of scent in ocean soundscape design is still relatively novel, earl implementations demonstrate its promise. They bring visitors closer to the smell of the sea and foster understanding through a sensory pathway that is often overlooked.

2.3.4 Interactivity and Participation

A crucial modality that spans across senses is interactivity, engaging the public as active participants rather than passive receivers. Interactive design in this context means that users can manipulate, play, or cocreate aspects of the experience, leading to a sense of agency and deeper engagement. In Demeulenaere's "Zijlijn" installation, for example, the simple act of moving one's body along a row of speakers changes the balance of natural vs. human-made sounds one hears.

This effectively turns visitors into a mixer, allowing them to discover the hidden soundscape by experimentation. Such interactivity personalizes the experience, each person may find their own mix of biophony and anthrophony, in doing so viscerally realizes how much noise dominates certain waters [31]. Interactive sound art can thus spark curiosity and self-driven discovery of the issue.

2.3.5 Conclusion

The ocean is a multisensory world, although we often think of it in visual terms, in reality it is equally a world of sounds, textures, and even tastes and smells. To raise awareness about environmental issues like noise pollution that are not immediately visible, we must design experiences that are correspondingly multisensory, engaging people on all these fronts. As the field of multisensory experience design suggests, doing so can evoke emotional resonance and capture attention in ways traditional outreach cannot. Whether through VR simulations with haptic feedback or physical exhibits with audio-visual-olfactory components, making ocean advocacy multisensory greatly enhances its impact. It ensures that messages about the changing soundscape of the ocean are not just understood intellectually, but also felt viscerally, a crucial step in motivating genuine awareness and concern.

2.4. Research Gap

Although soundscape research has expanded considerably in recent decades, it has primarily focused on terrestrial environments such as forests, wetlands, and urban parks. In comparison, underwater soundscapes remain relatively underexplored, despite their ecological significance and distinct sensory characteristics. Existing studies on ocean acoustics have largely adopted scientific or technical approaches, emphasizing measurement, monitoring, and data analysis.

From a design perspective, multisensory engagement with ocean soundscapes is still in an early phase. Most existing approaches focus primarily on auditory and visual modalities. Although these channels are effective for representing marine environments, they offer limited opportunities for embodied experience or emotional resonance. Tactile and olfactory senses, which have the potential

to strengthen empathy and deepen immersion, are rarely integrated. As a result, the full range of sensory interaction with underwater environments remains largely unexplored.

Figure 2.1 Key Areas in Ocean Sound Experience Design

Chapter 3
Concept Design

3.1. Core Concept

3.1.1 Concept Statement

This research proposes the design of a multisensory and interactive ocean sound experience that enhances human–ocean connection through perceptual engagement and emotional resonance.

The ocean soundscape plays an essential role in marine ecosystems. However, human understanding of these underwater sounds remains limited. This is mainly due to the constraints of human auditory perception and the communicative differences between species. Many acoustic signals in marine environments fall outside our hearing range or are difficult to interpret. At the same time, human activities have significantly altered the ocean soundscape. In particular, the rise of anthropogenic noise has introduced new and persistent disturbances into marine environments. However, the perceptual gap between humans and the underwater acoustic environment has contributed to a widespread lack of awareness regarding these changes. As a result, the transformation of the ocean soundscape often does not attract public attention or concern. Ocean sounds and the ecological information they contain are frequently overlooked in environmental discourse.

In response, the core concept of this research is to transform ocean sounds that are difficult to understand into environmental information that is easier to perceive and emotionally engaging. The project combines narrative frameworks with sensory cues, including visual, tactile, and olfactory stimuli, to create an immersive experience. Explore how sensory modalities beyond hearing can be integrated to expand the concept of "listening to the ocean" into a broader experience of "feeling the ocean sound." This multisensory and interactive design aims to help

the public better understand ocean sounds and form emotional connections with them. It also encourages recognition of their ecological significance, highlighting the essential role acoustic environments play in marine ecosystems. At the same time, it draws attention to the threats posed by human activities, particularly anthropogenic noise, which increasingly disrupts marine habitats and species. In doing so, the project seeks to foster greater public awareness of the changing ocean soundscape and to promote sustained attention and long-term listening.

3.1.2 Design Goal

The goal of this design is to foster emotional engagement with ocean listening through multisensory experiences, raise awareness of the impact of human activities on underwater acoustic environments, and promote a deeper understanding of the ecological diversity and fragility of marine soundscapes.

3.1.3 Design Principles

To guide the design process, three key principles were established:

- Sensory Translation: This principle focuses on transforming abstract ocean sounds into multisensory cues that are easier for users to perceive, interpret, and emotionally engage with. Translating auditory information into complementary sensory stimuli (such as visual patterns, haptic feedback, and olfactory elements), the design facilitates a more accessible understanding of the acoustic characteristics of marine environments. This process seeks to bridge the sensory and cognitive gap between humans and the underwater world, thus enhancing awareness of the ecological relationships embedded in underwater soundscapes.

- Narrative Embodiment: This principle concentrates on embedding ocean sounds within a narrative structure providing a meaningful context for user engagement. Through temporal sequencing, symbolic framing, and thematic storytelling, narrative elements help structure the sensory experience and guide users' attention toward specific environmental themes or emotional

dimensions. This approach enables users to construct personal interpretations of oceanic phenomena, fosters a deeper emotional resonance with marine life, and encourages empathy by inviting participants to imagine the world from the perspective of non-human animals.

- Participatory Empathy: This principle emphasizes the role of interaction and agency in cultivating emotional engagement and reflective awareness. By integrating interactive components (such as tactile interfaces, responsive feedback, or user-generated inputs), the design invites users to become active participants rather than passive observers. Such participation can foster a sense of co-presence with the ocean environment and promote empathetic engagement. It also supports a more sustained form of environmental attention by encouraging users to reflect on their own role in shaping, disturbing, or protecting marine soundscapes.

3.1.4 Design Hypotheses

- The integration of auditory and visual modalities improves the recognition and differentiation of various types of ocean sounds.
- The integration of auditory and olfactory modalities enhances emotional immersion and increases the memorability of the sensory experience.
- The narrative structure (audio narration) fosters empathy and strengthens environmental responsibility.
- Interactive exploration encourages deeper engagement and supports self-directed learning compared to passive observation.

3.1.5 Target User

The target group consists of students, particularly teenagers aged 10–18 years and young adults aged 19–30. This age range was chosen for several reasons:

- Formative stage of awareness: They are in a critical period of developing environmental values and are more open to new perspectives.

- Receptive to interactive learning: This age group responds well to hands-on multisensory experiences that align with the design methods used.
- Potential for long-term impact: Engaging them early can cultivate a sense of ecological responsibility that may influence future behavior, studies, and careers.

3.2. Survey and Data Collection

3.2.1 Initial Research

A custom-designed questionnaire was developed to better understand the public understanding level of ocean sounds. A total of 30 valid responses were collected.

Figure 3.1 Open-Ended Response Word Frequency Analysis: Reflecting Public Understanding of Ocean Soundscapes

The results indicated that most of the participants were limited familiar with the concept of an oceanic soundscape. Few respondents were aware of the diversity of underwater sounds beyond the well-known vocalizations of whales and dolphins.

In addition, many did not recognize the ecological impact of human-generated noise, highlighting a considerable gap in public awareness of anthropogenic influences on marine acoustic environments.

3.2.2 Audio Resources

In order to collect appropriate sound materials for the ocean sound experience, I explored a wide range of sound libraries and online databases. After careful evaluation of sound quality, licensing terms, and ecological relevance, I selected a total of 47 audio samples for production.

3.3. Multi-module Prototype Design

This study presents a multisensory interaction design centered on the theme of listening to the ocean soundscape. Its aim is to improve public understanding of underwater acoustic environments, raise awareness of the ecological impacts of human activities, and foster emotional resonance and ecological reflection. Ocean soundscapes are not merely aggregates of sounds; they are contextually embedded acoustic phenomena, shaped by spatial, temporal, and ecological dynamics. However, because of their inherent complexity and abstract nature, they often remain inaccessible or difficult to grasp through conventional auditory means.

To address this challenge, the prototype design adopts a multi-module structure. The overall experience is conceived as a sequence of interconnected and progressively layered modules, each addressing a specific but interrelated aspect of marine acoustic ecology. These aspects include the diversity of marine sounds, the temporal evolution of ocean soundscapes, and the ecological consequences of anthropogenic noise. Based on the methodology of multisensory interaction design, each module positions sound as a central medium for ecological understanding, while integrating visual, tactile, and olfactory modalities to facilitate cross-sensory engagement. This approach aims to construct cognitive bridges between sensory channels, making abstract acoustic information more concrete, perceptible, and emotionally impactful. Rather than functioning as isolated experiences, the modules are designed to operate in concert, both thematically and experientially, forming a multi-perspective and evolving narrative** of the ocean

soundscape. This modular design not only provides diverse entry points for users with different backgrounds and interests, but also deepens ecological awareness by gradually revealing the complex interrelationships among sound, marine life, and human influence.

3.3.1 Modular Structure

To address the complexity of communicating underwater acoustic environments, this project adopts a four-module design framework, each targeting a specific aspect of ocean soundscape perception and ecological understanding. Rather than functioning as isolated units, the modules are designed to be thematically progressive and complementary, allowing participants to gradually deepen their awareness across perceptual, cognitive, emotional, and ethical dimensions.

- Module 1 focuses on basic perceptual and cognitive recognition of different marine sounds (biological and human-made). Through auditory–visual mapping of marine models and sound sources, this module addresses the issue of low public familiarity with underwater acoustics by enhancing basic sound source identification and awareness of marine sound diversity.

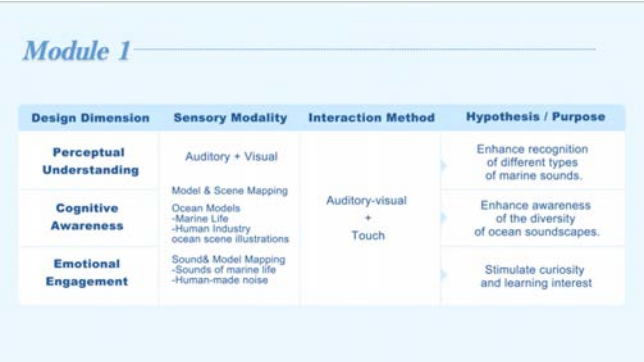

Figure 3.2 Design Logic of Module 1

- Module 2 introduces a temporal narrative structure that contrasts past, present, and future ocean soundscapes. Using audio–visual storytelling through NFC posters, it explores how human activities continuously re-

shape acoustic environments and promotes ecological reflection by illustrating potential sonic futures. Addresses the issue of public detachment from long-term oceanic change.

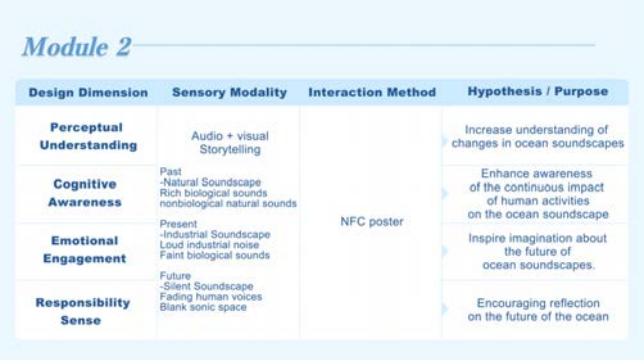

Figure 3.3 Design Logic of Module 2

- Module 3 emphasizes the sensory-emotional relationship between humans and coral reef ecosystems, using multimodal interaction (sensor-to-vision and sensor-to-audio) to illustrate coral health through visual brightness, color, and acoustic vitality. This module focuses on the need to foster emotional connection and behavioral awareness of human impacts on coral reefs.

