EcoTarium Explorer: Increasing Accessibility at the Worcester EcoTarium

A Major Qualifying Project Report
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Abstract

Today's technology provides a significant opportunity for those with accessibility needs to feel more connected to the world around them. Museums, zoos, and similar institutions have looked to mobile applications as a resource for guests with visual impairments. Our team of five WPI undergraduate students researched, designed, developed, and tested EcoTarium Explorer, an accessible mobile application for the Worcester EcoTarium. EcoTarium Explorer enhances the EcoTarium experience for all visitors and is an effective tool for guests with visual impairments.

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Conclusions	Owen McGinley, Dylan Phillips, Dylan Olmsted

Table of Contents

I. Introduction

Vision and hearing impairment can evoke the feeling of isolation, but many of those affected exhibit positive life philosophy, seeking ways to take control over their lives (Turunen-Taheri et al., 2023). As museums, zoos, and other exhibitory sites look for ways to innovate out of necessity for their shrinking customer base, mobile phones are becoming central to enhancing the exhibitory experience (Gilbert, 2016).

The EcoTarium is a science and nature museum that values inclusion and strives to inspire a passion in science and nature in each and every guest. Our team was tasked with creating a mobile application to enhance the experience for all museum guests, with an emphasis on accessibility and guests with visual impairments. The application will serve as a tool to guide visitors in walking around the many outdoor paths at the EcoTarium, and will provide additional information as users approach each exhibit.

The original goal of the mobile app, EcoTarium Explorer, was to make exhibits accessible to those with visual impairments through clear auditory descriptions. Additionally, we aimed to create a useful and intuitive tool for all visitors, regardless of accessibility needs. We have designed and developed a platform that is not only accessible to all but is also engaging, fostering each user's connection to the EcoTarium.

1.1 Sponsor Goal and Specifications

The EcoTarium asked for WPI's help in the design and development of a mobile application for iOS and Android devices. The EcoTarium communicated specifications for an application that aligns with the values of the EcoTarium and increases accessibility for guests with visual impairments. Through communicating and revisiting these specifications with our

sponsor, we concluded that an interactive map that can identify the rough location of the user and

load content based on nearby exhibits is a critical feature. The app also includes a gallery page

that presents information about various exhibits in an informative and user-friendly way. As

suggested by our sponsor, the app implements the Omeka S content management system,

allowing for easy upkeep as exhibits change (further reading in 4.2.1 Omeka Content

Management System).

II. Background

The research conducted by the 2022-23 Worcester Art Museum (WAM) Major Qualifying Project (MQP) team of WPI students inspired much of our work. To complement their research in visually accessible user interface design, and to align with the new sponsors from the EcoTarium, we conducted supplemental background research to gain a thorough understanding of the Worcester EcoTarium, additional mobile app accessibility considerations, and effective exhibit wayfinding experiences.

2.1 The Worcester EcoTarium

The EcoTarium is a science and nature museum that immerses visitors in a world of interactive exhibits designed to facilitate the exploration of the natural and physical sciences. The museum sits on a 45-acre property in Worcester, Massachusetts, and features both indoor and outdoor exhibits. Inside the museum's main building, visitors can experience hands-on science demonstrations, learn about weather and ecosystems, and see a variety of small live animals. Those who venture outside will encounter exhibits sprawling the museum grounds, connected by a network of paths. The outdoor exhibits include several habitats for larger animals, including otters, birds of prey, and even two mountain lions. Walking around the outside grounds is reminiscent of exploring a small zoo.

The mission of the EcoTarium is to inspire a passion for science and nature (*About Us | EcoTarium*, 2018). Their values are displayed in Figure 2.1, presented with the clever "ECOTARIUM" acronym. In short, their values emphasize inclusivity, teaching, the importance of protecting nature and wildlife, which tie together in an exciting exhibitory experience.
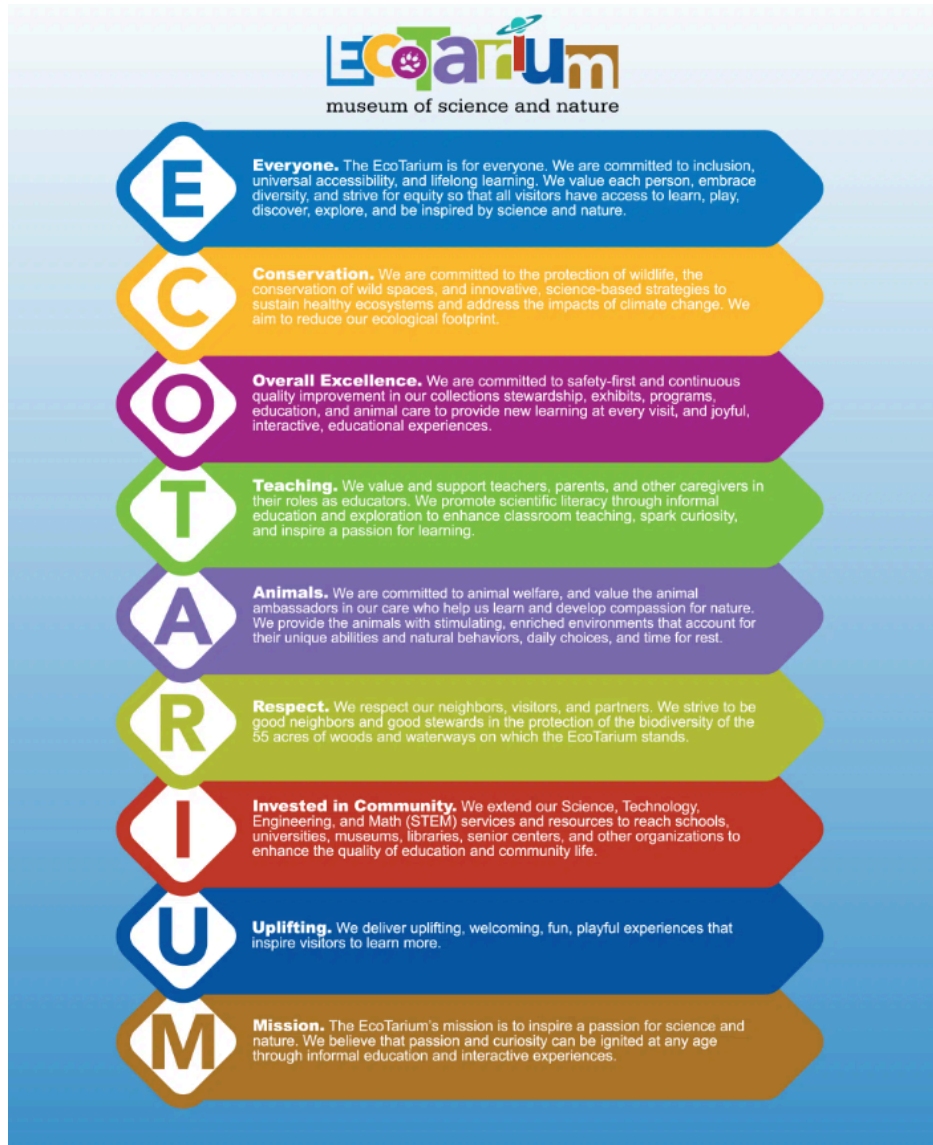
Figure 2.1: The EcoTarium's values emphasize fun, environmentalism, and education.

Drawing from their values, the EcoTarium's most recent strategic action plan details advancement of their institution, community, resources, and infrastructure. Most notably for this project, their objectives include: enhancing guest amenities and experiences, increasing accessibility and diversity, and inspiring deeper engagement with science and nature (*About Us | EcoTarium*, 2018).

2.2 Accessible Human-Computer Interaction

One of the EcoTarium's purposes is to provide an accessible experience for all guests. At the time of this project, navigation around exhibits is challenging for visitors with low vision, for the following reasons: (1) navigation relies entirely on reading signs, and (2) paths between exhibits have varying levels of terrain difficulty. For the entirety of our app development, we will consider visually impaired persons and their needs for navigation assistance. We will be following the Web Content Accessibility Guidelines (WCAG) 2.0 (n.d.) while designing our user interface (UI) and user experience (UX). Additionally, last year's Worcester Art Museum MQP team contributed significant research involving accessible UI/UX design (Zeolla & Vila, 2023).

2.2.1 Visually Impaired Persons

Low Vision and Blindness

Visual impairment and blindness come in several forms, including partially sighted, low vision, legally blind, and totally blind. Blind persons are completely unable to see, usually due to disease, injury, or genetic condition (Zeolla & Vila, 2023). Those who are visually impaired but not completely blind have had their vision gradually worsen to a point that it cannot be fully corrected with glasses, contact lenses, or medical treatments. Visual impairment can result from various underlying conditions, such as macular degeneration, diabetic retinopathy, glaucoma, or congenital eye conditions. Individuals with low vision often experience difficulties with tasks that require clear and detailed vision, such as reading small print, recognizing faces, or navigating unfamiliar environments (Kurniawan, 2017).

Print Impairment

A print impaired person experiences difficulties reading printed material. This can be due to learning disabilities like dyslexia or ADHD, which impact their understanding of printed text. Dexterity problems, such as Parkinson's disease or arthritis, can make it difficult to hold a phone and read printed material. Printed material can also be difficult for those with cognitive impairments such as dementia (Zeolla & Vila, 2023).

Color Blindness

Color blindness, similar to visual impairment, comes in different forms. As seen in Figure 2.2 below, we will consider four types of color blindness.
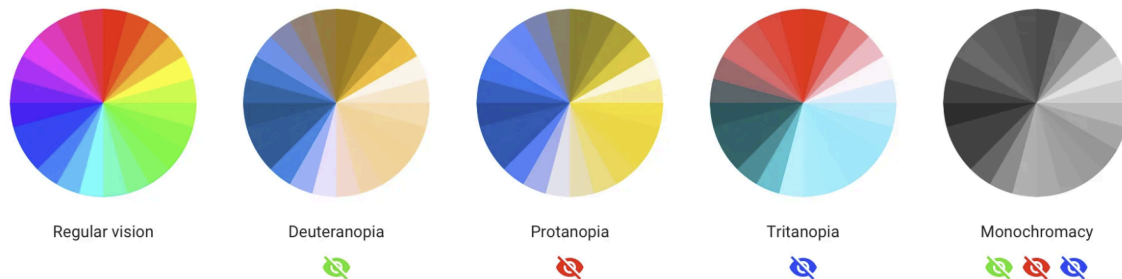
Figure 2.2 Types of Color Blindness (Tuchkov, 2019)

2.2.2 Mobile Application Features for Exhibit Accessibility

Creating an application designed to cater to the needs of those with blindness, low vision, print impairment, or color blindness demands the implementation of specific accessibility features. At the end of Section 2.2, Table 2.1 provides an organized summary of researched accessibility features.

App Navigation

Certain app development guidelines must be followed to make an app accessible for visually impaired persons. Screen readers are a tool that help Visually Impaired Persons (VIPs) understand the layout of the app through audio rather than visually. There are a few things to consider with screen readers, 1) the audio should not be interrupted by any other sounds coming from the app, 2) the descriptors of each element should be short and precise. Each element and image in an application has an alternative text that can be read with text-to-speech to describe what is presented by that element. Alternate texts for images should be as descriptive as possible in less than 125 characters. The alternative text will be read as the audio descriptor for an image, so it must include keywords of the focus of the image and must be written as a phrase that can easily be understood (*Accessibility – Material Design 3*, n.d.).

For those with low vision or print impairment, following along and reading printed material within an application can be difficult. To help with text legibility, options for larger font sizes and styles allow the user to read text presented in a more comfortable way. An example of a tool that helps users with ADHD and dyslexia focus while reading is Focus Ex. This browser extension offers a special font designed with letters proportioned specifically for readability purposes (*Focus Ex - Browser Extension*, n.d.).

In building an experience for blind individuals, application design must be creative, relying on voice, touch, and vibrations rather than visuals alone (Ghidini et al., 2016). Controlling the app using voice commands is a great alternative to touch navigation so long as there is a convenient way to initiate audio input. Audio command input will work together with the screen reader. The screen reader gives VIPs a sense of available app components, and voice

command allows them to interact with those components. Additional available inputs like gestures—e.g., shaking the phone—gives a VIP a consistent way to navigate (Chen et al., 2015).

Another recommendation for easy navigation is to simplify page hierarchy by limiting navigation depth from the landing page. Keeping everything within a few button presses will keep VIPs from getting lost navigating around the app and will simplify the experience for all users (*Accessibility – Material Design 3*, n.d.).

Physical Navigation

Moving around a new physical space can be challenging for VIPs. Providing audio directions around museum grounds between different exhibits offers a non-visual navigation experience to accommodate those who cannot see maps and signage. When creating a museum navigation system for VIPs, it is important to give the user a sense of freedom of discovery around the grounds, similar to the way a sighted museum guest may choose to meander around to anything that catches their attention. The app should provide guidance while letting each visitor customize their tour and experience based on their needs (Gonzalez, 2017).

Content Presentation

The Andy Warhol Museum in Pittsburgh, Pennsylvania does a great job at creating accessible experiences via engaging audio descriptions of their various exhibits. They have a great understanding of what makes a helpful and engaging audio clip. Finding a good balance between descriptiveness and keeping the listener engaged is essential. The Andy Warhol Museum presents audio clips ranging between 30 and 60 seconds in duration that prioritize content analysis after a short description. Visitors also prefer human voices reading the content rather than a robotic or automated voice. Human voices add a personal touch to the user experience, and a variety of human voices can keep visitors engaged. (Gonzalez, 2017)

Accessible Color

A well-designed color scheme—especially in an accessibility application—is critical to defining the user experience. When adding color, it is important to think about how a low vision or a colorblind person will interpret it.

For those with low vision, distinguishing between low contrast colors is difficult in imperfect lighting conditions. This applies to both icons and text. Making elements with high contrasting colors will help low vision users, and making text contrast to the background color helps both low vision and print impaired persons (*Accessibility – Material Design 3*, n.d.). In addition to generally using contrasting colors, implementing a high contrast mode can help users who particularly struggle with contrast issues.

The previous Worcester Art Museum MQP team conducted research on the best color combinations to be used in an app to give full accessibility in terms of colors (Zeolla & Vila, 2023). Below are the five color pairs their team provided as options for the color scheme.
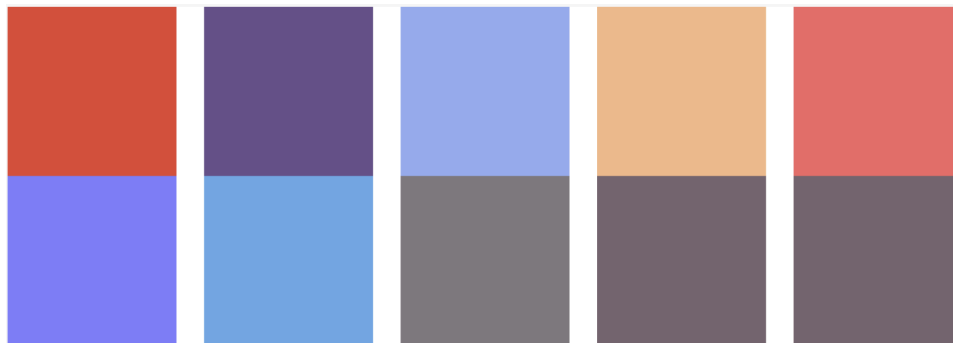
Figure 2.3 Accessible Color Schemes (Zeolla & Vila, 2023)

Besides having accessible color schemes, it is still important not to solely use color for indicators around the app. For example, green and red typically indicate yes and no within UI design, however, red-green color-blindness—caused by deuteranopia—makes it difficult to

14

differentiate those colors. Including icons or patterns to places where color is used as an indicator gives another layer that presents information with or without the color (Tuchkov, 2019).

Table 2.1: Recommended Accessibility Features

Feature	Examples & Sources	Description
Voice Assistant	Siri for iOS (*Siri*, n.d.) Google Assistant (*Google Assistant on Your Phone*, n.d.)	Interactive dialogue between user and their software environment, so user can perform actions, access information, or navigate through the app with voice commands
Simplified Layouts	WAM App Layout (Zeolla & Vila, 2023) Material Design (*Material Design*, n.d.)	Use fewer menus to navigate the app
Screen Reader	VoiceOver for iOS (*Hear iPhone Speak the Screen, Selected Text, and Typing Feedback*, n.d.) TalkBack for Android (*Get Started on Android with TalkBack - Android Accessibility Help*, n.d.)	Tells you exactly what's happening in the app, i.e., auditory descriptions of elements
Alternative Text & Descriptions	Material Design (*Material Design*, n.d.)	Images and visual content include descriptive text which users can read or hear
Adjustable Font Size	iOS Adjustable Font Size (*Change the Font Size on Your iPhone, iPad, and iPod Touch*, n.d.)	Integrate phone's text configurations
Dynamic Text	Focus Ex - Browser Extension (*Focus Ex - Browser Extension*, n.d.)	Dynamically highlight or increase text size according to intended flow of information
Voice Guidance	Andy Warhol Museum (Gonzalez, 2017)	Audio descriptions for exhibits and wayfinding
High-Contrast Color Themes	WAM App Color Scheme (Zeolla & Vila, 2023)	Include settings for color customization with high-contrast options

2.3 Effective Wayfinding in Mobile Applications

A crucial application feature, identified in sponsor specifications, is being able to assist with navigation around the outside grounds of the EcoTarium. Effective wayfinding systems should always describe where the user is, where the user can go, and how the user can get there. Pan et al. (2015) have listed common problems found within current wayfinding systems: 1) unreasonable information density, 2) inconsistent information, 3) inanimate form, 4) neglect for people with disabilities. In developing an application wayfinding feature, it is good practice to actively seek solutions for these problems.

Unreasonable information density, where information is presented in a vague or cluttered fashion, can lead to user frustration or disruptions. Inconsistent information, often stemming from inadequate on-site testing, can result in conflicting signage and confusion. Inanimate forms, typically displayed as static signboards, lack variety and interactivity, missing opportunities for user engagement.

Evelity offers a good example of an effective wayfinding solution that aims to guide people with or without disabilities through complex everyday places (*Evelity Inclusive Wayfinding Application for All | Evelity.Com*, n.d.). One thing that sets Evelity apart from other wayfinding apps is its inclusion of those with all types of disabilities. Evelity includes great navigation features like step-by-step navigation, auto recalculation of routes, and a "Where am I?" button. These features adhere to the basic principles of all wayfinding apps. Evelity also includes route preferences, which is important in allowing visitors to feel they are creating their own experience while maintaining a successful wayfinding implementation. Mobile wayfinding application developers that seek to increase ease of use for all users should look to Evelity as a model.

III. Methodology

This section details the methodology we used to gather and implement specifications for EcoTarium Explorer. Topics covered under methodology include gathering and updating stakeholder requirements, project management strategies, methods for on-site testing, and methods for the key demographic user studies.

3.1 Gathering Stakeholder Requirements

To begin, we had to understand the specifications for the project, as defined by the stakeholders. In the case of this WPI MQP, the stakeholders included the project advisor and the project sponsor. Due to the innovative and student-driven nature of the project, our advisor and sponsor communicated that they expected the scope to change over the course of implementation. As such, it was important that we not only had a thorough planning stage to begin their project, in addition to regular meetings with all stakeholders to ensure development continued to align with project goals.

3.1.1 Initially Communicated Specifications

At the end of the 2022-23 school year, we attended an initial meeting with the project advisor, to familiarize themselves with the project. We were introduced to each other, as well as two of the members who were finishing up work for the 2022-23 WAM MQP (Zeolla & Vila, 2023). In the meeting, general initial ideas for an EcoTarium React Native mobile application were communicated. The original description of the project was outlined on WPI eProjects (CS Neamtu: Increasing Accessibility at the Worcester Ecotarium for People with Visual Impairments | WPI eProjects, n.d.), as written below.

The Ecotarium aims to empower visually impaired people to access all their exhibits. The goal of this MQP is to produce an application for all users, widely accessible to the public, using React Native. React Native allows for development on dual platforms, Android and iOS, allowing the app to reach a larger audience while also taking advantage of built-in accessibility features. The major features of the app include the ability to have the phone read out UI options present on the screen, read out audio files, use modified touch gestures to navigate the screen, the ability to customize the app color palette, and give the user the option to control the app with their voice. By providing supplemental information about the Ecotarium's exhibits through text and audio descriptions, the role of the application is to expand access to exhibits to people with visual impairments.

It is important to note that this initial vision for the project was adapted from the previous year's WAM MQP (Zeolla & Vila, 2023). After gathering an understanding for the project purpose, we independently spent the summer practicing React Native app development.

3.1.2 Weekly Meetings with Stakeholders

At the start of the 2023-24 academic year, we set up a weekly all-hands meeting with the 2023-24 WAM MQP team. Each meeting was attended by both MQP teams, the projects' faculty advisor, and representatives from the EcoTarium and WAM, who will continue to be referred to as the sponsors. These all-hands meetings proved to be helpful, as all involved parties could bounce creative ideas towards the shared goal of enriching the exhibit experience for visually impaired guests. It was made clear by all stakeholders that we had the opportunity to innovate as long as their work demonstrated an efficient use of the previous WAM team's research & development.

After the first all-hands meeting, we decided on the following schedule: we would attend the weekly all-hands meeting as well as a weekly "sponsor sync" meeting with just their sponsor. The all-hands meetings created a general update system to keep WPI teams and stakeholders up to date on high-level project progression. The sponsor sync meetings were useful for

communicating specifications unique to the EcoTarium. The frequency of these meetings allowed for a dynamic project in which specifications continued to develop alongside the app.

3.2 Project Management

To effectively manage app development, we used standard industry coding practices modified for the needs of our MQP. Our combination of Agile development using the Scrum methodology, Jira for tracking tickets, and weekly sprints resulted in our team being able to effectively coordinate and work together to build our app.

3.2.1 Agile Software Development Methodology

Initially conceptualized in the 1990s, the Agile methodology has grown into the industry standard it is now. The process helps minimize problems faced when using more traditional software development approaches. The methodology excels in team self-organization and allows teams to work together and delegate tasks efficiently (Ghimire & Charters, 2022). We used the Agile methodology and incorporated the scrum framework to structure our working periods called sprints. We conducted sprint planning before the beginning of every sprint to brainstorm next steps, represented by larger milestones called epics, to be further broken into smaller tasks. In addition to sprints, we incorporated daily check-ins called scrums which helped with tracking the development progress and kept us working together as a cohesive unit.

3.2.2 Jira

Of the plethora of project management software tools available, we decided to use Jira due to its emphasis on Agile principles. Jira allowed us to organize and break down our larger

milestones into smaller and less overwhelming goals called tickets. Additionally, team members had experience using Jira from software engineering classes and industry experience.

3.2.3 Sprints and Ceremonies

Our team operated using one-week sprints, compared to the two-week sprints which are usually found in the industry. Initially experimenting with two-week sprints, we decided that it would be beneficial to switch to one-week sprints and maintain a shorter feedback loop alongside the weekly all-hands meetings.

Operating closely with Scrum standard practices, we practiced daily standup, sprint planning and retrospective ceremonies throughout the project. Our standups occurred three to four times per week, usually in the evenings over Discord voice chat.

We scheduled Sprint Planning and Retrospectives directly after our weekly all-hands meetings. This way, feedback received from these meetings could be efficiently funneled into the next sprint. We held retrospectives every other week or when necessary. In retrospective meetings, we discussed points for self-improvement as a team to implement in future sprints.

We did not partake in backlog grooming ceremonies. We generally kept the backlog well groomed, and any new tickets were usually organized into appropriate sprints as they came up.

3.2.4 Sprint Stories

During our weekly sprint planning meetings, we assigned each imminent ticket a point value and a team member to lead the task. Point values represented the difficulty of a ticket and were agreed upon by team consensus. As a general rule, ticket values ranged from half a point to two points. Tickets that were valued at half a point were estimated to be accomplished in an hour or two, whereas tickets with value two held tasks that were estimated to take more than a day and

some collaboration to complete. Tasks with a point value of greater than two triggered a team discussion to further dissect the ticket into smaller subtasks. In assigning point values to each ticket, we ensured that the work remained balanced over team members and across sprints.

3.2.5 Sprint Flow Tracking

As seen in Figure 3.1, our Jira board was organized with different columns that helped us visualize tasks and the progress of each ticket throughout the sprint. The columns are organized as follows:

Table 3.1: Jira Board Ticket Status Options

Column (Ticket Status)	Description
To-Do	Tickets that have not been started
In-progress	Tickets that have been started
Blocked	Tickets with a prerequisite that has not been met
Code review	Tickets that are pending review from another member
Done	Completed tickets
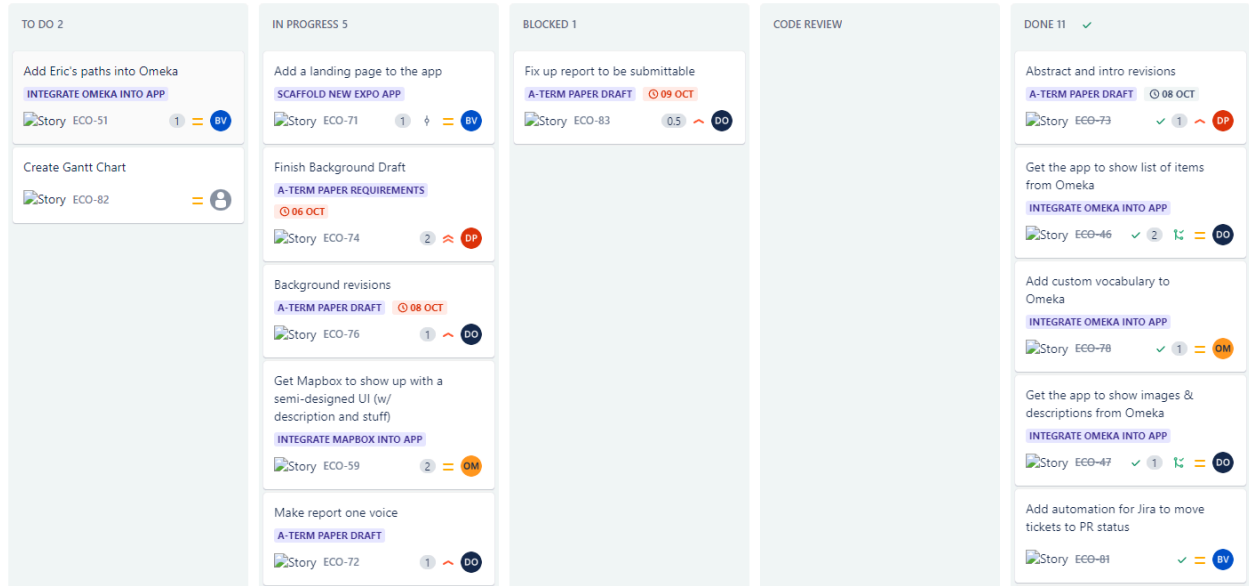
Figure 3.1: Sample Jira board visually organizing stories by their completion status