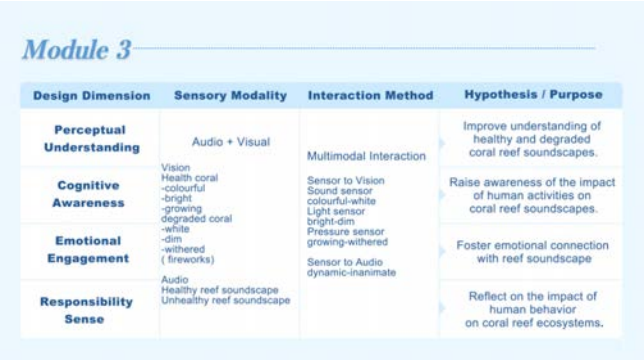

Figure 3.4 Design Logic of Module 3

- Module 4 further extends this engagement by incorporating olfactory interaction, mapping coral reef health onto pleasant or unpleasant smells along-

side audio-visual cues. It focuses on the sensory richness of reef environments and draws attention to issues of noise pollution and coral bleaching, aiming to support moral reflection and a sense of responsibility.

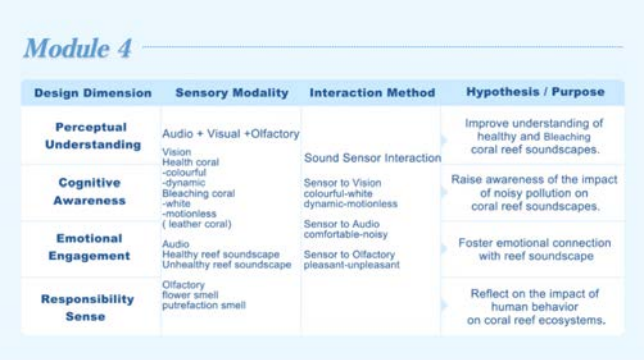

Figure 3.5 Design Logic of Module 4

3.4. Prototype Design: Module 1

3.4.1 Listening to the Diversity of Marine Sounds

The ocean soundscape is generally categorized into three main components: biological sounds produced by marine organisms, environmental sounds resulting from natural physical processes, and anthropogenic sounds generated by human activities. Despite the richness of the marine acoustic environment, public understanding of ocean sound tends to focus narrowly on familiar and iconic sources. Another significant challenge is the increasing prevalence of anthropogenic noise, which has raised considerable ecological concerns. However, public awareness of underwater noise pollution remains limited.

This gap between the richness of the underwater acoustic environment and the limited public awareness highlights the need for new approaches to ocean sound perception and education. One potential entry point lies in the act of listening itself, which offers a novel perspective for perceiving and exploring the marine environment. Recognizing the diversity of marine sounds can serve as an important step toward understanding the complexity of underwater acoustic ecosystems.

However, while listening has great potential, relying solely on traditional audio playback makes it difficult for most audiences to recognize and differentiate various types of ocean sound, especially when contextual or multisensory cues are absent.

The idea was to create a playful and interactive environment in which sound is mapped to physical scenes, allowing participants to discover diverse ocean sounds through touch. In addition to exploring existing sounds, users can also compose their own combinations of ocean soundscapes by selecting and triggering different types of sound. By integrating auditory and visual modalities, the experience expands perception beyond hearing alone and transforms it into a multisensory engagement. This approach improves the recognizability of ocean sounds and makes abstract acoustic information more concrete and meaningful.

3.4.2 Design Goal

The experience is designed to shift participants from passive listeners to active explorationists. They are encouraged to notice the acoustic presence of different marine species and environments and to recognize the diversity of the underwater acoustic world.

3.4.3 Multisensory Interaction Design

This experience combines auditory, visual, and touch interaction. By integrating Makey Makey with Scratch, participants can trigger marine animal or human-made sounds simply by touching models.

- Audio and Visual Interaction Design: Used marine toys and created illustrated ocean scenes, associate specific ocean sounds with corresponding visual elements, to build a realistic sound–visual mapping environment.
- Physical Interaction Design: The toys were integrated with Makey Makey and programmed using Scratch to trigger specific ocean sounds through physical touch, enabling an interactive sound experience.
- Touch-to-Sound System: Each sound-producing model is embedded with conductive copper foil and connected to a specific input on the Makey Makey

board, serving both as a visual cue and as an intuitive interactive interface. At the beginning of the experience, participants wear a conductive wristband and hold two metal rods, forming a closed circuit that is required for interaction. Interaction occurs when participants touch the copper foil areas on the toy models placed within the illustrated ocean scene. Each touch sends a signal through the circuit and triggers the corresponding ocean sound via a Scratch program. This Touch-to-Sound system encourages multi-touch exploration. Participants can touch multiple models simultaneously to compose layered or composite ocean soundscapes.

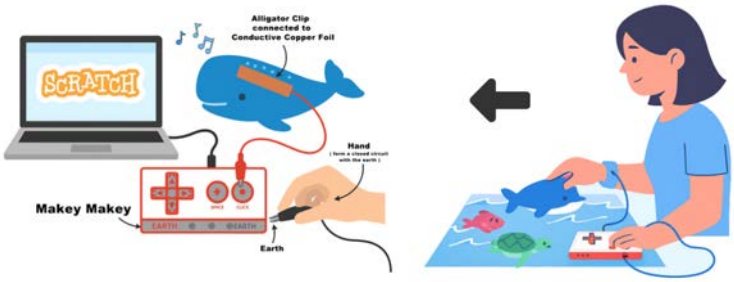

Figure 3.6 Touch-to-Sound System Using Makey Makey and Scratch

3.4.4 Design Process

Sound Design

The audio sources used in this experience consist of eleven publicly accessible recordings. These audio clips include a variety of biological marine sounds as well as anthropogenic noises related to human activity in the ocean. All audio files were edited and composed using Scratch, a block-based creative platform. The editing process involved trimming, adjusting volume levels, and applying fade-in and fade-out effects to create a smooth and immersive auditory experience. This sound design aims to help participants recognize and distinguish between natural and human-made ocean sounds. In addition, it seeks to spark curiosity and foster a deeper interest in the rich and diverse voices of the ocean, thus promoting acoustic awareness and ecological empathy.

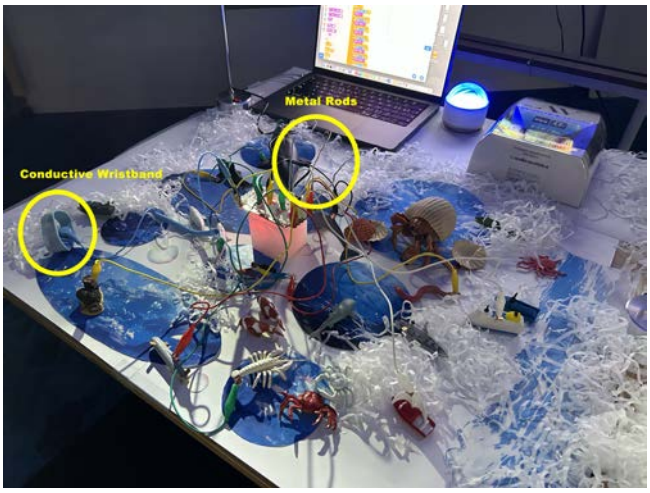

Figure 3.7 Module 1: Listening to the Diversity of Marine Sounds

3.4.5 Results

Although this experience successfully introduced an interactive format that integrates auditory and visual modalities, such as the association of ocean sounds with physical models and illustrated marine scenes, to support the recognition of sound diversity, it also revealed several limitations with respect to the study's broader objectives. By allowing participants to listen to and combine different types of marine sounds, facilitated the perceptual differentiation of biological, environmental, and anthropogenic sources. This multimodal approach, rooted in sensory mapping and object-based interaction, aligns with prior findings that pairing visual and auditory information can enhance categorization and recall in sound-based learning environments.

However, this form of localized sound recognition tends to privilege momentary perception over temporal understanding. As Truax notes in his work on acoustic ecology, meaningful awareness of soundscapes involves not only identifying sounds but also understanding their ecological context and change over time. Module 1 lacked a narrative or temporal dimension, making it difficult for participants to grasp the cumulative and often invisible impact of human activity on marine acoustic environments. Emotional involvement was also inconsistent. Previous research suggests that emotional responses to sound are highly dependent on

contextual framing and listener interpretation. Without a temporal or ethical framework, the sounds themselves, natural or anthropogenic, did not consistently evoke reflection or concern.

3.5. Prototype Design: Module 2

3.5.1 Listening to Transitions in the Ocean Soundscape

In Module 1, the integration of sound and visual elements was introduced as a means of supporting participants in the recognition and differentiation of ocean sound types. By listening and combining various marine sounds, participants were encouraged to explore the richness of the underwater acoustic world. However, this approach provided limited information on the broader transformation of ocean soundscapes over time. It remains difficult for users to understand the long-term impact of human activities on marine acoustic environments. This limitation highlighted the need for Module 2 that would incorporate story-driven interaction and temporal layering to better align with the research objective of fostering long-term environmental awareness and empathy.

Ocean soundscapes have changed significantly from the pre-industrial period to the present. In the past, marine acoustic environments were shaped mainly by natural elements. These included biological sounds from marine organisms, as well as geophysical sounds such as waves, wind, and rain. In recent decades, the increase in anthropogenic noise has disrupted these natural patterns. In some regions, this has resulted in persistently high background noise levels. In others, reduced biological activity caused by overfishing and habitat degradation has led to quieter, less vibrant soundscapes. As a result, ocean environments have become excessively noisy or unusually silent. Both conditions pose serious risks to marine ecosystems.

The idea was to create an interactive experience driven by the story, embedding past, present, and imagined future ocean soundscapes into a speculative environmental narrative. The story unfolds along a fictional timeline that moves from acoustic historical richness to a future shaped by ongoing ecological degradation or potential recovery. Within this imagined scenario, participants are invited to

listen and reflect on the transformation of ocean soundscapes over time. Through audio-visual storytelling, the experience seeks to immerse users in this speculative journey. By engaging your senses and emotions, it encourages critical reflection on the consequences of human actions and the urgency of preserving the acoustic heritage of the ocean. This approach transforms passive listening into an active process of environmental awareness and ethical imagination.

3.5.2 Design Goal

The experience was designed to shift participants from passive observation to active and reflective engagement. It aims to improve understanding of the changes in the ocean soundscape and, most importantly, inspire imagination and responsibility for the future of the ocean.

3.5.3 Multisensory Interaction Design

- Audio Storytelling Design: A dystopian narrative guides participants through three temporal phases of the ocean soundscape: natural, industrial, and future-silent. The natural phase includes biological and environmental sounds. The industrial phase introduces anthropogenic noise. The future-silent phase gradually reduces the acoustic activity to near silence.
- Audio and Visual Interaction Design: Conceptual posters were designed to visually communicate the temporal transitions of ocean soundscapes, highlighting changes from natural to human-altered acoustic environments.
- Physical Interaction Design: To enable embodied participation, NFC-enabled posters were integrated into the experience. Participants could scan designated areas on the posters using a mobile device to trigger corresponding ocean soundscapes.
- Journey Map: At the beginning of the experience, each participant receives an envelope from someone living in the future ocean. Inside the envelope is an unfinished letter, along with a sticker of a randomly assigned sound-producing marine animal or coral species. The participants then encounter three NFC-enabled posters representing the past, present, and future of the

ocean soundscape. By scanning NFC tags with smartphones, they can access related audio content and listen through the seashell player, immersing themselves in the shifting soundscape. After listening, participants are invited to read the complete version of the letter.