We tracked sprint progress using the reports generated by Jira. During sprints, we referenced the auto-generated burnup report to ensure work was getting done at a reasonable pace. At the end of each sprint, we retrospectively reviewed the sprint reports at a higher level, to ensure the greater project was on track and moving towards achieving goals we defined.
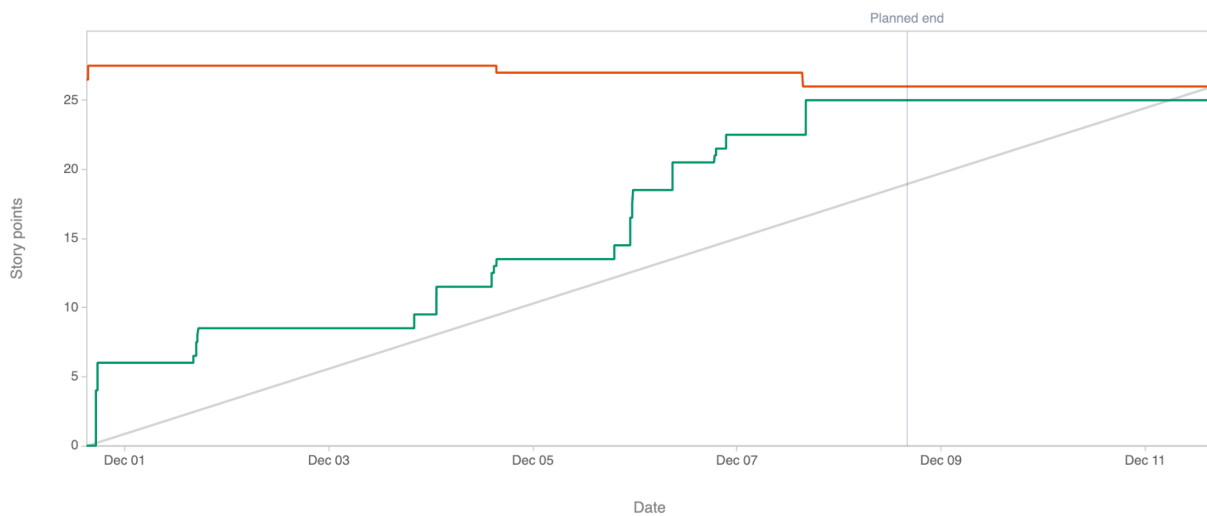
Figure 3.2: Sprint Burnup Report

In its early stages, planning major milestones for the entire project was not feasible, because we were still figuring out project specifications and priorities. The first seven weeks of the project were focused on background research and working with the EcoTarium to solidify app features. We added epics to our Jira board as our research or sponsor found them necessary. For the remainder of the project, our team planned each of our major milestones at the start of each seven-week academic term and wrote tickets working towards each milestone at the start of each sprint.
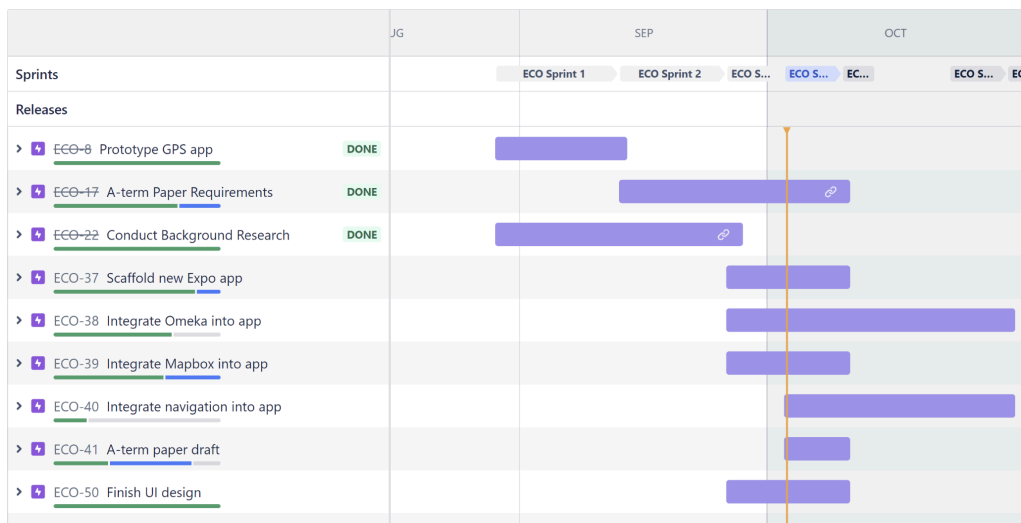
Figure 3.3: Jira Gantt Chart

3.2.6 GitHub for Version Control

In the context of app development, the effective use of a version control system is critical to the success of a team. We used GitHub to fulfill this role, due to our team's prior experience and its widespread use in industry-level software engineering projects. GitHub and other effective version control systems enable teams to manage and track changes to software code. Using GitHub, we maintained a detailed revision history, making it possible to trace and address any bugs that arose during the development process. Additionally, it empowered our team to

work collaboratively and simultaneously on each aspect of the app. Each team member could write code in their own development branch, allowing them to focus on specific tasks or test experimental features without interfering with the progress of others.

3.2.7 Pull Requests

Once a feature was programmed and ready to be added to the application, the developer opened a pull request. A pull request signifies that a feature is ready for review, after which it will be ready to be pulled into the main development branch. Development branches were named after their Jira ticket for organization and automation purposes. Jira has GitHub integration, which we used to automate ticket status progression. Table 3.2 shows the automations that we set up.

Table 3.2: Jira Ticket Automation

Action	Automation
Branch Creation	To-do → In progress
Pull request created	In progress → Code review
Branch merged into main	Code review → Done

3.2.8 Code Reviews

To ensure the quality of the codebase, at least one team member conducted a code review after a feature development branch was deemed ready for merging into the main development branch. Consistent code reviews guaranteed that the main development branch maintained the latest functional version of our app. Once approved, a branch's commits were squashed into one

then all the changes were pushed onto the main development branch. If a reviewer found a bug or poor quality of code, they requested changes. This system helped keep bugs from reaching the main development branch.

3.3 On-Site Testing

One of the crucial specifications for EcoTarium Explorer is effective navigation between outdoor exhibits. Navigation between indoor exhibits is not being covered in this MQP, but a framework for expanding scope into indoor navigation has been considered throughout the design process. Our initial idea was to use global positioning system (GPS) technology to pinpoint the user's location and provide directions to exhibit locations around the map. Using beacons for outdoor navigation was considered, but ultimately dropped due to the simplicity and low cost of GPS implementation.

3.3.1 Prototyping GPS

To further research GPS as a mechanism for wayfinding, we developed a prototype app to see if GPS signals would be sufficiently accurate at the EcoTarium. The prototype app was developed using Expo and React Native. It printed the user's current latitude and longitude, along with the reported accuracy of the GPS signal. The prototype app was loaded with a list of significant locations around the EcoTarium campus, referred to as waypoints, such as Siegfried Statue and the Sundial Plaza. On user input, the app calculated the five nearest waypoints to the user 'as the crow flies.'

Latitude: 42.2638435
Longitude: -71.7673234
Accuracy: 3.92 meters

UPDATE POSITION

Owls - 18 ft away
Eagles - 39 ft away
Entrance Path - 42 ft away
Norton Observatory - 93 ft away
Pond Meadow Path - 139 ft away

Figure 3.4: Screenshot from the prototype app

When we tested the app on the grounds of the EcoTarium, GPS accuracy as reported by the device was approximately four meters in most cases, with an accuracy loss of between one and two meters in wooded and covered areas. The app was able to pinpoint the closest waypoints to the user's location with roughly 10 to 20 feet of accuracy. Figure 3.4 shows a screenshot taken when we were near the Owls exhibit. It shows that the Owls exhibit was closest at 18 feet away and the nearby Eagles exhibit was 39 feet away, with a reported GPS accuracy of 3.92 meters. This was consistent with our observations throughout our site walkthrough.

After our site walkthrough, we presented our findings to our sponsor. They agreed that GPS would be a cost-effective and easy-to-implement solution for wayfinding around the EcoTarium. Thus, we settled on using GPS as our wayfinding method.

IV. Implementation

This section details the structure, content, and features of EcoTarium Explorer as it stands at the completion of this project (March 1, 2024). The implementation is subject to change as further development teams or the EcoTarium see fit.

4.1 App Structure

To establish the foundation for the app's codebase, we adhered to the original project description and used a React Native development environment. For dynamic content management, EcoTarium Explorer pulls media and other exhibit data from the Omeka Content Management System. We use Mapbox to load a map and power the wayfinding experience. The following sections detail how each of those technologies were implemented.

4.1.1 Execution: React Native & Expo

EcoTarium Explorer was developed in React Native and used Expo to ease deployment on iOS and Android. React Native is described as a framework that allows developers to use the React front-end library to build apps on iOS, Android, and additional platforms (*React Native · Learn Once, Write Anywhere*, n.d.). A major attraction of React Native for developers is that one codebase yields a functional app on multiple platforms. We additionally used Expo in our app, which is a collection of developer tools that sits on top of React Native and allows for easier development and deployment (*Expo*, n.d.).

Using just React Native (without Expo) would have opened up possibilities of using native Software Development Kits (SDKs) in the app. We ultimately did not choose this path due to the higher overhead associated with deploying our app to the App Store and Play Store.

4.1.2 Map Provider

The map page in EcoTarium Explorer displays a map that shows users important waypoints and is the basis of outdoor navigation around the EcoTarium campus. As such, we put a large emphasis on selecting the correct mapping provider for the EcoTarium's needs.

A number of mapping providers provide SDKs for integration into apps. After researching feasible options, we decided that using Mapbox was the best choice for our needs. Mapbox provides a set of Application Programming Interfaces (APIs) and SDKs to integrate their maps into applications. Mapbox has libraries for React Native available to further speed up development (*Mapbox | Maps, Navigation, Search, and Data*, n.d.). By using Mapbox, we avoided incorporating native code into our app or finding another solution that would result in significant development overhead.

Lastly, we found that Mapbox largely relies on OpenStreetMap (OSM) for mapping data. OSM is an open-source map editable by anyone online and forms the basis of numerous mapping services online (*OpenStreetMap*, n.d.). The EcoTarium already had data in OSM created by editors, which in turn made it available in Mapbox for our use. Nonetheless, we asked our sponsor to edit OSM so that the app could load precise path locations. This ensured that location information was as accurate as possible for navigating around the EcoTarium campus.

4.2 Content Management

Content in EcoTarium Explorer includes exhibit waypoint descriptions, locations, audio files, and images. All content is easily editable by the app manager, which is critical for a museum with dynamic exhibits.

4.2.1 Omeka Content Management System

In early communications, our sponsor suggested that we investigate Omeka S for content management. Omeka S is self-described as a "next-generation web publishing platform for institutions interested in connecting digital cultural heritage collections with other resources online" (*Omeka S*, n.d.). Omeka is a Content Management System for museums and institutions to catalog and digitize their exhibits.

The EcoTarium was already interested in using Omeka for cataloging their own exhibits. Alongside the development of the app, the EcoTarium was incentivized to create and populate an Omeka database to store exhibit information. EcoTarium Explorer pulls information directly from Omeka, enabling the EcoTarium to control the content of the app without needing our intervention to push updates onto the App Store or Play Store.

Through researching Omeka, we discovered that Omeka has a built-in API for querying content hosted in Omeka. The Omeka API returns details about each exhibit, including links for media (images, audio, etc), name, location, description, and any other fields that the content manager chooses to populate with data. Omeka's API uses a concept known as JSON Linked Data, where links are provided within API calls to make further recursive calls to retrieve additional data about specific exhibits, media types, etc. EcoTarium Explorer uses these API calls to programmatically render content within the app.

4.2.2 Exhibit Content

Exhibit data includes a combination of images, audio files, text descriptions, location data, and custom parameters that determine the way content is displayed in EcoTarium Explorer. For example, one custom parameter takes in a boolean value that determines if an exhibit will be

featured on the home page in the "featured exhibits" section. Another custom parameter determines the type of icon the exhibit will be represented by. Proper use of all custom parameters and instructions for managing the app effectively were documented and shared with the EcoTarium.

4.3 App Map Diagram

A typical start to user experience design in mobile app development is to create an app map which details the app hierarchy. Our design process did not start with creating an app map, but we created one during development to document the relationships between each page and feature. The app map is displayed below in Figure 4.1.
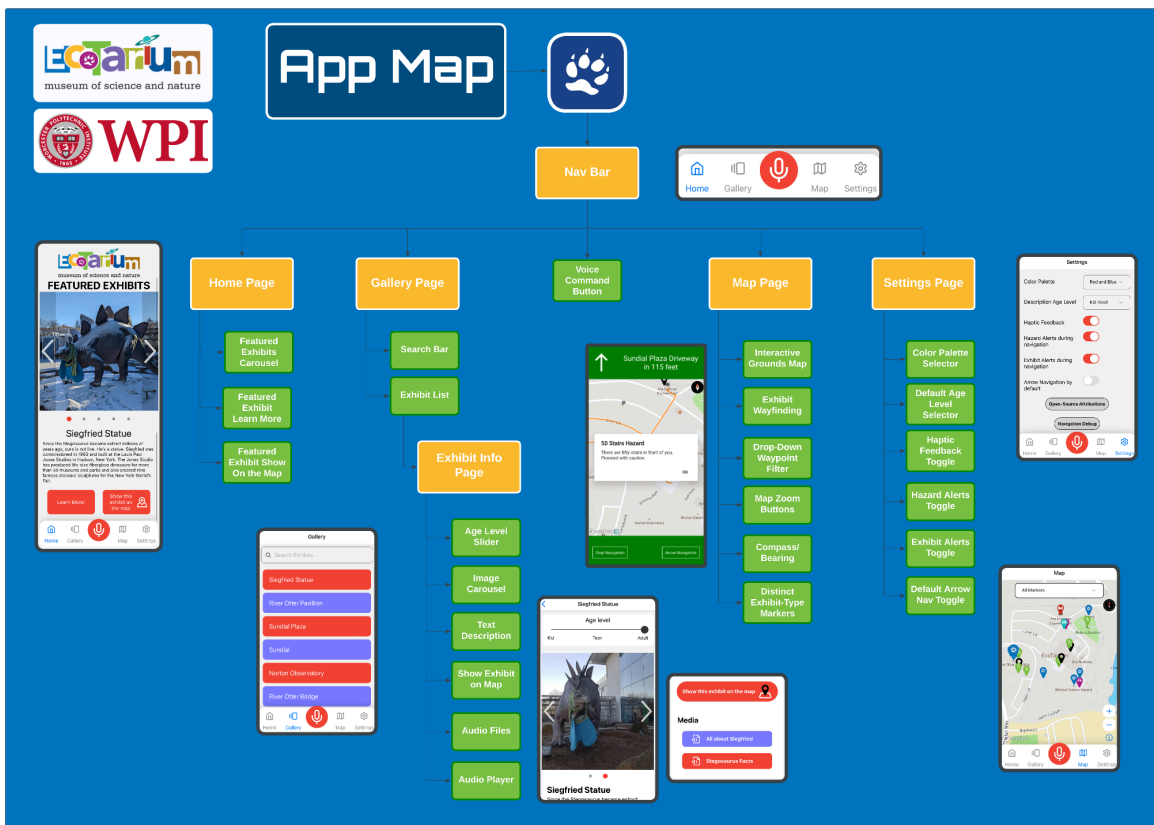

Figure 4.1: The EcoTarium app has simple navigation across its many unique features

The app map is organized hierarchically, starting from the top-most component—the navigation bar—and moving down through each page and feature. While our development ideally would have followed after the creation of the app map, we find that this structure displays proper organization of pages and features. As development continued, this app map was not maintained, and is therefore missing a couple details, including Low Vision Mode and the refactors made to the Gallery page.

4.4 User Interface Design

Thoughtful UI design is critical to making an accessibility-focused app. We created UI mockups that were stylized to the EcoTarium and followed researched accessibility guidelines. We planned the user interface with two low-fidelity wireframe storyboards—one hand-drawn and one digital. From the wireframe mockups, we generated a high-fidelity UI on Figma that we sought to replicate in the app.

4.4.1 Low-Fidelity Wireframes

We began the UI design process by brainstorming ideas on a whiteboard to get a list of pages and components we might implement in EcoTarium Explorer. We sketched basic renditions of the map page, and jotted notes about interfacing on each page. This process kicked off the design process and helped generate ideas for user-friendly features (Appendix A.1).

Our first digital design was created in Lucid Charts (*Lucidchart*, n.d.) to create a storyboard for the user navigation path through the application. Starting at the home page, the storyboard links to other functionalities and pages, including an interactive site map, a guided tour, and a settings page (Appendix A.2).

4.4.2 High-Fidelity Wireframes

Our final rendition of our UI design was created using Figma, a UI design application that we used to create a high-fidelity prototype to serve as a template during development (*Figma*, n.d.). In our final design, we created a landing page, a map page along with mockups of a location node selection and an active path navigation, pages that will include information about all exhibits, and a settings page. To navigate between these pages, we designed a persistent navigation menu located at the bottom of each screen which switches between different sections of the app. The menu also includes a voice control button to allow for low-vision navigation around the app. Below are some examples of different pages designed using Figma.
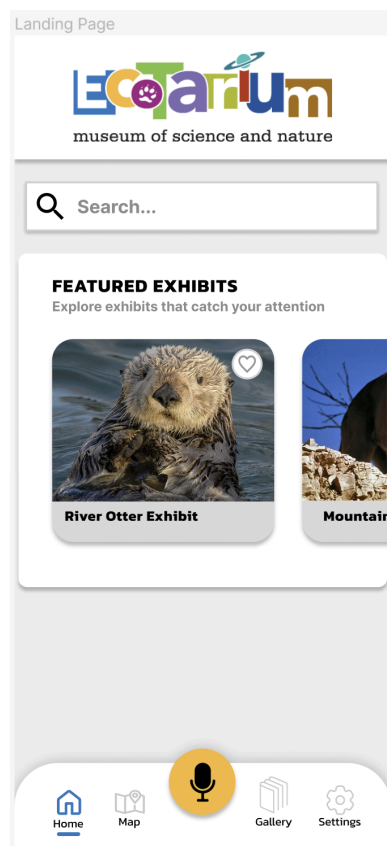
Figure 4.2: Original home page design includes featured exhibits, search bar, and nav bar
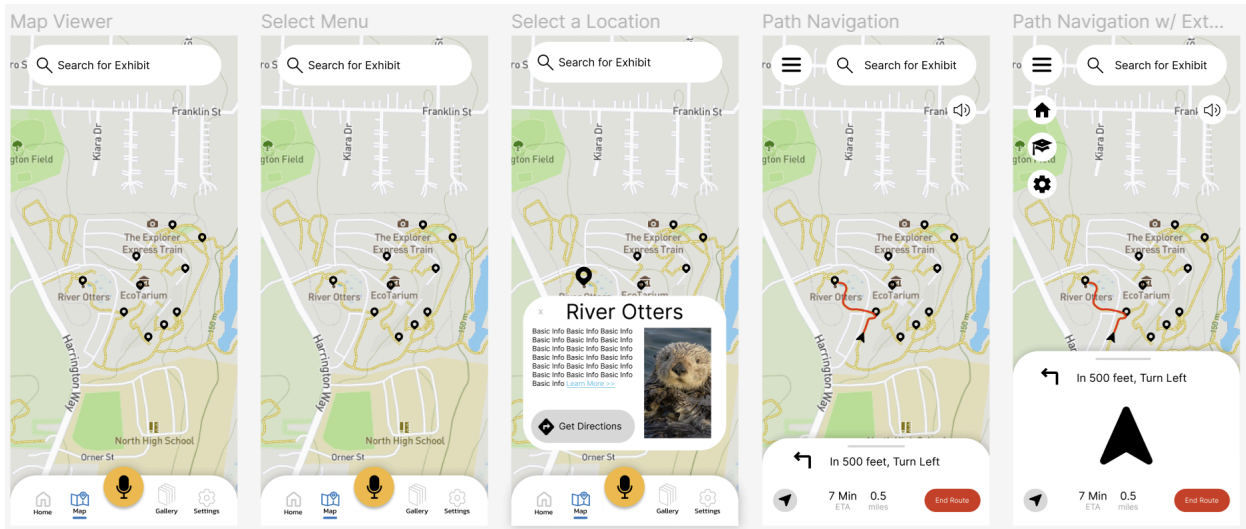
Figure 4.3: Original map page design includes map with exhibits, and demonstrates planned

strategies for on-site exhibit wayfinding
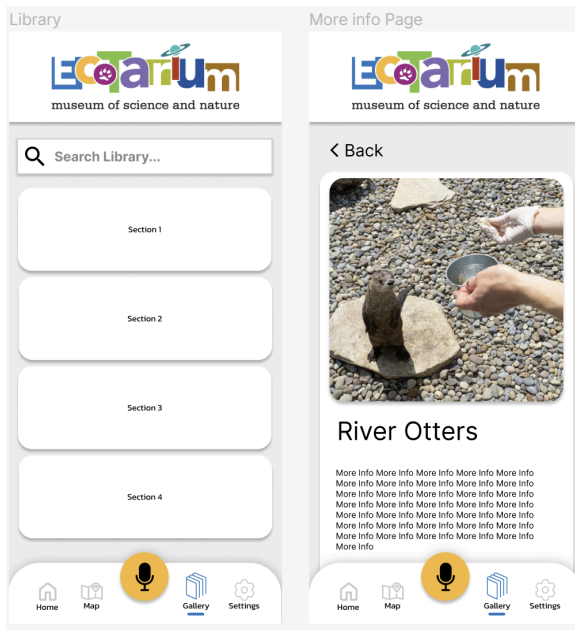
Figure 4.4: Original gallery view mockup displays large buttons for exhibits and a search

bar; individual item screen displays exhibit image, header, and description
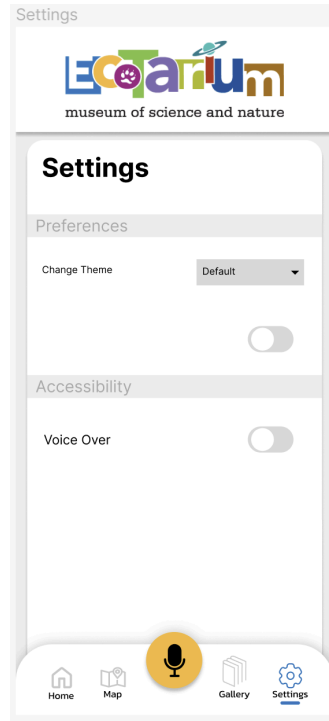
Figure 4.5: Original settings page mockup allows for adjusting accessibility options

4.4.3 Color Schemes

We prioritized effective app structure and page layout over color schemes in initial

designs, hence the mostly white and gray examples above. The colorless templates allowed us to

experiment with various color schemes before finalization. It is important to design layouts that

look professional and appealing alongside a range of color schemes, to account for

color-blindness settings and EcoTarium preferences. Figure 4.6 shows the initial landing page

mockup colored with the colors from the color palettes found in Section 2.2.3.
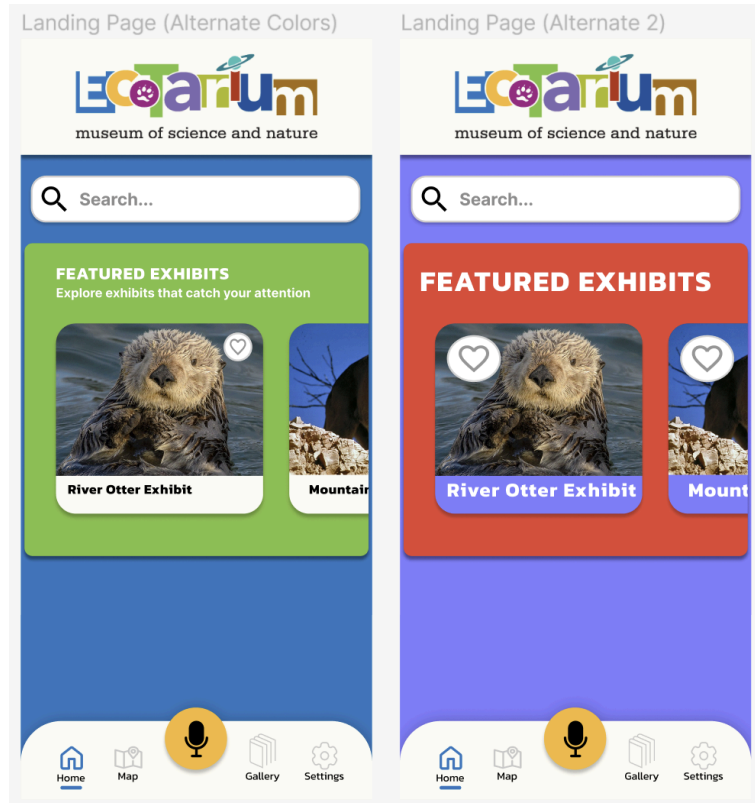
Figure 4.6: Alternate Color Schemes

4.4.4 Interactive Figma Mockups

Throughout the implementation process, the app's user interface naturally shifted away from our first iteration high-fidelity wireframes. When it came time to demonstrate our ideas for Low Vision Mode (LVM), we agreed that we should take the opportunity to not only create interactive mockups for LVM, but also for Standard Mode. The detailed views of each interactive page we designed are found in Appendix A.3.

Low-Vision Mode

The first important aspect of LVM we had to model was the simplified landing page. In response to feedback from our first key demographic user study (Section 6.1), we wanted the

gallery to act as the new landing page, so that users could access information in fewer button presses. Figure 4.7 shows mockups for the LVM gallery/landing page.
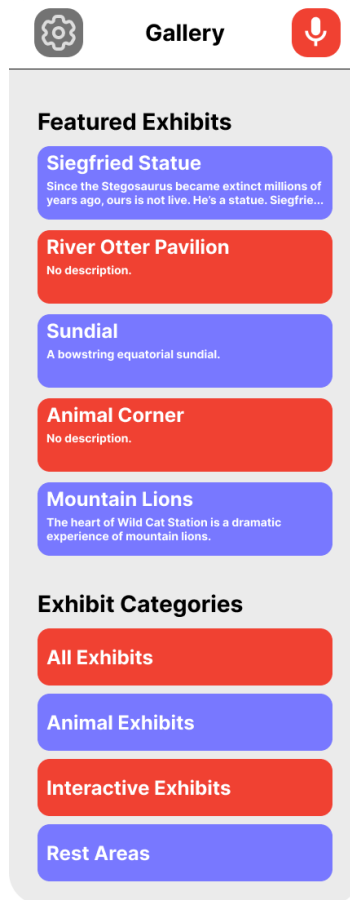
Figure 4.7: LVM landing page has a simple design with only labels and buttons

The LVM gallery page layout was designed entirely for screen readers. The order of components, as well as the information they carried was built based on feedback from participants in our low vision user study. Their feedback suggested that navigation buttons should be kept at the top of the page for quick access (e.g., settings and voice assistant). They also suggested that components be kept as simple as possible.