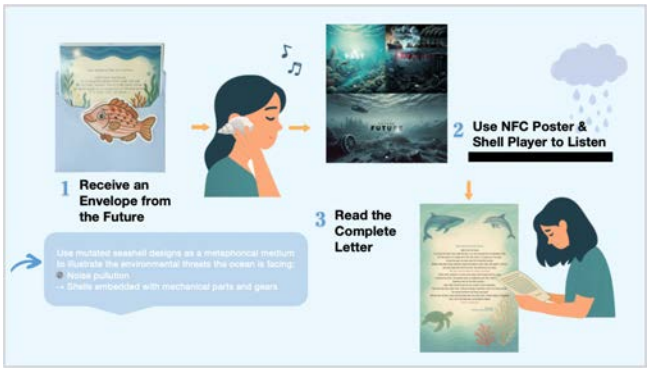

Figure 3.8 Scan-to-Sound System Using NFC Poster and Shell Player

3.5.4 Design Process

Storyline

- Past - Natural Marine Soundscape

  Plot: The journey begins by returning to the natural marine environment of the past, an era largely free from human noise pollution. During this time, the ocean soundscape was made up almost entirely of natural elements.

  Sound Content: Rich biological sounds and nonbiological natural sounds.

- Present - Impact of Industrialization on the Ocean Soundscape

  Plot: The narrative shifts to the present day, revealing the dramatic transformation of the ocean soundscape with the rise of industrial activity. Pervasive mechanical noise now interferes with the natural acoustic environment.

  Sound Content: Loud industrial noise and increasingly faint biological sounds.

- Future - The Silence of the Deep Sea

  Plot: The final chapter imagines a dystopian future in which humans have migrated to live on the ocean floor. As marine species vanish, the human voice disappears as well, transforming the ocean into a silent world.

  Sound Content: Gradually fading human voices, followed by blank sonic space.

Sound Design

Audio Example 1: Mixed Soundscape

These audio clips used in this experience include environmental sounds, biological marine sounds, and anthropogenic noises relevant to different stages of the narrative. All audio files were edited and combined using CapCut. The editing process involved trimming, layering, adjusting volume levels, and applying fade-in and fade-out effects. Where necessary, sound clips were juxtaposed or overlapped to create contrast and emphasize the transformation of the oceanic soundscape over time. Although raw materials were not recorded first-hand, the selection, composition, and sequencing of sounds was curated to support the intended emotional and thematic arc of the experience. The final soundscape is an original narrative arrangement designed to reflect the shifting relationship between humans and the ocean.

Seashell Player Design

The device is modeled after mutated seashells, symbolizing the environmental crises that are currently affecting the ocean. Each seashell player was 3D printed on the basis of a conch shell form and fabricated using different materials to reflect specific types of marine degradation. For example:

- Plastic material represents plastic pollution
- Discarded fishing nets represent overfishing
- Industrial components represent noise pollution

This tactile and symbolic object allows for a more immersive and intimate listening experience. It also functions as a physical metaphor for how human activities have reshaped the marine environment, both in ecological and acoustic terms. It encourages users to reflect on what has been lost, what still remains, and what kind of future might yet be imagined.

3.5.5 Results

The experience successfully integrated auditory, visual, and narrative interaction to create an immersive and reflective experience. Participants were guided through three stages of the ocean soundscape: natural, industrial, and future silent. This progression allowed them to perceive changes in the acoustic environment across different time periods. The use of temporal framing, together with audio storytelling and visual representation, helped participants better understand how human activities have gradually shaped and disrupted marine soundscapes. In addition, the narrative structure improved emotional engagement. Previous studies have shown that narrative-based experiences can effectively promote environmental concern and foster empathy.

Despite these strengths, Module 2 revealed certain limitations. The interaction remained largely passive, relying on linear audio playback and static visual media. This limited the participants' ability to actively influence or respond to the experience. Previous research in environmental education and interaction design suggests that embodied and participatory engagement is critical to deepening environmental understanding and agency. In addition, the integration of auditory and visual channels lacked real-time feedback, which may have weakened the sense of immediacy and immersion. These shortcomings highlight the need for more dynamic and participatory forms of multisensory interaction to fully support awareness and reflection on the long-term acoustic impact of human activity on marine ecosystems.

3.6. Prototype Design: Module 3

3.6.1 Listening to the Human Impact on Reef Soundscapes

Module 2 introduced a multisensory approach that combined sound, visual elements, and narrative structure to support understanding of changes in the ocean soundscape. Participants were encouraged to reflect on the temporal dimension of underwater acoustic environments. The narrative framework improved emotional participation and added conceptual depth to the experience. However, the interaction remained largely passive and linear. Participants had limited opportunities to actively engage with the soundscape or influence the narrative flow. This limitation highlighted the need for Module 3 that focused on embodied and participatory interaction. To strengthen ecological awareness and support long-term reflection, the next design should incorporate real-time feedback and enable users to explore and co-construct soundscape experiences through physical and sensory engagement.

This experience focuses on creating a multisensory digital coral experience that emphasizes both visual engagement and physical interaction. The core idea is to translate the ecological impact of human activities on coral reefs into tangible sensory responses. Participants interact with a digital coral model through a series of actions, each representing a specific form of human interference. These interactions trigger dynamic visual feedback that reflects the changing health of the reef. By linking physical input with visible ecological consequences, the experience encourages participants to reflect on the cause-and-effect relationship between human behavior and environmental degradation. The aim is to support an intuitive and embodied understanding of the vulnerability of coral reefs.

Given the complexity of ocean soundscapes, I chose to focus on coral reefs as a representative case. Coral reefs are vital to marine biodiversity and serve as key habitats for a wide range of marine species. Healthy reefs are often associated with vibrant and diverse underwater soundscapes. These soundscapes are generated by reef-dwelling organisms and reflect the ecological richness of the environment. However, coral reef systems are under severe threat due to the growing impact of human activities, and their soundscapes are also undergoing noticeable changes. In addition, the vivid shapes and colors of corals offer a strong potential for visual

and multisensory design.

Module 3 focuses on creating a multisensory digital coral experience that emphasizes both visual engagement and physical interaction. The core idea is to translate the ecological impact of human activities on coral reefs into tangible sensory responses. Participants interact with a digital coral model through a series of actions, each representing a specific form of human interference. These interactions trigger dynamic visual feedback that reflects the changing health of the reef. By linking physical input with visible ecological consequences, the experience encourages participants to reflect on the cause-and-effect relationship between human behavior and environmental degradation. The aim is to support an intuitive and embodied understanding of the vulnerability of coral reefs.

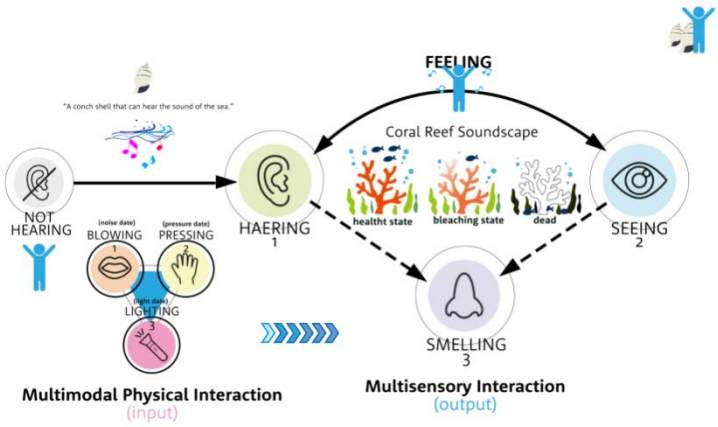

Figure 3.9 Multisensory Coral Reef Soundscape Experience

3.6.2 Design goal

The goal of this design is to raise awareness of human impact on reef soundscapes, to foster emotional connection, and to encourage reflection on responsibility for marine environments. Ultimately, this prototype explores how sensor-driven interactive design can serve as a powerful tool for environmental storytelling. It transforms abstract ecological issues into visceral and emotionally resonant experiences.

3.6.3 Multisensory Interaction Design

- Audio and Visual Interaction Design: This prototype translates the acoustic characteristics of vibrant and degraded reef soundscapes into dynamic visual representations. The system responds to changes detected by sensors in real time, allowing users to perceive the ecological condition of coral reefs through synchronized audio and visual cues.

- Physical Interaction Design: Sensor-based interaction is implemented using sound, light, and pressure sensors. Users can affect the system by changing environmental inputs. These inputs trigger responsive changes in both the soundscape and coral visuals, offering immediate, multisensory feedback.

- Multisensory Interaction System: This system integrates Touch Designer and Arduino to construct a responsive multisensory interaction framework. It is structured into four main layers: input, processing, design, and output.

  In the input layer, sound, light, and pressure sensors collect real-time environmental data. The processing layer uses Arduino to manage circuit connections and transmit sensor data.

  In the design layer, Touch Designer serves as the central platform for managing interaction logic, real-time parameter control, and the generation of dynamic visualizations and reactive audio. Sensor inputs are mapped to changes in the visual appearance of digital coral models, while simultaneously triggering corresponding sound responses that reflect environmental shifts.

  In the output layer, synchronized dynamic visuals and reactive sound work together to produce an immersive experience. This allows participants to "feel" the coral reef soundscape under varying environmental conditions through an integrated audio-visual interaction.

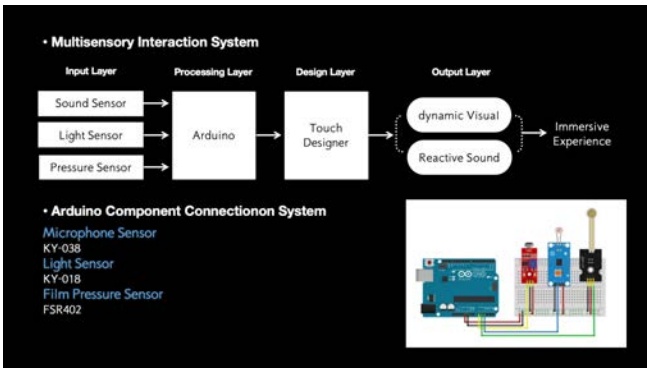

Figure 3.10 Multisensory Interaction System: Module 3

3.6.4 Design process

Graphic design

The visual concept is inspired by fossilized coral forms. It combines the transformation of coral from health to bleaching and eventual death. This process is visually linked to the brief explosion and gradual fading of the fireworks. This visual metaphor underscores both the beauty and fragility of coral ecosystems. The digital coral graphics were developed using Touch Designer, enabling dynamic visualizations that respond in real time to the participant's interaction.