Next, we designed the look of individual exhibit pages. Our main feedback for exhibit pages was that there was too much information. The age-level slider and image carousels were hard to navigate with the screen reader. Figure 4.8 shows a mockup example for an individual exhibit page to remedy those issues.
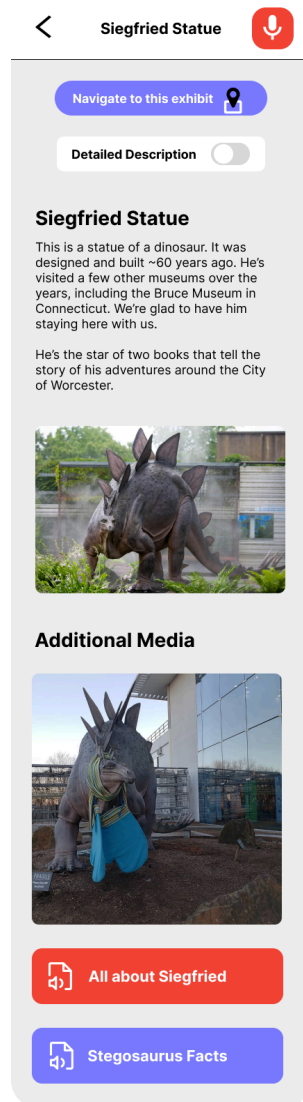
Figure 4.8: LVM exhibit page displays prioritized, sequential information.

Note: images were ultimately removed from the LVM exhibit page.

Similar to the landing page, the order of items and purpose of each button is carefully thought-out. Every section is clearly labeled, and GPS navigation, a primary function, is before content. The "Detailed Description" button was a new idea in place of the age-level slider. See Appendix A.3.2 for a closer look at the effect of toggling the detailed description button. In this design, there is no image carousel as elements are laid out one-at-a-time. Ultimately, images were entirely removed from the LVM exhibit page. This change was not reflected in the interactive Figma mockups, as it was a decision made towards the end of development. Additional media is kept at the bottom, where the user can access audio files.

For LVM, we also removed all modal pop-up boxes. That meant we needed to find a different way to interact with Voice Assistant since it previously would create a pop-up. To address this, we designed a new Voice Assistant Page, displayed in Figure 4.9.
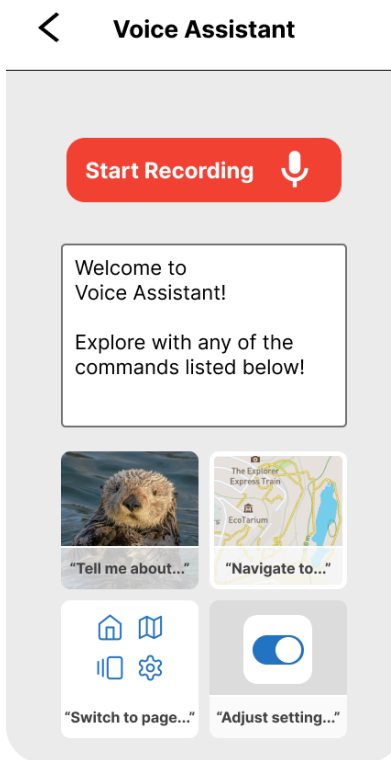
Figure 4.9: Voice assistant page interactive Figma mockup

With the previous design, users had trouble both finding the voice assistant button and figuring out how to use it. The goal of this design was to solve both of those problems by again prioritizing order of elements, simplifying the layout, and making thoughtful components.

Other Interactive Figma Mockups

Following the effort to create interactive mockups for LVM, we decided to create detailed mockups for any new pages we added to Standard Mode. The new features we added to Standard Mode which we created interactive designs for were the Onboarding screen and Map Help page.

The Onboarding screen was designed to be the first thing new users saw when they opened the app for the first time. It explains to them the purpose of the app (enhancing the EcoTarium experience for all visitors), explains the enhanced accessibility features that LVM offers, and prompts the user to select whether or not they would like to experience the app in LVM. Figure 4.10 contains the Onboarding Screen sequence.
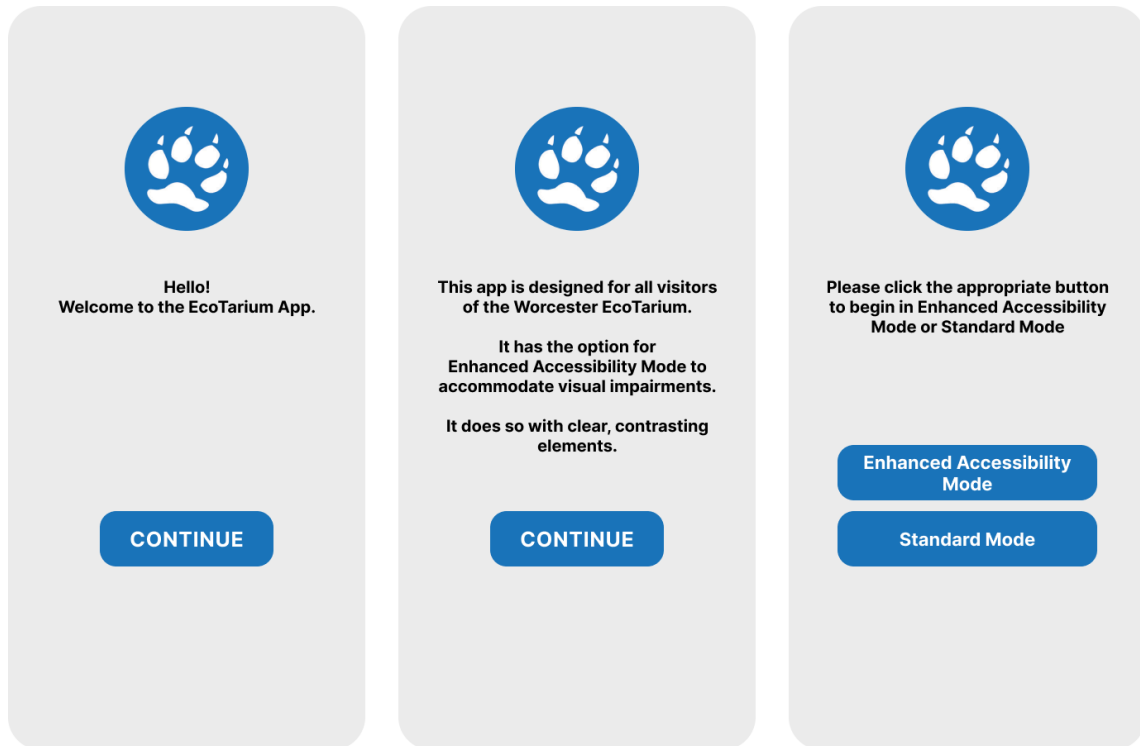
Figure 4.10: Onboarding screen prompts user to start app in LVM or Standard Mode.

Note: "Enhanced Accessibility Mode" was later renamed "Low Vision Mode"

Our goal when making this design was not only to provide information in a clear, readable manner, but also to put effort into the friendliness of the user experience. The EcoTarium paw at the top of the screen acts as the user's guide through the questions, and remains constant as the user navigates from page to page. The color palette and all design choices are kept simple to be conscientious of visually impaired users who intend on selecting LVM. Finally, on the right-most page, users are taken to the home page of whichever version of the app they select: Low Vision Mode (previously called Enhanced Accessibility Mode) or Standard Mode.

Our final interactive Figma mockup was made for the Map Help Page. The Map Help Page was a concept devised to help users of all visual capabilities; it was made to help

understand the Map Screen, which has a lot of information to unpack. Figure 4.11 displays our

design for the Map Help Page, side-by-side with the Map Screen.
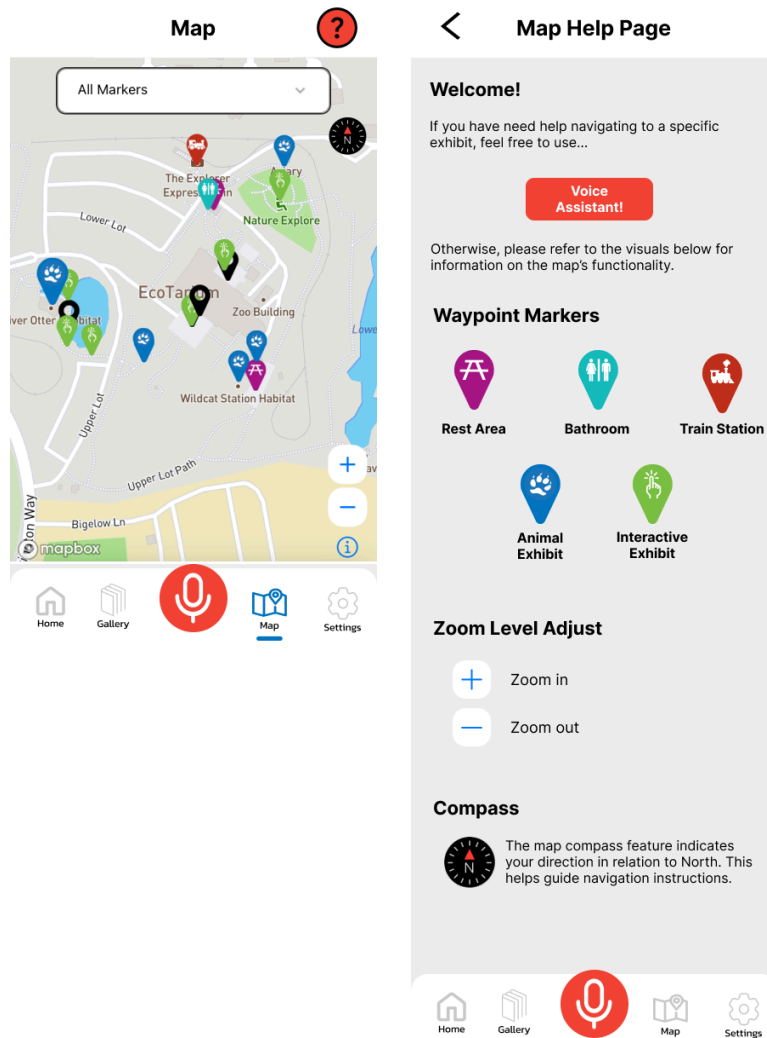
Figure 4.11: Map Help Page clarifies unique buttons and markers on the Map Screen

4.5 Implemented Features

Throughout the development journey, we have implemented features to improve the

outdoor wayfinding and exhibit experience for all visitors at the EcoTarium. These features

include a homepage that displays featured exhibits curated by the EcoTarium staff, a gallery page

that shows a list of exhibits and information about them, a dynamic map showing the EcoTarium grounds, and a settings page to customize the app experience. We also implemented a Voice Assistant feature that gives users the option to control the app by speaking into the microphone. This section details the major features of EcoTarium Explorer, version 1.1.0 (March 1, 2024).

4.5.1 Navigation Bar

The app experience largely revolves around the bottom navigation bar. The purpose of the navigation bar is to ensure users can easily navigate between different parts of the app as they see fit.

The navigation bar can be used to access four pages - the Home page, the Gallery page, the Map page, and the Settings page. The button for each page is clearly labeled with an icon and text. Additionally, the navigation bar is centered around a microphone icon to interact with the Voice Assistant feature, which will be explained in-depth in the next section.

During the implementation process, we ensured that the navigation bar adapts to various screen sizes across a variety of devices. Figures 4.12 and 4.13 demonstrate how the navigation bar scales across screen sizes.
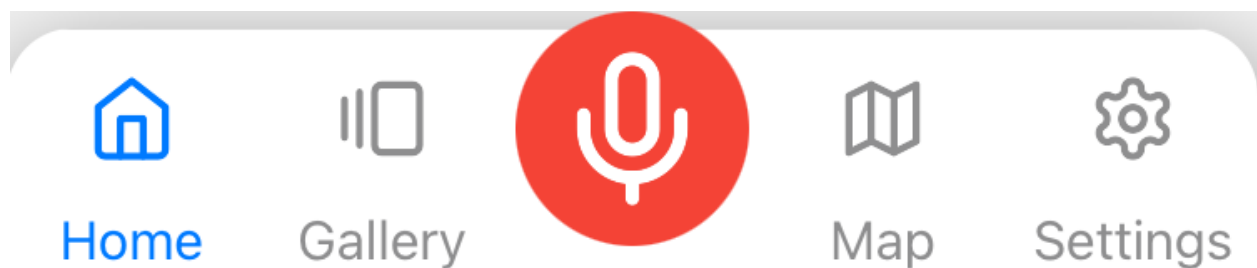
Figure 4.12: The navigation bar on a smaller phone, the iPhone SE

Figure 4.13: The navigation bar on a larger phone, the iPhone 15 Pro Max

Voice Assistant

Brightly colored in the center of the navigation bar sits the Voice Assistant button. The button is circular and labeled with a microphone icon to distinguish it from the other buttons on the navigation bar. Users can use this button to access any page on the app or to start wayfinding to any location on the map. Upon pressing the button, the user is redirected to the voice assistant screen, shown in Figure 4.14. A button to start listening for a command is located at the top of the screen. As the user speaks, the screen displays the speech-to-text data as the microphone picks it up. Once the user stops talking, or presses the voice command button again, the app stops using the microphone. If it recognizes an action, it will navigate to the correct page. No speech data is stored by the app.
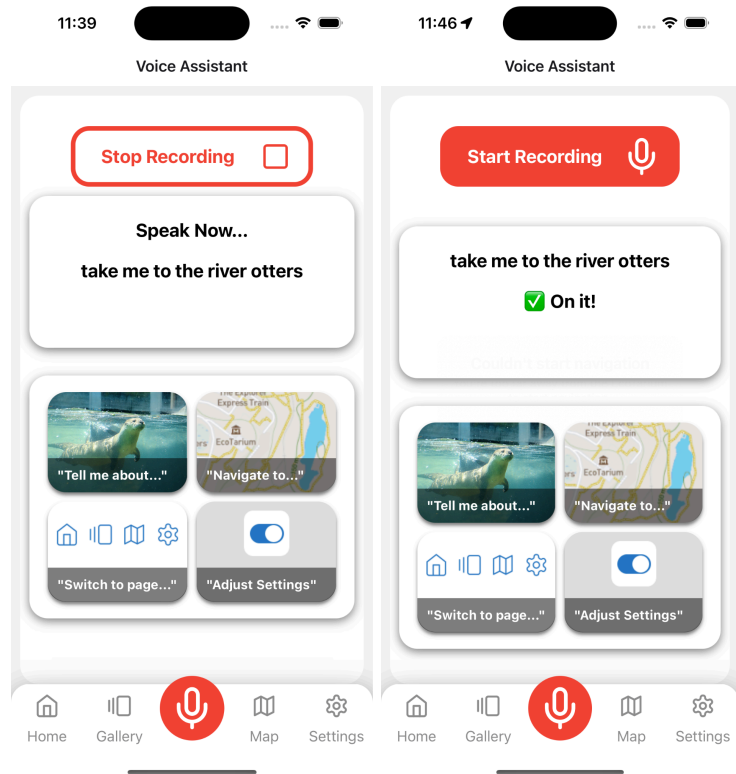
Figures 4.14 (left) and 4.15 (right): Voice Assistant screen with examples of commands.

Figure 4.15 shows the screen after a successful voice command.

The voice command recognition algorithm is relatively simple, but performed well in tests. It looks for keywords and combinations of keywords to determine the user's request. Further work could include improvements to the voice command recognition algorithm.

Lucide Icons

For most of the EcoTarium app icons—most notably in the navigation bar—we used an open-source React Native icon library called Lucide (*Lucide Icons*, n.d.). Lucide made adding icons throughout the app simple and consistent. Each icon we used from Lucide saved us the time and storage it would take to traditionally store and import a png, jpeg, or svg file locally.

4.5.2 Home Page

The Home page welcomes the user to the app and provides them with a few featured exhibits to inspire their interest in exploring outdoor exhibits. See Figure 4.16 below to view the home page which includes the featured exhibit carousel.
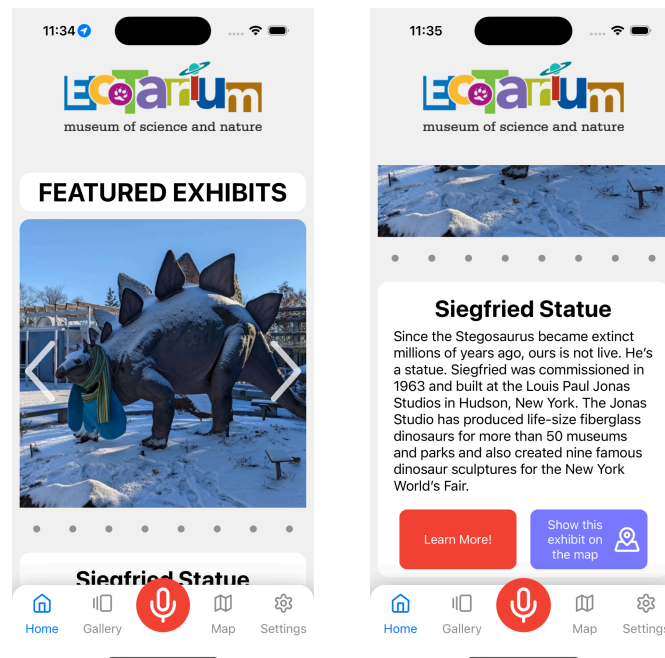
Figure 4.16: Home Screen and Featured Exhibit Carousel

For each featured exhibit, the carousel displays an image, the exhibit title, and a short description of the exhibit. Additionally, each featured exhibit panel contains buttons that will take the user to either the Exhibit Info page to learn more about the exhibit, or to the exhibit's map marker, if the exhibit exists as a marker on the Map page.

4.5.3 Gallery Page

The Gallery page is a collection of all of the exhibits and attractions that can be found at the EcoTarium. It queries the Omeka database and generates buttons to all of the exhibits'

information pages. As seen in the figure below, the list of exhibits is listed with alternating colored buttons. Through user testing, we found that categorizing the different types of exhibits resulted in a more intuitive user experience for all users. Users can search the gallery using the search bar at the top of the page.
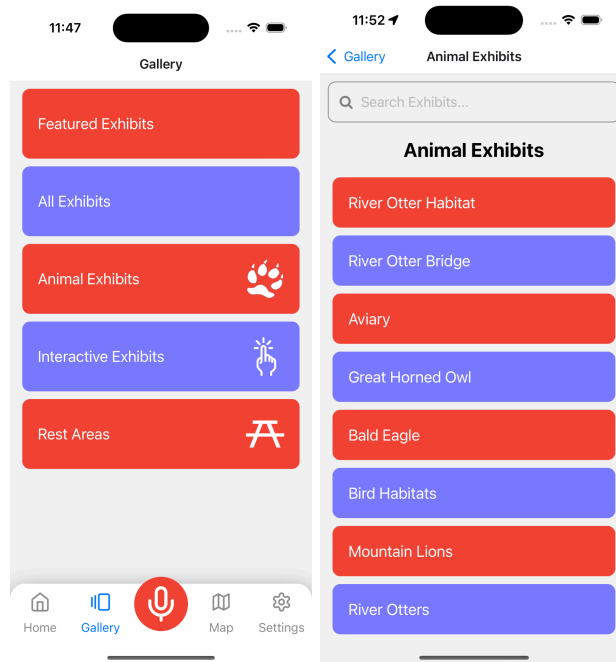
Figure 4.17 (left): Gallery Categories Screen

Figure 4.18 (right): The Animal Exhibits gallery screen, showing all animal exhibits

4.5.4 Exhibit Information Page

Once a user clicks on an exhibit from one of four places in the app - the Home page, Gallery page, or Map page, or by using the Voice Assistant - they are presented with a fullscreen user interface which provides information about the exhibit.
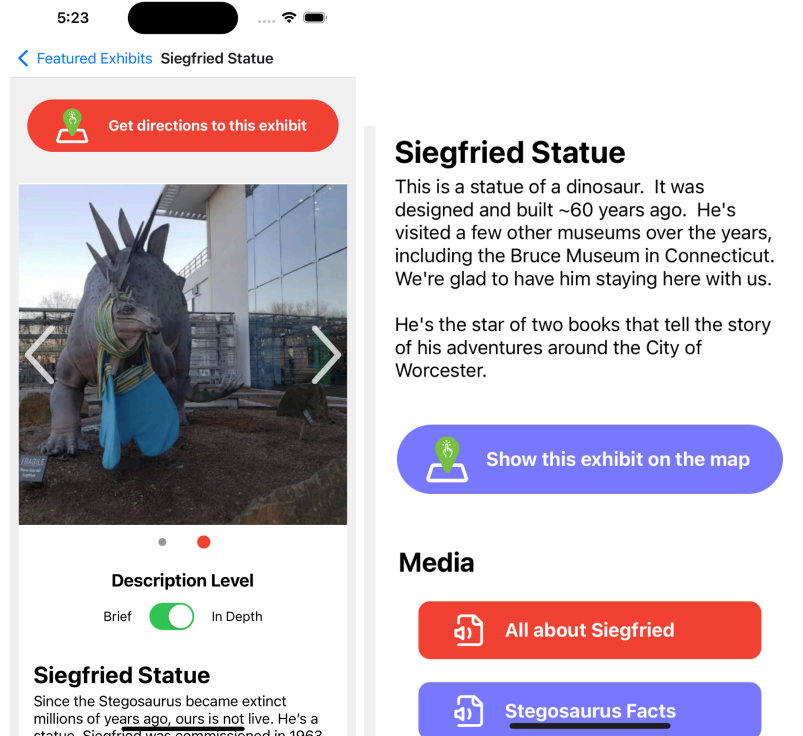
Figure 4.19: Exhibit Information Page

The first part of the Exhibit Information page is the image gallery. The user can swipe through each of the images stored in Omeka under the exhibit. The page also loads a description, a button to show the exhibit on the map, and audio media.

Description Level Slider

The EcoTarium requested that we implement a way for users of different ages, interest levels, and attention spans to read descriptions of different lengths. Descriptions at various detail levels help the EcoTarium provide a meaningful learning experience for all ages. Users can use the description level slider to set their content preference from the Exhibit Information page. The description level persists across all Exhibit Information pages, so users can easily keep the

content to the level that they prefer. This setting can also be adjusted in the Settings page, which will be discussed in Section 4.5.6.
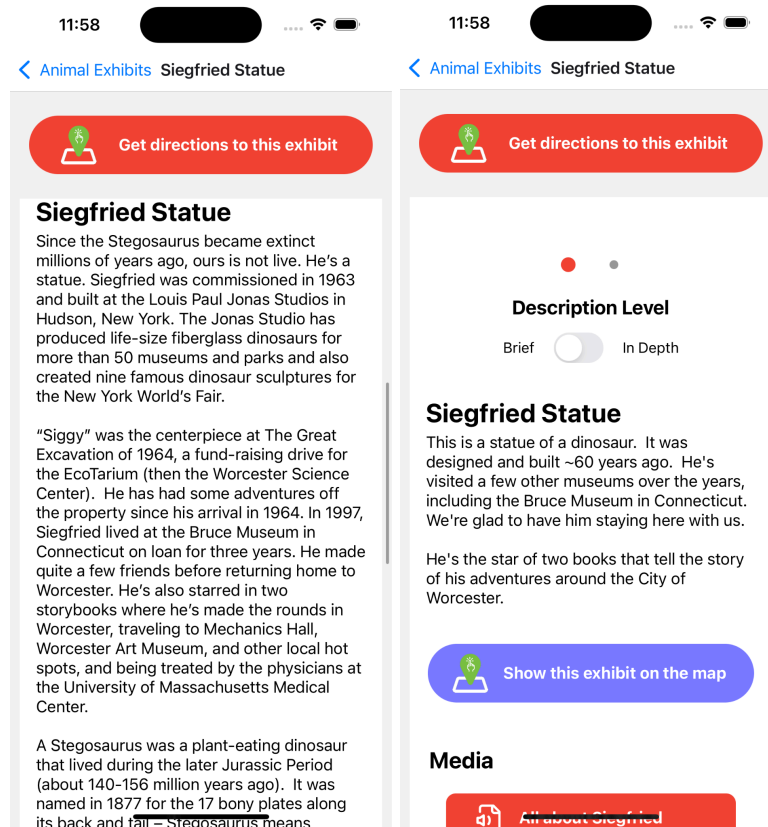
Figure 4.20: Side-by-side examples of the two different description levels. All descriptions are stored in Omeka and can be edited by the app manager.

Audio Player

The app manager can upload audio files that enhance the learning experience for an exhibit, such as the call of an owl or a story about a statue. To that end, we developed an audio player so users could easily listen to these extra media files. The audio player includes several controls for playback - including buttons to play, pause, skip backward or forward 10 seconds, and increase or decrease playback speed.
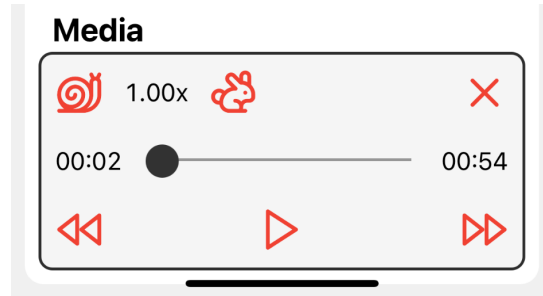
Figure 4.21: The audio player

4.5.5 Map Page

The Map page gives users a detailed outdoor wayfinding experience around the EcoTarium campus. The map shows exhibits and other points of interest around the EcoTarium. The outdoor GPS-based navigation feature gives users directions between points of interest across the EcoTarium grounds.
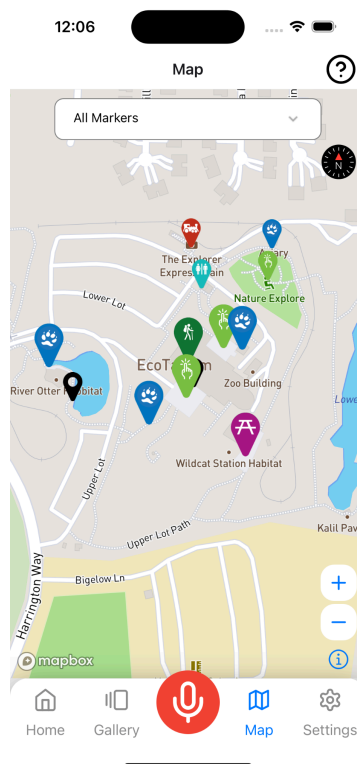
Figure 4.22: Map page

The Map page uses Mapbox as the map provider to display markers on exhibit markers on the screen. The map is automatically centered on the EcoTarium campus and restricts movement outside of this zone. Custom markers represent various waypoint types, which are shown in Figure 4.23.