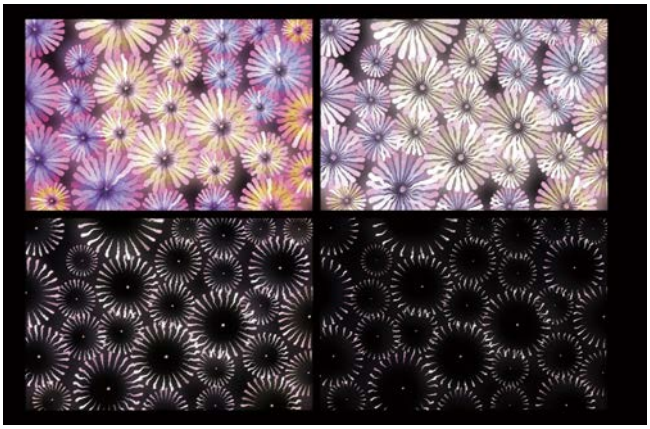

Figure 3.11 Digital Coral-Inspired Fireworks

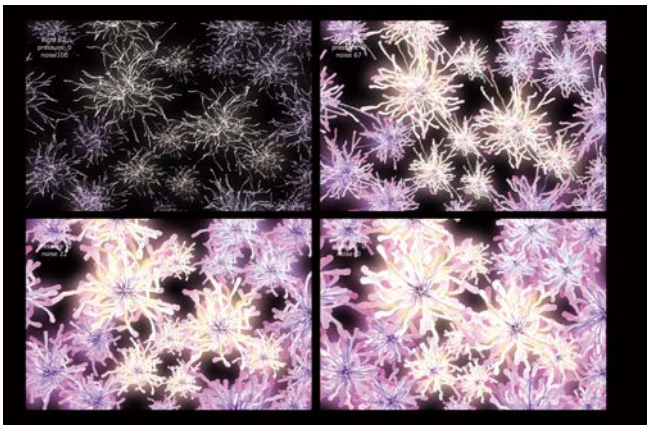

Figure 3.12 Sound Interaction Visual Diagram: Module 3

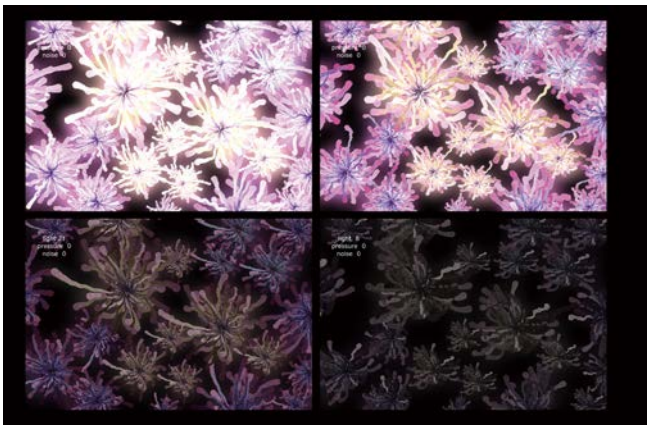

Figure 3.13 Light Interaction Visual Diagram

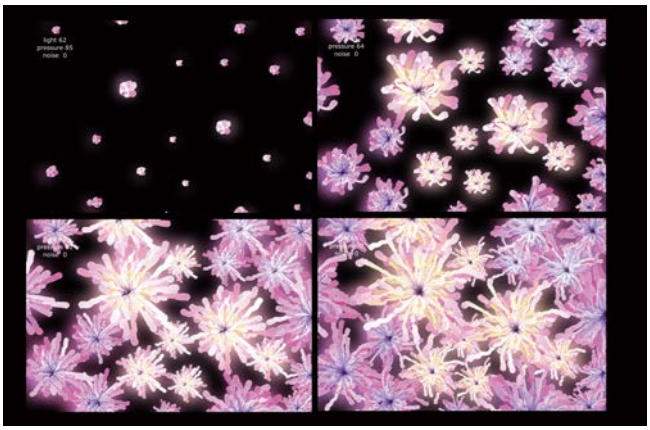

Figure 3.14 Pressure Interaction Vision Diagram

Sound design

- Audio Example 2: Healthy Soundscape
  Represents a rich ocean soundscape with biophony, geophony, and minimal anthropogenic interference.

- Audio Example 3: Unhealthy Soundscape
  Represents a degraded ocean soundscape dominated by anthropophony and noise pollution.

The audio clips used in this experience encompass a range of biophony, geophony, and anthrophony, representing the diverse components of the ocean soundscape. All files were edited and combined using CapCut, following the same methodological approach applied in Module 2, which included trimming, layering, adjusting volume levels, and applying fade-in and fade-out effects to achieve a coherent composition.

Sensor logic

The sound sensor represents noise pollution. Participants can speak or blow near the sensor to alter the noise level. As noise increases, the digital coral becomes thinner and weaker. When the noise decreases, the coral appears fuller and healthier.

The light sensor reflects light pollution. By shining a flashlight or moving under ambient light, participants can change the brightness value. Higher light levels make the coral appear overly bright and overstimulated, while lower light levels result in a dimmer coral state.

The pressure sensor represents a physical disturbance. Participants apply pressure to the sensor to simulate touch or interference. Increased pressure causes the coral form to contract tightly. When pressure is reduced, the coral gradually returns to a relaxed, expanded state.

3.6.5 Results

Module 3 integrated auditory and visual sensory modalities to represent the ecological impacts of noise pollution, light pollution, and physical contact on coral reefs. These anthropogenic factors were assigned to specific sensors, allowing participants to manipulate both the coral soundscape and its dynamic visual state through multimodal interaction. This approach effectively improves the perceived connection between human activity and marine ecological change, reinforcing a tangible sense of cause and consequence. The design aligns with previous research suggesting that embodied interaction can facilitate situated environmental awareness.

Participants demonstrated strong participation in visual feedback, which served as an intuitive metaphor for ecological degradation and offered an immediate understanding of environmental consequences. However, the auditory dimension was less easily interpreted. To address this limitation, future iterations should incorporate additional sensory modalities, such as tactile or olfactory feedback, to communicate ecological change through more embodied and emotionally resonant channels. Multisensory design has been shown to improve emotional engagement and improve the comprehensibility of abstract information. By broadening the sensory spectrum, the experience can support a more holistic understanding of coral reef vulnerability and foster a deeper cognitive and affective engagement with the consequences of anthropogenic disturbances in marine environments.

3.7. Prototype Design: Module 4

3.7.1 Listening to the Impact of Noise on Reef Soundscapes

Compared to Module 3, this experience expands the multisensory experience by integrating sound interaction and olfactory feedback into existing visual and physical interaction. Participants interact with the digital coral model through vocal input. Their voice changes affect not only the coral's color and movement, but also trigger corresponding reef soundscapes and related scents. As the decibel level of the voice increases, different combinations of sound and smell are activated. These changes simulate both the acoustic and chemical changes that occur in coral reef environments. This multisensory integration emphasizes the impact of noise pollution on coral reef ecosystems. Translating acoustic disturbances into visual, auditory, and olfactory cues, the experience makes the invisible effects of sound more perceptible and affective. It encourages participants to reflect on how noise not only disturbs underwater life and changes the ocean soundscape, but also disrupts the sensory balance of marine environments.

3.7.2 Design goal

The design aims to improve public understanding of healthy and bleaching coral reef soundscapes. It seeks to raise awareness of the impact of noise pollution on these underwater environments and to foster an emotional connection with reef soundscapes. Ultimately, the design encourages users to reflect on how human behavior influences coral reef ecosystems.

3.7.3 Multisensory Interaction Design

- Audio and Visual and Olfactory Interaction Design: This prototype translates the characteristics of vibrant and degraded reef soundscapes into corresponding coral visuals and contrasting scents. The system responds to real-time input from a sound sensor. Users can perceive the ecological condition of coral reefs through the synchronized combination of audio, visual, and olfactory cues.

- Physical Interaction Design: This interaction is based on a sound sensor. Users influence the system by altering the ambient noise levels. These changes trigger responsive variations in the soundscape, coral visuals, and scent. Feedback is immediate and multisensory, allowing users to experience the environmental impact through layered sensory input.

- Multisensory Interaction System: This prototype also utilizes Touch Designer and Arduino for interaction control.

  In the input layer, a sound sensor collects real-time environmental stimuli. These inputs reflect changes in acoustic intensity and serve as triggers for olfactory output. The processing layer is handled by Arduino, which manages sensor inputs and communicates with the design layer.

  The design layer is built using Touch Designer. Processes incoming sensor data and maps them to multiple output modalities. This includes generating dynamic visual content and triggering reactive sound responses, along with activating scent release through the atomizer modules.

  In the output layer, the system generates synchronized visual, auditory, and olfactory feedback to create a more immersive sensory experience. This enables participants to perceive the coral reef soundscape under varying noise conditions through an integrated audio-visual-olfactory interaction.

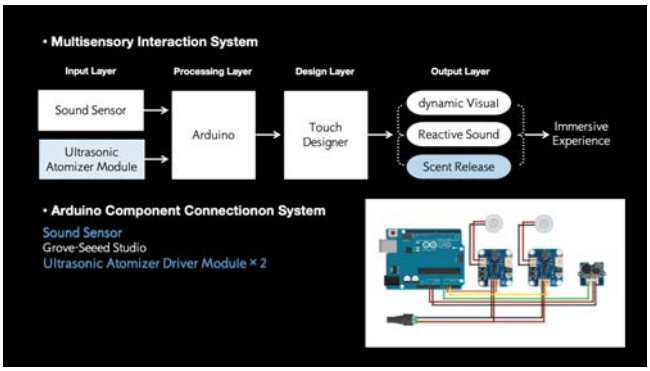

Figure 3.15 Multisensory Interaction System: Module 4

3.7.4 Design process

Graphic design

The visual concept draws inspiration from long-polyp leather coral, a soft coral species known for its vibrant coloration and flowing tentacle-like structures. In its healthy state, digital coral shows vivid, multicolored tones and dynamic, sweeping movements that suggest vitality and diversity. In its healthy state, digital coral shows multicolored tones and sweeping movements. In contrast, under stressed or degraded conditions, the coral gradually changes to monochrome hues. Its motion becomes slow or entirely static. The swaying of the coral tentacles is also used as a visual metaphor for the diffusion of scent. This movement is synchronized with the olfactory output, allowing the release of scent to naturally blend into the experience.

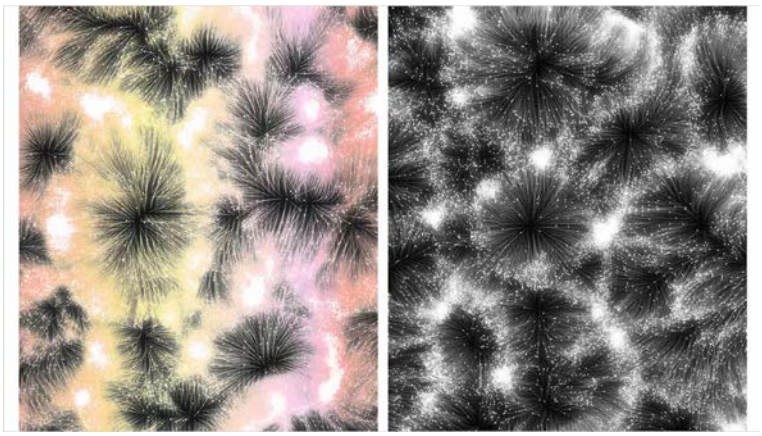

Figure 3.16 Digital Coral-Inspired Leather Coral

Sensor logic

The sound sensor represents anthropogenic noise. Participants can speak or blow near the sensor to change decibel levels. When the input sound is at a high decibel level, the digital coral changes color to black and white and moves more slowly, indicating stress or degradation. At low decibel levels, the coral displays vibrant multicolored hues and sways actively, reflecting a healthy state. The audio input

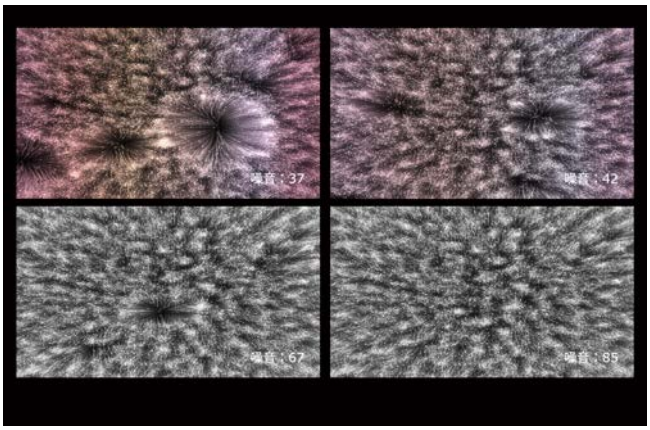

Figure 3.17 Sound Interaction Vision Diagram: Module 4

is also linked to the playback of environmental soundscapes. The high decibel input triggers loud and unpleasant acoustic environments, while the low decibel input activates lively and natural reef soundscapes.

Ultrasonic Atomizer Modules Two ultrasonic atomizers are embedded within the 3D-printed seashell models. The atomizers are synchronized with both the participant's vocal input, the soundscape change, and the corresponding visual feedback from the digital coral. Varying sound levels trigger different olfactory outputs. At lower decibel levels, the system releases a pleasant floral scent, representing a healthy and balanced acoustic environment. At higher decibel levels, it emits an unpleasant odor, symbolizing a stressed or degraded soundscape.

3.7.5 Results

This experience integrated auditory, visual, and olfactory sensory modalities to emphasize the ecological impact of noise pollution on coral reef environments. Participants participated in the installation through a sound sensor. Changes in environmental noise altered the coral soundscape and dynamic visuals, while also triggering the release of contrasting scents. This multisensory configuration aimed to deepen participants' perceptual and emotional understanding of how anthropogenic noise affects underwater ecosystems. Previous research has shown that olfactory stimuli can reinforce affective responses and support memory retention

in environmental experiences. In this experience, the addition of scent, combined with visual and auditory feedback, created a more immersive interaction. It allowed participants to associate sensory changes with ecological deterioration.

Despite these contributions, the interactive scope of the experience was limited. It presented only binary representations of coral reef conditions: healthy and unhealthy. The absence of gradual transitions reduced the ability to convey the complexity of ecological degradation. In addition, the emotional responses of participants to sensory stimuli showed subtle variations. This variation highlights the inherently subjective nature of smell perception. As reported in the existing literature, olfactory responses are shaped by personal experience, cultural background, and contextual factors. These influences pose challenges in designing emotionally consistent sensory cues. Future iterations may benefit from more nuanced and layered sensory feedback. Gradual representations of environmental change could improve interpretability. Adaptive or personalized mechanisms can also help align emotional responses with the intended ecological meanings.

Chapter 4
Proof of Concept

4.1. Evaluation Objectives

The objective of this evaluation is to assess the effectiveness, impact and user reception of the multisensory ocean sound experience developed in this study. By collecting qualitative and quantitative feedback, the evaluation aims to determine the degree to which the design goals have been achieved successfully. These goals include fostering emotional engagement through ocean listening, raising awareness of the effects of human activities on underwater acoustic environments, and promoting a deeper understanding of the ecological diversity and vulnerability of marine soundscapes.

The evaluation seeks not only to validate the value of a multisensory approach but also to explore how design can function as a medium for environmental communication and education. In addition, it aims to gather user insights and suggestions to inform future refinements and iterations of the design. Ultimately, the findings will provide a foundation for developing empathy-driven experiences within the broader context of marine conservation.

4.1.1 Evaluation Framework

To evaluate the designed multisensory ocean sound experience, a multidimensional assessment framework was developed. It comprises six core dimensions: perceptual understanding, cognitive awareness, emotional resonance, sense of responsibility, interaction usability, and memorability. Each dimension includes specific indicators to support both qualitative and quantitative evaluation.

- **Perceptual Understanding**

This dimension evaluates the participants' ability to perceive and interpret various types of ocean sounds. Given the inherent limitations of human auditory perception in underwater environments, the multisensory design approach aims to enhance perceptual access by integrating auditory cues with complementary sensory modalities. By mapping sound information onto visual, tactile, or olfactory representations, the experience helps participants to better recognize and understand the composition and dynamics of ocean soundscapes.

Indicators include:

1. The ability to distinguish between different categories of ocean sound sources.
2. The ability to differentiate between healthy and degraded marine soundscapes.
3. The ability to match sound sources with the corresponding visual or contextual representations.
4. The ability to associate specific sounds with olfactory elements.

- **Cognitive Awareness**

  This dimension evaluates whether participants have developed a deeper understanding of the ocean soundscape. It aims to assess the effectiveness of multisensory interactive design in conveying the complex interrelations between anthropogenic activities and marine acoustic environments, as well as its capacity to foster ecologically informed awareness.

  Indicators include:

  1. Awareness of the diversity of ocean sounds and the complexity of the marine soundscape.
  2. Recognition that human activities are continuously altering the ocean soundscape.
  3. Understanding of causal relationships between specific human actions and changes in the acoustic environment.

4. Awareness of underwater noise pollution as a pressing environmental issue with wide-ranging ecological consequences.

- **Emotional Resonance**

  This dimension evaluates whether the experience elicits emotional responses, empathy, or a sense of connection to the ocean. Emotional engagement is a key component in fostering ecological awareness and care, as it strengthens the affective bones of participants in the marine environment. By assessing the emotional responses triggered during the experience, this dimension examines the potential of the multisensory design to evoke ecological empathy and personal relevance.

  Indicators include:

  1. Expression of affective states such as awe, wonder, sadness, curiosity, or concern in response to specific oceanic scenarios or sensory stimuli.
  2. Verbal or non-verbal indications of empathy towards marine species or degraded underwater environments.
  3. Reflective comments demonstrating emotional identification with marine life or greater appreciation of the vulnerability of ocean ecosystems.

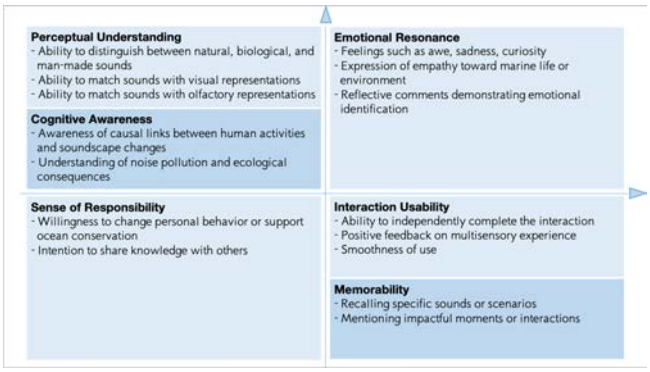

Figure 4.1 Evaluation Dimensions of Multisensory Ocean Sound Experience

- **Sense of Responsibility**

Aligned with the goals of environmental education, this dimension evaluates whether the experience fosters a sense of ecological stewardship and encourages participants to adopt environmentally responsible behaviors. Focuses on the extent to which the multisensory experience motivates individuals to transform awareness into action.

Indicators include:

1. Participants expressed a willingness to reduce their personal contribution to underwater noise pollution or to actively support ocean conservation initiatives.
2. Intention to share the insights gained from the experience with peers or broader communities, thus contributing to the wider dissemination of environmental awareness.

- **Interaction Usability**

  This dimension assesses the intuitiveness, accessibility, and overall user satisfaction of the multisensory interaction system. Effective usability is critical for minimizing cognitive effort and facilitating meaningful engagement with the content.

  Indicators include:

  1. Participants' ability to navigate and complete the interaction sequence independently and without confusion.
  2. Positive feedback regarding the integration and clarity of multisensory elements
  3. Evidence of sustained attention and active engagement throughout the experience.

- **Memorability**

  Memorability is a key factor in long-term awareness-building. This dimension assesses whether the experience leaves a lasting impression and enables participants to retain key aspects over time.

  Indicators include:

1. Accurate recollection of specific soundscapes, scenarios, or emotional reactions following a delay.
2. References to particularly impactful or transformative moments during post-experience reflection or interviews.

4.1.2 Evaluation Methods

To assess the effectiveness of the prototype design, a mixed-methods approach was adopted. This evaluation prioritized qualitative research, supplemented by quantitative analysis to verify the concept.

Qualitative Research

- **Observation of Participant Interaction:** During the experience, I conducted on-site observations to record how participants engaged with each prototype module. This included what elements they engaged with the most, the time spent on each activity, and observable emotional or physical reactions. Special attention was paid to moments of curiosity, hesitation, or repeated engagement, which helped to assess the intuitiveness and appeal of the interactive design.
- **Open-Ended Questionnaire:** Upon completing the experience, the participants were invited to respond to a questionnaire consisting of open-ended questions. This instrument was designed to collect feedback on four main dimensions of evaluations (including cognitive change, emotional resonance, behavioral intention, and interaction quality). The open-ended questions complemented the observational findings and offered deeper insight into the user experience.
- **Semi-Structured Interviews:** In-depth follow-up interviews were conducted with a selected group of participants who exhibited strong or weak emotional engagement during the experience. The purpose of these interviews was to clarify ambiguities arising from the observational and questionnaire findings and to identify potential implications for future design iterations.

Quantitative Analysis

- **Structured Evaluation Questionnaire:** Participants were invited to complete another structured evaluation questionnaire after experience. The questionnaire adopted a Likert scale format to collect quantitative data on participants' responses. By quantifying subjective responses, this evaluation helped supplement qualitative findings with statistically interpretable results. This combination allowed for a more comprehensive assessment of how effectively the multisensory design achieved its intended and emotional and educational goals.

4.2. Experimental Settings

4.2.1 Environment

Play Exhibition (June 1, 2025)

This public event provided an open and participatory setting in which the ocean sound experience was presented to a wider audience. The exhibition setting allowed naturalistic user interaction with the prototype and enabled the collection of real-time feedback from a diverse group of participants. During this phase, an experiential survey was conducted to systematically collect information on user experience. The evaluation focused on the following key dimensions:

- Cognitive change: whether participants developed a deeper understanding of the ocean soundscape and the impact of human activities on marine environments.
- Emotional resonance: the extent to which participants felt emotionally engaged or connected to the content presented through sound, visuals, and other sensory stimuli.
- Behavioral intention: whether the experience inspired participants to reflect on their own actions or consider supporting ocean conservation efforts.
- Interaction quality and usability: participants' impressions of how intuitive, accessible, and engaging the interaction with the prototypes felt.

The exhibition setting also allowed for observational research. These observations supported the self-reported data and contributed to a more comprehensive understanding of the effectiveness of the design in achieving its educational and affective goals.

4.2.2 Participants

A total of 15 participants took part in the experience project, including 7 males and 8 females, all between 10 and 30 years old.

For the purpose of future comparative analysis, the age range was further divided into specific groups as shown in the following figure. Most of the participants fell into two main primary age brackets: 24–26 (7 participants) and 27–30 (7 participants).

Figure 4.2 Final Play Exhibition

4.3. Experimental Procedure

4.3.1 Pre-Experiment

Before starting the experience, participants receive a brief introduction to the project, describing the key steps involved, and important notes to ensure clarity of purpose and active engagement. A pre-survey is then conducted to assess participants' initial awareness and understanding of ocean soundscapes.

4.3.2 Experimental Process

The participants were engaged with four interactive prototype modules, each representing different aspects of the ocean soundscape.

- **Module 1: Listening to the Diversity of Marine Sounds**
  Participants activated various ocean sounds through touch, composing different ocean soundscapes.
- **Module 2: Listening to Transitions in the Ocean Soundscape**
  Participants scanned NFC-enabled posters to access and listen to ocean soundscapes from different time periods.
- **Module 3: Listening to the Human Impact on Reef Soundscapes**
  Participants interacted with a digital coral installation using sound, light, and pressure sensors. Their inputs triggered responsive visual and auditory feedback, simulating the ecological impacts of human activities on coral reef environments.
- **Module 4: Listening to the Impact of Noise on Reef Soundscapes**
  Participants interacted with a digital coral installation using sound sensors. Their inputs triggered responsive visual, auditory and olfactory feedback, simulating the destructive effects of noise pollution on coral reef soundscapes.