Figure 4.23: Custom map markers

When a user clicks on an icon on the map, they are presented with a pop-up modal that allows them to see a short description and featured image of the exhibit if populated. From the modal, users can navigate to the Exhibit Information page or start outdoor navigation.
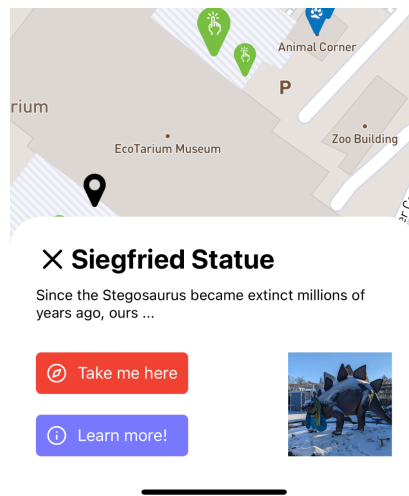
Figure 4.24: Pop up modal on the map screen

Users can use the selection box at the top of the page to filter the markers by a certain type of exhibit, or one specific exhibit. An example of this filtering is shown in the Figure 4.25 below.
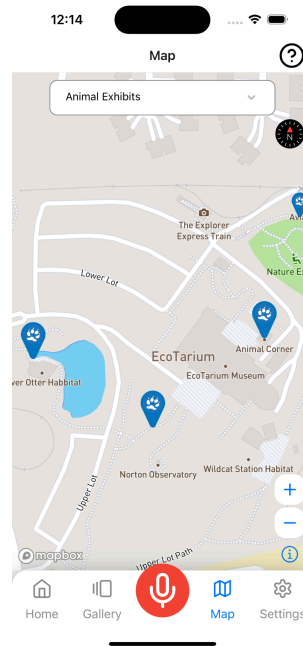
Figure 4.25: An example of marker filtering on the map screen.

During development, we noticed that when the map is zoomed out, the markers of closely adjacent exhibits would overlap with each other, making it difficult to view individual exhibits. To avoid related exhibits from overlapping on the map, markers of similar, nearby exhibits group together when the map is zoomed out. We call this feature an exhibit hierarchy, and the app manager can set custom Omeka properties to set up an exhibit hierarchy.

In an exhibit hierarchy, the map will conditionally show either the high-level group marker or the individual exhibit markers based on the current zoom level. While zoomed out, if the exhibit group marker is selected, it will center the marker on the screen and zoom into a level where the grouped items will appear.
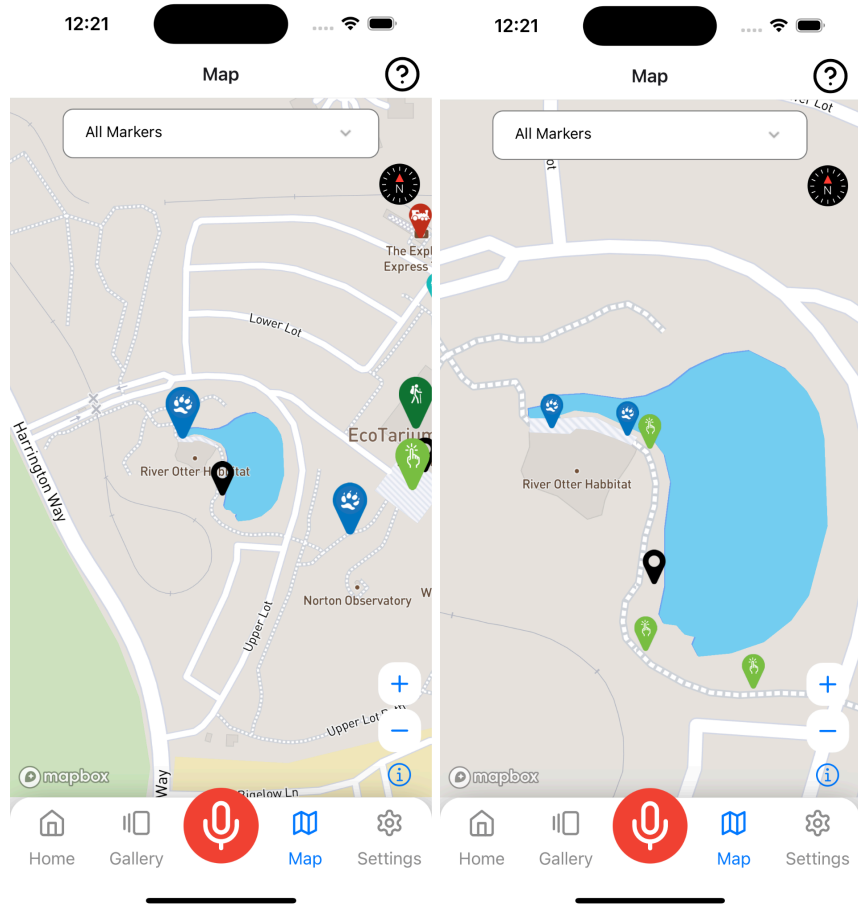
Figure 4.26: Exhibit hierarchy example. On the left, the river otter habitat is one large marker. After zooming in (shown on right), the marker splits into two exhibits, the river otter pavilion and river otter bridge.

GPS Location Data Privacy

Due to the nature of collecting high-precision location information from users to power the wayfinding experience, it is paramount that we protect this data in the interest of user privacy. As such, we have developed mechanisms to ensure only necessary data is collected to power the wayfinding experience.

When requesting location permission from the user, a system dialog appears on both iPhone and Android. An example of this dialogue is shown in Figure 4.27.
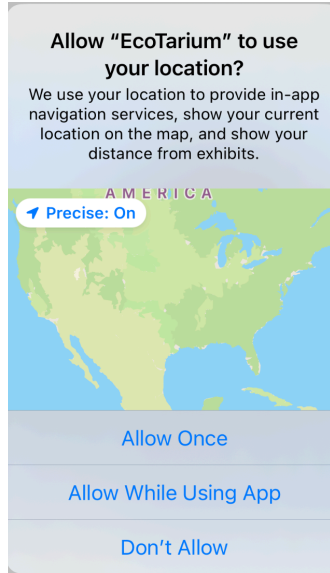
Figure 4.27: The location permissions prompt on iOS for the app

Users can choose at this step, or at any time in their device settings, to deny EcoTarium Explorer access to location data. If a user denies location permissions, the app shows a general map of the EcoTarium campus with no wayfinding experience.

The app was programmed such that location information is locally processed on the device in most cases. In cases where location information has to be sent to a wayfinding service, only the user's starting location and intended destination are sent. Any further location updates are processed on the user's device.

Outdoor GPS Navigation

Due to the nature of using Expo to develop for both iOS and Android, we were unable to use libraries that have already implemented navigation through Mapbox. We did consider moving away from Expo, however, this would have required us to switch our tech stack from React Native for both platforms to Kotlin for Android and Objective C and Swift for iOS.

Instead, we made our own navigation component by leveraging the Mapbox map we used in the

Map page. When a user starts navigation to a waypoint, the app queries the Mapbox navigation

API to get the route in the form of line geometries. We took inspiration from Evelity, a

navigation app that takes accessibility into consideration. Like Evelity (*Evelity Inclusive*

Wayfinding Application for All | Evelity.Com, n.d.), we created another type of navigation that we

called arrow navigation, which is a simplified form of navigation that only shows an arrow

acting like a compass, pointing towards the direction users should go. Figure 4.28 shows the UI

for both classic and arrow navigation.
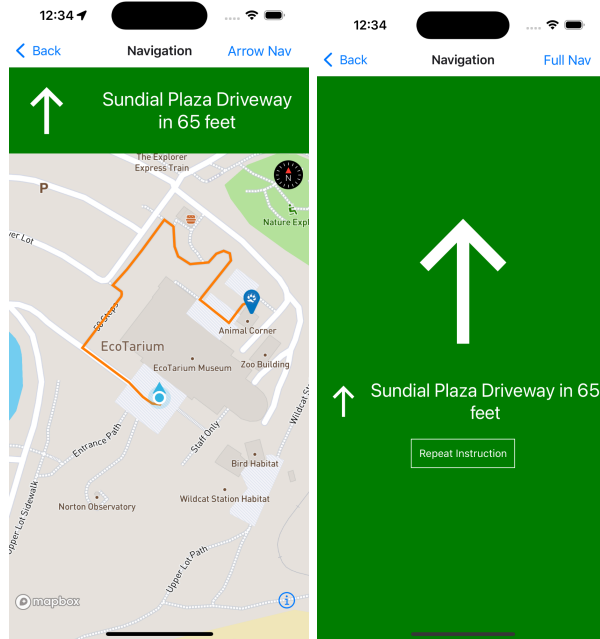
Figure 4.28: Outdoor Navigation Screens

Hazard & Exhibit Alerts

While on the navigation screen, the app alerts users as they approach hazards and

exhibits. Hazard alerts warn users of stairs, gates, and other difficult terrain while in navigation.

Exhibit alerts notify users when they approach interactive or animal exhibits that they encounter

along the way to their destination. Both types of alerts are toggleable in settings, and there is an option to turn them off whenever they pop up on the navigation screen. The app manager can add and edit alerts in Omeka. The app manager creates the message that appears on the screen and is read to the user upon triggering the alert. The app manager can also set a proximity radius that controls the distance that the user must be to the alert's location data for the alert to trigger.
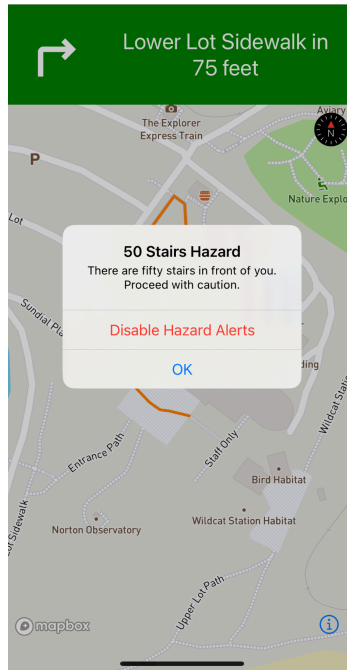
Figure 4.29: Example hazard alert

4.5.6 Settings Page

The Settings page allows users to customize how the app looks and behaves. Users can also switch between Low Vision Mode and Standard Mode from this page. In addition, users can access the open-source attributions and a place to send feedback. A photo of the settings page is shown in Figure 4.30.
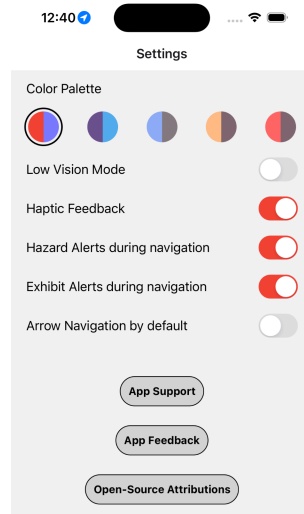
Figure 4.30: Screenshot of the Settings page

Haptic Feedback

More and more apps have been incorporating haptic feedback into the user experience as a way of validating user actions, which has proved to be particularly useful for those who have trouble seeing. We used the Expo Haptics library to ensure that haptic feedback would work across iOS and Android. On actionable buttons across the app, haptic feedback provides the user further confirmation of their actions. We used a mix of haptic levels across the app - medium haptics for changing between screens, light haptics for button presses in other locations in the app, selection haptics on the settings page, and notification success/warning haptics in Voice Commands.

4.6 Low Vision Mode

After our initial user testing, we realized that there were elements of the app that presented challenges for visually impaired persons, notably the interactive map and the landing

screen with the featured exhibit carousel. We decided to add a setting that takes these elements away and optimizes the app to work well with a screen reader called Low Vision Mode.

With LVM enabled, the landing screen is the Gallery page and the navigation bar is absent. The buttons that navigate to the Settings and Voice Assistant pages are now at the top of the page for easy access with a screen reader. The Map page is not accessible in LVM, as visually impaired users found it difficult to use and interpret. GPS navigation can still be accessed through the Exhibit Information page or the Voice Assistant.
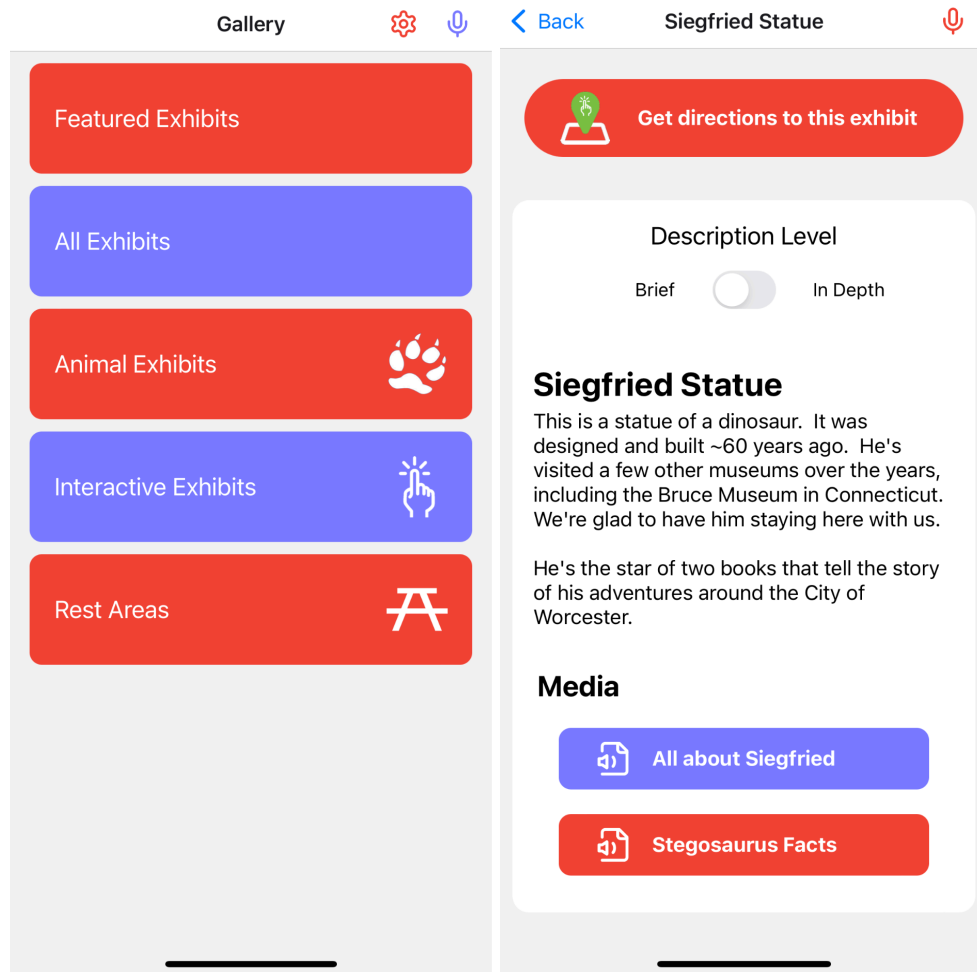
Figure 4.31 (left): LVM Landing Screen