4.3.3 Post-Experiment

At the end of the experience, participants will be invited to complete questionnaires. They can choose between a paper version or a digital format. The aim is to collect their impressions and evaluations of the project. In addition to the survey, in-depth interviews will be conducted with selected participants.

4.4. Result

4.4.1 Observation

In terms of user observation, the majority of participants engaged in the experience for approximately 15 to 20 minutes, indicating a high level of sustained interest. The ocean scene model in Module 1 and the digital coral displays in Modules 3 and 4 attracted attention and encouraged more active and prolonged exploration. Module 1 elicited some of the most noticeable emotional responses. Participants expressed surprise when they encountered unfamiliar marine animal sounds and some were startled by sudden anthropogenic noise. By comparison, Modules 3 and 4 exhibited a higher frequency of repeated interaction. This can be attributed to the incorporation of multiple sensors and various sensory modalities. Among these, the olfactory interaction in Module 4 was particularly engaging, eliciting strong emotional reactions and improving the immersive quality of the experience.

4.4.2 Qualitative Research

This qualitative research aimed to explore how people engaged with the interactive ocean soundscape prototype and how these experiences shaped their cognitive understanding and emotional responses to marine environments.

Data were collected from multiple sources, including open-ended questionnaire responses and semi-structured interviews. Participants were encouraged to freely reflect on what they felt and imagined throughout the multisensory journey. These open-format responses generated rich descriptive insights, providing a more holistic understanding of the user experience that extends beyond the scope of quantitative measures. The analysis focused on four key dimensions: cognitive change,

emotional resonance, behavioral intention, and interaction quality. The selected participant quotes were thematically categorized and interpreted to reveal meaningful perspectives on the effectiveness, emotional impact, and design limitations of each prototype.

Module 1: Listening to the Diversity of Marine Sounds

- **Cognitive Change**
  Participants demonstrated increased awareness of the diversity of marine soundscapes. For example, a participant stated:

  > *"I learned about the sounds made by different marine animals."*

  This suggests that the experience successfully broadened their knowledge about the acoustic characteristics of marine life, supporting the module's objective of improving our understanding of ocean sound diversity.

- **Emotional Resonance**
  The sound experiences evoked a range of emotional responses. Some participants expressed affection and delight:

  > *"The sounds of the sea creatures were very cute."*

  Others described mixed emotions:

  > *"Some sounds are disturbing while others are pleasant."*

  These reactions indicate that the auditory elements effectively triggered emotional engagement, an essential component for fostering empathy toward marine life.

- **Behavioral Intention**
  Several participants expressed a desire to continue engaging with marine soundscapes beyond the experience. One noted:

  > *"I would like to hear more sounds from different marine animals."*

This reflects a potential shift in behavioral intention towards greater curiosity and continued exploration, which is a positive outcome for educational and environmental awareness objectives.

- **Interaction Quality**
  Participants highlighted specific aspects of interactive design that contributed to their engagement. One participant shared:

  > *"My favorite part was interacting with the metal rods."*

  However, some usability issues were identified. The participants also provided feedback on the physical setup. Suggestions included:

  > *"Make the interactive nodes more visible."*
  >
  > *"Place the wiring underneath the display table to interact with multiple sounds at the same time more easier."*

  These insights underscore the importance of tactile and auditory feedback in maintaining user interest and immersion.

Key Findings: These findings indicate that while the experience effectively encouraged exploration and interest, future iterations should focus on improving the intuitiveness of the interaction, providing clearer emotional and narrative cues, and enhancing the physical layout to support smoother and more meaningful engagement.

Module 2: Listening to Transitions in the Ocean Soundscape

- **Cognitive Change**
  Participants reported gaining new insight into the ecological role of sound in marine environments. One participant admitted:

  > *"I did not know that sound could be an important factor for the ocean."*

  This reflects a cognitive shift in recognizing the importance of underwater acoustics, an often overlooked dimension of marine ecology.

- **Emotional Resonance**
  The experience also elicited emotional reflection. One participant shared:

  > *" It encouraged me to consider how marine life might feel."*

  These responses suggest that the sonic transitions over time evoked a sense of empathy toward marine life and nurtured emotional connections.

- **Behavioral Intention**
  Some participants expressed greater curiosity and a sense of urgency about the unknown aspects of the ocean. One reflected:

  > *" I realized that much of the ocean remains unexplored and unknown to us."*

  This indicates that the experience may have inspired a desire to learn more about ocean environments and their acoustic characteristics.

- **Interaction Quality**
  Comments on the interactive setting pointed to opportunities to improve user agency and engagement. One participant recommended:

  > *"Fewer instructions from facilitators would be better. Let participants explore and engage with the experience on their own."*

  In terms of design, one suggestion stood out:

  > *" Live storytelling!! It will be more interesting!!"*

  This indicates that incorporating narrative elements into soundscape transitions, perhaps through live or recorded storytelling, could deepen participant engagement and emotional immersion.

Key Findings: These findings suggest that while the narrative component of the experience was impactful, future iterations should focus on **increasing the level of interactivity and immersion. For example, through branching narratives or responsive storytelling, fully realize the potential of participatory, multisensory environmental storytelling.

Module 3: Listening to the Human Impact on Reef Soundscapes

- **Cognitive Change**
  Participants demonstrated significant cognitive change, One participant reflected:

  > *"I gained a better understanding of the marine ecosystem and its important interaction with human behaviors."*

  Highlighting the effectiveness in communicating ecological complexity.

- **Emotional Resonance**
  participants responded to the contrast between healthy and disturbed reef states. Comments:

  > *" We may be harming marine life without realizing it."*
  >
  > *" The healthy soundscape felt vibrant with so many colors and pulsating life forms."*

  This reveals both concern for anthropogenic harm and appreciation for natural vitality, indicating that the sensory design effectively supported emotional engagement.

- **Behavioral Intention**
  The experience also encouraged behavioral reflection, with participants expressing intentions to minimize their own environmental impact, for example by stating:

  > *"When diving, try not to disturb the natural environment."*

  This suggests that the prototype not only informed, but also motivated more conscientious behavior in nature-based settings.

- **Interaction Quality**
  The coral's reactions to sound and light stimuli were well received, with comments:

"The visualization of audio interaction with the coral reef was impressive."

"The response of digital coral to light and noise was interesting."

However, the user noted that:

"Some sensors could have been more sensitive."

This indicates minor usability limitations. Improving sensor responsiveness in future iterations could improve interaction fluidity and reinforce the connection between participant behavior and simulated environmental effects.

Key Findings: This experience successfully translated the abstract notion of acoustic ecological impact into an intuitive and embodied experience, promoting both awareness and emotional connection. Further refinements to sensor design and feedback sensitivity could deepen its educational and affective potential.

Module 4: Listening to the Impact of Noise on Reef Soundscapes

- **Cognitive Change**
  Participants reported significant cognitive shifts, expressing a new awareness of how noise itself can be a form of pollution. One participant commented:

  "Sounds are the way animals connect with their surroundings. The noise of sounds can also be a form of pollution."

- **Emotional Resonance**
  The prototype also elicited strong emotion. The moment when the coral turned white was particularly impactful, a participant said:

  "The moment the coral turned white, I felt sad."

  Other noted:

  "I did not expect the experience to involve smell, it was surprising."

  This reflects the power of multisensory interaction in evoking unexpected and memorable emotional responses.

- **Interaction Quality**
  Feedback was generally positive. A participant described the system as "immersive" and "comprehensive", and were especially moved by the simulation of reef damage caused by human noise. However, some participants experienced technical limitations, noting that:

  "blowing air onto the sensor was not always effective."

  This highlights the need for improved sensor sensitivity and calibration to ensure smooth and intuitive interaction in future iterations.

Key Findings: This experience successfully demonstrated the potential of multisensory interaction, especially through the combination of audio, visual, and olfactory elements, to communicate environmental degradation in a way that is both emotionally powerful and cognitively informative. Enhancing the technical responsiveness of the system could further strengthen its ability to foster eco-empathy and behavioral awareness.

4.4.3 Quantitative Analysis

A structured evaluation questionnaire was administered for Modules 3 and 4. The instrument used a five-point Likert scale (1 = strongly disagree, 5 = strongly agree) to assess four key dimensions: cognitive awareness, emotional resonance, behavioral intention, and usability and interaction. In addition, emotion mapping was incorporated using a Semantic Differential Scale, allowing participants to express their emotional responses across opposing pairs of adjectives.

Cognitive Awareness Evaluation

The results indicate that most of the participants agreed or strongly agreed that the experience improved their understanding of key concepts. High levels of agreement were observed in statements such as "visualize human impact on marine life", "understand human activity altering sound", "understand coral reef degradation", and "multisensory elements helped understanding". These findings suggest that the multisensory approach was effective in supporting cognitive engagement and conveying the consequences of anthropogenic influences on ocean soundscapes.

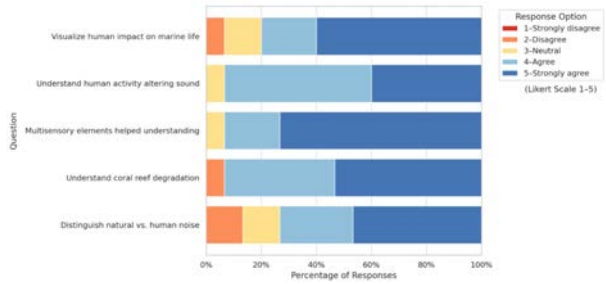

Figure 4.3 Distribution of Participant Responses on Cognitive Awareness

However, responses to the item "distinguish natural versus human noise" were more mixed, with a noticeable proportion of participants selecting "Neutral" or "Disagree". This suggests that although participants were able to perceive environmental changes and degradation, they faced difficulty clearly differentiating between natural and anthropogenic sound sources. To address this, future iterations of the experience could incorporate more distinct auditory contrasts and provide guided sound exploration to improve participants' ability to identify and interpret acoustic differences.

Emotional Resonance Evaluation

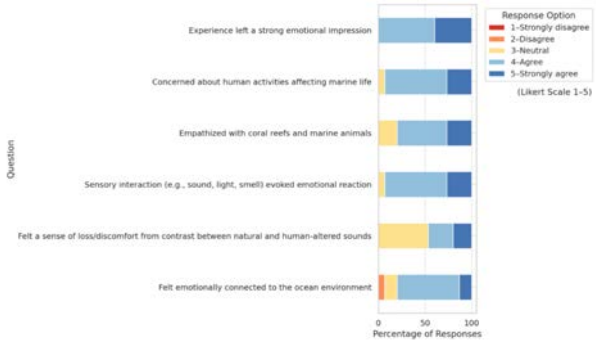

Figure 4.4 Distribution of Participant Responses on Emotional Resonance

The results suggest that the multisensory experience was effective in fostering emotional engagement with the theme of ocean soundscapes. Most of the partic-

ipants agreed or strongly agreed that the experience emotionally connected them to the ocean environment and heightened their concern about the impact of human activities on marine life. These findings highlight the potential of sensory-rich design to evoke empathetic and environmentally conscious responses.

However, responses to the item "felt a sense of loss / discomfort in the contrast between natural and human-altered sounds", which was more neutral, indicating that auditory contrasts alone may not have been sufficient to fully convey the intended emotional message. This points to certain design limitations that may have reduced the affective impact of the experience. For example, the symbolic and narrative aspects of the coral reef interaction may not have been explicit or immersive enough to clearly communicate a sense of environmental degradation. In addition, the transitions between different soundscapes or sensory states may have lacked adequate contrast or temporal pacing to trigger deeper emotional responses.

Emotion Mapping Evaluation

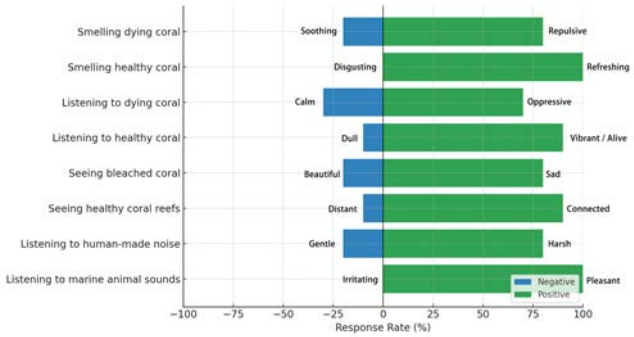

Figure 4.5 Distribution of Participant Responses in Positive and Negative Emotional Mapping

The results reveal clear contrasts in the affective responses of participants to different marine stimuli. Overall, participants responded positively to sensory experiences associated with "healthy coral reefs" and "marine animal sounds", with descriptors such as "vibrant", "refreshing", and "pleasant" selected at high rates. Degraded marine environments, such as "smelling or listening to dying coral",

observing “bleached coral”, and hearing “human-made noise”, generated predominantly negative emotional responses, including “disgust”, “sadness”, “oppression”, and “irritation”. This emotional divergence underscores the effectiveness of sensory contrast in highlighting the difference between natural and human-impacted ocean environments.

However, the data also indicate a perceptual gap. Some participants assigned neutral or even positive descriptors to experiences intended to convey ecological degradation. For example, a small percentage of responses to “dying coral* or “human-made noise* were marked as “calm”, “soothing”, or “gentle”, suggesting ambiguity in the way certain sensory cues were interpreted. This misalignment between the intended emotional message and participant interpretation points to a need for design refinement. Specifically, sensory elements that represent environmental harm, such as sound, smell, and visual indicators, should be made more explicit, symbolically clear, and affectively targeted to evoke stronger and more consistent emotional responses. Enhancing the clarity of sensory-emotional mappings could help foster deeper empathy and engagement with environmental issues in future iterations of the experience.

Behavioral Intention Evaluation

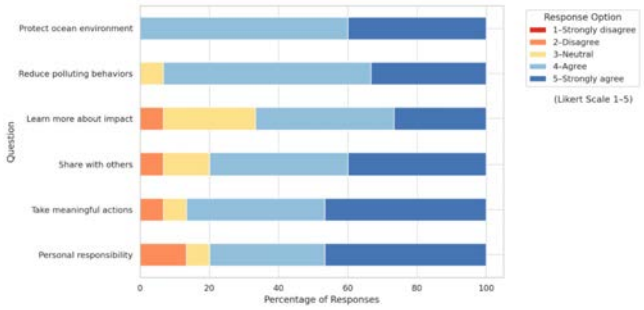

Figure 4.6 Distribution of Participant Responses on Behavioral Intention

The results indicate that the experience had a generally positive influence on the environmental motivation of the participants. Most of the participants agreed or strongly agreed that they were more willing to “protect the ocean environment” and “reduce polluting behaviors” after the experience. These findings suggest

that the multisensory storytelling approach was effective in improving the pro-environmental attitudes of the participants on a cognitive and emotional level.

However, responses to items such as "Take meaningful actions", "Share with others", and "Personal responsibility" were more varied, with a noticeable portion of participants choosing neutral or even disagree responses. This suggests that while the participants were emotionally engaged and aware, their intentions to extend this engagement to concrete or interpersonal action were less consistent. This variation may reflect a limitation in the degree to which the experience facilitated a sense of personal agency or long-term behavioral relevance. It highlights the need to strengthen the behavioral messaging and calls to action within the experience design. Specifically, translating emotional resonance into real-world action may require more explicit, practical, and personally relatable prompts, helping participants move from awareness to sustained environmental commitment and advocacy.

Usability and Interaction Evaluation

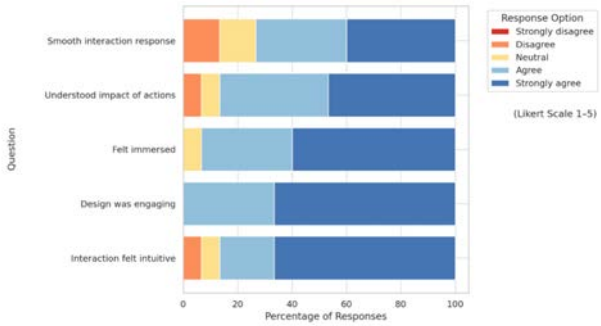

Figure 4.7 Distribution of Participant Responses on Usability and Interaction

Participants generally responded positively to the interactive aspects of the experience. As shown in the evaluation, the majority agreed or strongly agreed that the system was "intuitive", "engaging", and provided a "smooth interaction flow". These results support the overall effectiveness of the physical interface design and multisensory integration in facilitating a coherent and engaging user experience.

However, a small proportion of the responses indicated challenges with interaction responsiveness. Future iterations should focus on increasing interaction reliability and improving the clarity of feedback to ensure that participant actions are consistently recognized and reflected meaningfully within the system.

4.5. Discussion

The evaluation results indicate that the multisensory ocean sound experience effectively achieved its intended objectives. Improved participants' cognitive awareness, enhanced emotional resonance, and encouraged environmental responsibility. By combining questionnaires, behavioral observation, and open-ended interviews, the evaluation examined the experience from multiple dimensions, including perception, emotion, intention, and interaction.

From a cognitive perspective, most participants had limited prior knowledge of the ocean soundscape and the impact of anthropogenic noise. After the experience, their understanding improved significantly. This suggests that using tangible and multisensory formats to present abstract ecological concepts can effectively bridge the gap between public perception and environmental knowledge.

In terms of emotional response, the experience successfully elicited feelings of empathy and concern for marine life. Multisensory feedback, particularly the combination of scent and sound, played a key role in evoking emotional engagement. Some participants expressed surprise, discomfort, or deep emotional impact, highlighting how immersive design can strengthen environmental awareness on a personal level.

Regarding behavioral intention, while most participants expressed a willingness to protect the marine environment, some showed hesitation about further learning or sharing what they had learned. This reveals that although experience can raise awareness and motivation, transforming these into long-term behaviors may require ongoing support and follow-up involvement.

In terms of usability and interaction, participants generally found the system intuitive and engaging. However, some encountered technical limitations, such as low sensor sensitivity and difficulty locating interactive elements. Some relied heavily on facilitator guidance, suggesting that the current setup could benefit

from improved affordances for self-directed exploration. These findings point to clear directions for improvement, such as improving sensor responsiveness, refining interface clarity, and providing better system cues.

In summary, the evaluation confirms the effectiveness and potential of a multisensory interactive approach to marine environmental education. The experience not only communicated complex ecological issues, but also used sensory stimulation to create emotional and cognitive engagement. However, to further support long-term behavioral change, future work should focus on improving continuity, interaction clarity, and educational outreach. Future research could also expand to include a broader participant base and long-term follow-up to explore the sustained impact of such experiences on environmental attitudes and behavior.

Chapter 5
Conclusion

This study investigated the potential of multisensory interaction design to translate ocean soundscapes into perceivable and emotionally resonant experiences. The primary objective was to improve the public understanding of underwater acoustic environments and to raise awareness of the ecological consequences of human activities on marine ecosystems.

Based on the conceptual premise of listening to the ocean, the research extended beyond auditory perception by integrating additional sensory modalities, such as visual and olfactory cues. This multisensory strategy aimed to compensate for the inherent abstraction of underwater sound and to construct more tangible, immersive, and emotionally accessible experiences.

The project adopted a multi-module prototype, in which each module explored a specific yet interconnected aspect of marine acoustic ecology. These included the recognition of sound diversity, the perception of long-term soundscape transitions, and the interpretation of anthropogenic noise impacts on coral environments.

Through this layered approach, the study demonstrated that multisensory interactive design can serve as an effective bridge between abstract ecological phenomena and human perception. It can foster deeper emotional engagement, promote ecological reflection, and support new forms of public learning and environmental awareness.

5.1. Contributions

This research achieved several outcomes:

- **Experience System**
  This study developed and validated a multisensory interaction system for ex-

periencing ocean soundscapes. The system integrated auditory, visual, and olfactory modalities to support both cognitive understanding and emotional engagement. By combining these sensory channels, the design aimed to translate abstract underwater acoustic environments into more perceivable and affectively resonant experiences, thus improving participants' awareness of marine ecological dynamics.

- **Prototype Development**
  This study developed four experiential modules utilizing tools such as Makey Makey, Arduino, and Touch Designer. Each module addressed a specific but interrelated dimension of marine acoustic ecology, including sound diversity, temporal transitions, and the ecological impact of human activities. Collectively, these modules demonstrated the potential of multi-module prototyping to support public engagement with ocean soundscapes.

- **Empirical Evaluation**
  User observation, questionnaires, and post-experience interviews were conducted to evaluate the effectiveness of multisensory interactive experiences. The results indicated that the system successfully generated positive engagement and sustained attention. The participants showed emotional responses to different scenarios of ocean soundscapes. In particular, the combination of auditory, visual, and olfactory cues enhanced emotional resonance and supported deeper ecological reflection.

- **Environmental Communication**
  This study advances the discourse on environmental communication by emphasizing the role of sound as a carrier of ecological meaning. Through multisensory design interventions, it illustrates how the acoustic experience can be used as a form of ecological storytelling, bridging scientific insight with public engagement across the domains of ocean literacy, acoustic ecology, and experiential learning.

5.2. Limitations

Despite its contributions, the research has several limitations:

- **Evaluation Scope**
  Due to limitations in time and resources, user evaluation in this study was restricted in scale and methodological depth. The sample size was relatively small, which limited the reliability and statistical validity of the quantitative analysis. In addition, the participant group lacked sufficient age diversity, particularly with respect to teenage users.

- **Scalability and Accessibility**
  The reliance on physical components imposes inherent limitations on the scalability and accessibility of the prototype. Its current format may hinder implementation in broader educational or public engagement contexts, especially in settings where space, equipment, or technical support is limited.

- **Soundscape Synthesis**
  To align with the narrative structure and experiential objectives of the project, underwater recordings were edited and composited during post-production to enhance the emotional and sensory impact. Although these materials maintained a basic degree of acoustic authenticity, they were not developed in consultation with marine bioacousticians or ecological sound specialists. This lack of expert collaboration limits the scientific validity of the soundscape representations and raises concerns about their ecological fidelity and interpretative accuracy.

- **Sensory Integration**
  The integration of olfactory and auditory elements in this design remained limited. Smell is a strong emotional and sensory stimulus. However, its potential was not fully explored in the current prototype. The design connects two types of coral reef soundscape, healthy and degraded, with pleasant and unpleasant scents to enhance sensory engagement. However, this form of sensory mapping was too simplified to reflect the complex dynamics of coral reef ecosystems, which may not have supported participants in forming a deeper ecological understanding.

5.3. Future Design

Ocean sound experience design is a rapidly evolving and deeply interdisciplinary field. It lies at the intersection of marine ecology, human perception, and technological innovation. As demonstrated throughout this study, the field has significant potential. Not only does it help deepen the public understanding of ocean acoustics, but it also supports transformative change in marine conservation, human well-being, and sustainable development.

5.3.1 Redefining the Ocean Soundscape

Looking ahead, future design efforts must go beyond isolated installations or one-time educational events. A key conceptual shift involves redefining the ocean soundscape as more than just a background element. It should be seen as a shared acoustic resource: a vital, collective, and designable dimension that shapes both marine life and human experience. As Slabbekoorn et al. suggest, underwater sound is essential to ecological function and human engagement. It must be treated as a common good that calls for responsible management [32]. Similarly, Lindborg et al. [33] emphasize the importance of recognizing marine acoustic environments as part of our human and ecological heritage. This reinforces the view that the ocean soundscape is not only an environmental concern but also a cultural and perceptual one. This perspective encourages us to approach underwater sound not only as data to be heard or visualized. Instead, it should be understood as a co-experienced part of the marine environment that deserves ethical and creative care. Ocean sound is, in this sense, a designable component of both ecological health and cultural heritage.

5.3.2 Toward Collective Auditory Responsibility

Future design must therefore shift its focus from individual sensory engagement to a wider sense of collective auditory responsibility. As anthropogenic noise continues to rise across global oceans, it is essential to raise public awareness. Designers must help audiences develop emotional resonance and critical reflection on how human activities affect the underwater acoustic world. Ocean soundscapes should

be appreciated and shaped with intention. They represent a key part of our shared planetary heritage, reflecting both ecological conditions and cultural meaning. In this context, interdisciplinary and multisensory approaches will remain central. Designers, scientists, artists, and technologists must work together to create experiences that are inclusive, emotionally rich, and ecologically sensitive. These experiences should do more than communicate scientific facts. They must also evoke empathy and encourage a lasting commitment to ocean care. The ultimate challenge is not just to hear the ocean. It is to listen with intent, feel with empathy, and design with responsibility. Through thoughtful design, we can open new ways to sense, understand, and protect the acoustic life of the sea. Shaping the ocean's auditory space is not only an act of communication. It is also an expression of shared care and design responsibility. By building a stronger social relationship with the marine acoustic environment, future design can help ensure that the ocean remains a place of biodiversity, memory, and meaningful multisensory connection. As our relationship with the ocean evolves, so must our ways of listening and designing for others to listen, feel, and act.

References

[1] R. Murray Schafer. *The Soundscape: Our Sonic Environment and the Tuning of the World*. Destiny Books, 1994. Accessed: 2025-06-18. URL: `https://monoskop.org/images/d/d4/Schafer_R_Murray_The_Soundscape_Our_Sonic_Environment_and_the_Tuning_of_the_World_1994.pdf`.

[2] Wikipedia contributors. Soundscape ecology, 2025. Accessed: 2025-06-18. URL: `https://en.wikipedia.org/wiki/Soundscape_ecology`.

[3] Juan Carlos Azofeifa-Solano, Miles JG Parsons, Rohan Brooker, Robert McCauley, Daniel Pygas, William Feeney, Steve Simpson, Sophie L Nedelec, Eve M Croxford, Mark Meekan, et al. Soundscape analysis reveals fine ecological differences among coral reef habitats. *Ecological Indicators*, 171:113120, 2025.

[4] Michael Stocker. Fish, mollusks and other sea animals' use of sound, and the impact of anthropogenic noise in the marine acoustic environment. *Journal of the Acoustical Society of America*, 112(5):2431, 2002.

[5] A John R Cotter. The "soundscape" of the sea, underwater navigation, and why we should be listening more. *Advances in fisheries science*, 50:451–471, 2008.

[6] Geraint Rhys Whittaker. Creatively connecting science, society and the sea: a mini-review of academic literature focusing on art-science collaborations and the ocean. *Frontiers in Marine Science*, 10:1234776, 2023.

[7] Susan Clayton and Susan Opotow, editors. *Identity and the Natural Environment: The Psychological Significance of Nature*. MIT Press, Cambridge, MA, 2003.

[8] Constance Classen. *The deepest sense: A cultural history of touch*. University of Illinois Press, 2012.

[9] Val Plumwood. *Environmental culture: The ecological crisis of reason*. Routledge, 2005.

[10] R. Murray Schafer. *The Tuning of the World: Toward a Theory of Soundscape Design*. University of Pennsylvania Press, Philadelphia, 1977.

[11] Bryan C Pijanowski, Luis J Villanueva-Rivera, Sarah L Dumyahn, Almo Farina, Bernie L Krause, Brian M Napoletano, Stuart H Gage, and Nadia Pieretti. Soundscape ecology: the science of sound in the landscape. *BioScience*, 61(3):203–216, 2011.

[12] Martin O Archer, Natt Day, and Sarah Barnes. Demonstrating change from a drop-in space soundscape exhibit by using graffiti walls both before and after. *Geoscience Communication*, 4(1):57–67, 2021.

[13] Samuel RP-J Ross, Darren P O'Connell, Jessica L Deichmann, Camille Desjonquères, Amandine Gasc, Jennifer N Phillips, Sarab S Sethi, Connor M Wood, and Zuzana Burivalova. Passive acoustic monitoring provides a fresh perspective on fundamental ecological questions. *Functional Ecology*, 37(4):959–975, 2023.

[14] David Howes. *The sensory studies manifesto: Tracking the sensorial revolution in the arts and human sciences*. University of Toronto Press, 2022.

[15] Charles Spence. *Sensehacking: How to use the power of your senses for happier, healthier living*. Penguin UK, 2021.

[16] Chen Song, Saixin Cao, Hao Luo, Yinghui Huang, Siwei Jiang, Baimeng Guo, Nian Li, Kai Li, Ping Zhang, Chunyan Zhu, et al. Effects of simulated multi-sensory stimulation integration on physiological and psychological restoration in virtual urban green space environment. *Frontiers in Psychology*, 15:1382143, 2024.

[17] Tianqi Han, Lina Tang, Jiang Liu, Siyu Jiang, and Jinshan Yan. The influence of multi-sensory perception on public activity in urban street spaces:

An empirical study grounded in landsenses ecology. *Land*, 14(1):50, 2025. doi:10.3390/land14010050.

[18] Michael F Dahlstrom. Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the national academy of sciences*, 111(supplement_4):13614–13620, 2014.

[19] Paul Schultz. New environmental theories: Empathizing with nature: The effects ofperspective taking on concern for environmental issues. *Journal of Social Issues*, 56:391 – 406, 01 2000. doi:10.1111/0022-4537.00174.

[20] Donna J Haraway. *Staying with the trouble: Making kin in the Chthulucene*. Duke University Press, 2016.

[21] Elise Talgorn and Helle Ullerup. Invoking 'empathy for the planet'through participatory ecological storytelling: From human-centered to planet-centered design. *Sustainability*, 15(10):7794, 2023.

[22] Yuke Yang and Peijuan Cai. Multisensory experience design: A literature review. *Communications in Humanities Research*, 27:34–37, 2024.

[23] Mel Slater. Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1535):3549–3557, 2009.

[24] Yang Gao and Charles Spence. Enhancing presence, immersion, and interaction in multisensory experiences through touch and haptic feedback. In *Virtual Worlds*, volume 4, page 3. MDPI, 2025.

[25] Federico Gardoni, Fabio Mojetta, Chiara Sorrentino, Roberta Etzi, Alberto Gallace, Monica Bordegoni, Marina Carulli, et al. Raising awareness about the consequences of human activities on natural environments through multisensory augmented reality: Amazon rainforest and coral reef interactive experiences. *Computer-Aided Design and Applications*, 18(4):815–830, 2020.

[26] Monterey Bay Aquarium Research Institute. Soundscape listening room, 2024. Accessed: 2024-06-18. URL: https://www.mbari.org/project/soundscape-listening-room/.

[27] Yu Ren, Tian Wu, Chuanzhi Li, Pengfei Yao, and Weiwei Ding. Bridging science and art: Auralization and visualization of the ocean soundscape. *iScience*, 27(9), 2024.

[28] Sounds of the Ocean. Sounds of the ocean – listen, 2025. Accessed: 2025-06-18. URL: `https://www.soundsoftheocean.com/sound`.

[29] Ben Hughes and Jenny Tillotson. Design as a means of exploring the emotional component of scent. In *Proceedings of the 5th Conference on Design and Emotion*, Gothenburg, Sweden, September 2006. Chalmers University of Technology.

[30] Indissoluble. Scented shores: Interactive olfactory installation, 2024. Accessed: 2025-06-18. URL: `https://www.indissoluble.com/project/scented-shores-interactive-olfactory-installation/`.

[31] Stijn Demeulenaere. Zijlijn, 2020. Accessed: 2025-06-18. URL: `https://www.stijndemeulenaere.be/zijlijn.html`.

[32] Hans Slabbekoorn, Niels Bouton, Ilse van Opzeeland, Aukje Coers, Carel ten Cate, and Arthur N Popper. A noisy spring: the impact of globally rising underwater sound levels on fish. *Trends in ecology & evolution*, 25(7):419–427, 2010.

[33] Sara Lenzi, Juan Sádaba, and PerMagnus Lindborg. Soundscape in times of change: Case study of a city neighbourhood during the covid-19 lockdown. *Frontiers in psychology*, 12:570741, 2021.

Appendices

A. Audio Sources Used

The audio materials used in this study were obtained from publicly accessible platforms for educational and research purposes. These sources include:

- **Woods Hole Oceanographic Institution (WHOI) Whale Sounds Archive**
  Whale and dolphin vocalizations collected for marine mammal acoustic research.
- **NOAA Fisheries – Marine Sound Library**
  A collection of underwater animal and environmental sounds maintained by the U.S. National Oceanic and Atmospheric Administration.
- **Borealis Soniferous Fish Database**
  A Canadian repository containing fish sound recordings with scientific metadata.
- **EAR0 – Ocean Sound Sharing Platform**
  A Chinese-language platform for sharing underwater sounds from public and community contributors.
- **SanctSound Web Portal (NOAA & ONMS)**
  A public access platform for standardized sound recordings from U.S. marine sanctuaries.
- **Freesound.org**
  A collaborative sound database licensed under Creative Commons, contributed by a global community.

- **Maritime.org – Historic Naval Sound Archive**
  Declassified U.S. Navy archival underwater sound recordings, provided for educational purposes.
- **Fish Ecology Sound Database (fishecology.org)**
  A specialized archive of fish sound recordings used in ecological studies.
- **FishSounds.net – Global Fish Bioacoustics Repository**
  An open-access database aggregating fish acoustic data from peer-reviewed research.
- **FishBase Sound Archive**
  Supplementary audio material from the FishBase global species database.
- **Sound in the Sea – Maritime.org**
  A historic U.S. Navy underwater sound reference collection curated for public listening.
- **WHOI Dolphin and Whale Recordings Archive**
  Bottlenose dolphin echolocation and whale vocalization recordings from WHOI.
- **Carolina Fishes Soniferous Database**
  A regional scientific archive of North American fish sounds.

All audio materials were used in accordance with their stated terms of use for educational or non-commercial purposes. Where necessary, only hyperlinks were provided rather than embedding raw audio files, to respect original platform guidelines.

B. Supplementary Links

- **Full link for Audio Example 1:** `https://drive.google.com/file/d/11HI-UTZm5iZTG-w_JJpnExws9GZdbLfr/view?usp=sharing`
- **Full link for Audio Example 2:** `https://drive.google.com/file/d/1wUj97ojsE-l32YEvDro38V5qhzGoQiF6/view?usp=drive_link`

- **Full link for Audio Example 3:** `https://drive.google.com/file/d/1R7FLFDuvZC1Cjyx6dnIhdHosrXurJKYr/view?usp=drive_link`