Figure 4.32 (right): LVM Exhibit Information Page

V. Key Demographic User Studies

To address the project's original goal of providing an exhibit experience enriched and accessible to users with visual impairments, it was critical to set up user studies with visually impaired individuals. We were fortunate to have a connection from the previous year's WAM project team with the Worcester Audio Journal. The Worcester Audio Journal is an organization which broadcasts news and entertainment and shares other forms of media to connect and serve those with visual impairments (*Audio Journal Inc. - Worcester, Massachusetts, United States | Professional Profile | LinkedIn*, n.d.). They describe themselves as a "radio reading service for individuals who are blind, low vision, or cannot access print material due to a disability" (Zach, 2023). Audio Journal has approximately 150 volunteer readers. The Worcester location is one of six locations making up the Massachusetts Audio Information Network. Audio Journal provided us with volunteer readers with various levels of visual impairments who were excited to test beta versions of EcoTarium Explorer. We worked closely with Audio Journal to make user testing days that maximized data collection while respecting the volunteers' time.

5.1 Guided Procedures

A key part of the user study getting approved was establishing effective guided procedures for the day of testing. We developed a set of procedures to test each app feature. The procedures placed emphasis on testing compatibility with iOS and Android screen readers. The full set of guided procedures can be found in Appendix C. Once procedures were set, we went through the guided procedures on our own devices with iOS VoiceOver and Android TalkBack enabled to catch any obvious bugs with screen readers.

We organized the procedures into general tasks and navigation tasks. The general tasks can be conducted from any space with internet connection, while the navigation tasks must be conducted outdoors at the EcoTarium. In the guided procedures, these are distinguished as off-site and on-site tasks. The off-site testing procedures are broken down into app usability and visual accessibility, and involve navigating between pages, understanding each page's components, testing features, and adjusting settings. After completing the off-site tasks, participants answered reflection questions about their experience using the app and what they thought could be improved. Participants were then guided through the on-site tasks, which were conducted outdoors. Participants were instructed to navigate between outdoor exhibits until reaching the rest area, where they would answer the outdoor reflection questions. The expected path between outdoor exhibits is illustrated in Figure 5.1 below.
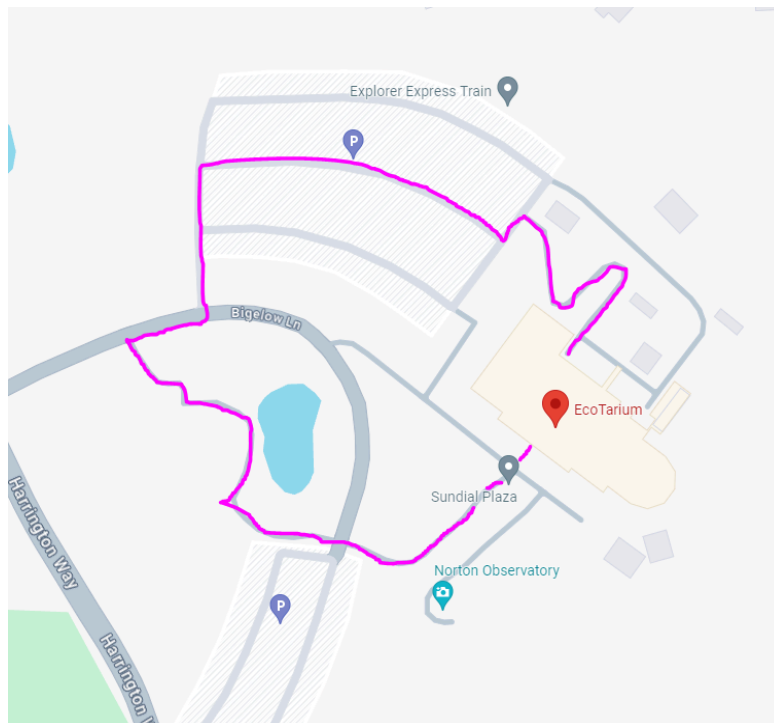
Figure 5.1: Path loops around the EcoTarium through several outdoor exhibits

The path displayed above is slightly different than the path suggested in the guided procedures, but it is the path we ended up using for testing. Participants started off in the lower lot (see the "P" symbol for parking), then navigated up to Siegfried Plaza. Participants then walked through the EcoTarium building and used the elevator to arrive at Sundial Plaza. From there, they navigated to the River Otter Exhibit, seeing the Eagles and Owls Exhibits along the way.

5.2 First Key Demographic User Study

We were approved to perform a user study by the WPI Institutional Review Board (IRB), and ran our first key demographic user study with five visually impaired volunteers in early December 2023. To respect the volunteers' time, we partnered with the WAM team and ran two user studies in one day: one at the WAM and one at the EcoTarium. An agreed-upon schedule for the first key demographic user testing session is shown below in Table 5.1.

Table 5.1: Key demographic user study schedule

Time	Event
9:30 - 10:15 am	Arriving at the Worcester Art Museum (WAM)
10:15 - 11:00 am	Briefing testers on how to use the WAM app and gaining consent from testers
11:00 am - 12:00 pm	Testing the museum app and performing interviews with testers
12:00 - 12:30 pm	Lunch break
12:30 - 1:00 pm	Briefing testers on how to use the EcoTarium app and gaining consent from testers
1:00 - 2:00 pm	Going to the EcoTarium
2:00 - 3:00 pm	Testing the EcoTarium app and performing interviews with testers

To prepare for risks and requirements associated with testing with people, we completed the required Collaborative Institutional Training Initiative (CITI) certification trainings to become knowledgeable on conducting the human protocol user study (*Research, Ethics, and Compliance Training | CITI Program*, n.d.). With a plan for safe and efficient execution and analysis of the user study as well as logistics in place, we submitted our IRB application and became IRB certified to conduct the study.

The user study ran smoothly, albeit with some modifications to the original plan. After presenting participants the informed consent document (Appendix B) at the art museum, we moved to the EcoTarium for on-site testing. Transportation arranged by Audio Journal to the EcoTarium arrived earlier than expected, meaning we had to do all testing at the EcoTarium, starting with the first outdoor task, then our indoor tasks & reflections before resuming with the remainder of the outdoor tasks & reflections. Due to time overruns and volunteer time constraints, we asked reflection questions while waiting for their transportation at the EcoTarium entrance. Despite the changes in schedules, we were able to gather all intended data and feedback from the guided procedures. After testing was finished, we created tickets in Jira aimed at improving the app based on the feedback from the participants. The results of the first key demographic user study are further discussed in Section 6.1.

5.3 Second Key Demographic User Study

After processing the feedback from the first key demographic user study, we implemented Low Vision Mode (read more in Section 5.6). Without prompt from stakeholders or our advisor, we decided it would be best practice to conduct another user study to test the effectiveness of LVM. For the second round of user testing, we used the same guided procedures

as in the first key demographic study to adhere to what was approved by the WPI IRB. We had

six visually impaired volunteers complete the second round of user testing. The results of the

second key demographic user study are discussed in Section 6.2.

VI. Results

During each user testing session, we took notes while assisting participants through the guided procedures. We created high-level goals and individual tickets for the next stage of development from the data collected through user testing. Through the first key demographic user study, we found many difficulties for low vision users, which inspired the creation of Low Vision Mode. During the second key demographic user study, we discovered small bugs with LVM and accessibility features. This section will summarize the qualitative results which we collected from each study.

6.1 First Key Demographic User Study

Through the first round of user testing, it was clear that EcoTarium Explorer was not fully accessible to visually impaired users. While following our participants as they executed guided procedure tasks and reflection questions, we noted which elements of the app gave them trouble. All notes that we gathered were accumulated into a table, which is found in Appendix D. When citing notes from the data table, we will use the following format:

(Indoor Procedures | Task 1 | Participants 3, 4 & 5)
(A)   (B)   (C)

which can be written in short-hand as

(IP | Task 1 | Participants 3, 4 & 5)

The citation above refers to a row-column combination from the table in Appendix D. Section A refers to the section header of guided procedures, e.g., Indoor Procedures (IP), Outdoor Procedures (OP), Indoor Reflection Questions (IRQ), or Outdoor Reflection Questions (ORQ). Section B refers to the task or question being cited; if no task or question is provided,

then the notes can be found in the row containing the section header. Section C refers to the participants who provided the feedback; note that participants 4 and 5 were providing feedback in tandem, which is why their data is combined into one row in the table.

Most problems had to do with compatibility with each device's screen reader. The most common issues we observed during the indoor procedures were trouble navigating the landing screen and map screen, getting lost in unnecessary elements, and misinterpreting nondescript accessibility tags. Through the outdoor procedures, we discovered common issues with our GPS technology as well as our navigation instructions. The following sections will provide detailed analysis and references.

6.1.1 Landing Page

The featured exhibit carousel on the landing screen of EcoTarium Explorer is intended to provide direction to the average visitor who is not familiar with the exhibits of the EcoTarium. The functionality of image carousels is generally intuitive for sighted users; however, this is not the case for low vision users. When the participants were prompted to navigate through the carousel and list all featured exhibits, many of them had trouble finding the "Next Image" button with the screen reader. This task took the volunteers much longer than we expected. For reference notes, see (IP | Task 1 & 2 | Participant 2) and (IP | Task 2 | Participants 3, 4 & 5).

In addition to the featured exhibit carousel, we also noticed that participants had trouble with the navigation bar. The navigation bar is located at the bottom of the screen, which is typical practice in mobile applications, as users can access any page of the app through buttons that are near to where their thumb rests. However, the visually impaired testers shared that they would prefer the navigation functionality to be placed at the top of the screen, since screen

readers always read elements on a screen from top to bottom. For reference notes, see (IP | Task 1 | Participants 4 & 5) and (IRQ | Question 8 | Participants 4 & 5).

6.1.2 Map Screen

The map screen is intended to provide a visual summary of the EcoTarium grounds and outdoor exhibits. Immediately, the word "visual" indicates a red flag for procedures with low-vision participants. Issues with the map screen ranged from failing to understand map markers to being confused by the navigation modal, and all issues suggested that the page had too much information to be effectively relayed by screen readers.

Screen readers read through the list of every marker on the map, confusing multiple testers. With markers spread out everywhere on the screen, it was also easy to accidentally click on a marker and jump to a completely different part of the page. We quickly understood that the map and markers were only helpful for sighted individuals. For reference notes, see (IP | Task 3 | Participants 2, 3, 4 & 5).

A modal pop-up appears when the user selects an exhibit marker on the map screen. It offers options to either learn more about the exhibit or to request navigation instructions. We found that this modal—and modals in general—are not well-understood by those using screen readers because they change the layout of a page without notification. For reference notes on modals being problematic for participants, see (OP | Task 3 | Participants 2, 4 & 5), (IP | Task 1 | Participant 3), and (IRQ | Question 7 | Participants 4 & 5).

6.1.3 Unnecessary Elements & Non Descriptive Accessibility Tags

Throughout all pages, we found small issues with unnecessary elements and non descriptive accessibility tags. Unnecessary elements include visual cues that provide helpful

context for sighted users, but which clutter views for low-vision users. Non descriptive accessibility tags were a product of inconsistent labeling in development.

One example of unnecessary elements were button labels. Because buttons have their own accessibility tags which explain what they do, participants let us know that button labels were not necessary to add context. In fact, when labels were not tagged as "labels," the participants often mistakenly thought they were buttons. For example, one of the features in the app during the first user study was an age-level slider that changed the detail level of exhibit descriptions. The slider was its own component and below it were three labels for each of the three slider positions: kid, teen, and adult. Participants had trouble changing age-level descriptions because they did not know how to adjust the slider—a task which involved its own unique gesture—and they assumed that the labels below were buttons to select each respective option. From this issue, we learned that labels should be tagged as "labels," and the same logic should follow for all accessibility tags, so that all buttons are labeled as "buttons", descriptions as "descriptions", and so on. For reference notes, see (IP | Task 6 | Participants 4 & 5) and (IRQ | Question 3 | Participant 1).

6.1.4 GPS Navigation

Overall, the GPS navigation portion of the user testing session was promising. Some smaller problems we observed regarding outdoor navigation were GPS drift and less-than-frequent navigation instructions.

GPS drift is a term used to define when the GPS position relayed by mobile device to the app is not sufficiently accurate, usually in unpredictable ways. We experienced this problem in our own on-site testing, and even with attempted bug fixes, the app's GPS technology was not cooperating for user testing. Some participants experienced different instructions when they were

right next to each other. Occasionally, the app would complete navigation early if the GPS drifted near the path endpoint. For reference notes, (OP | Participants 4 & 5) and (OP | Task 3 | Participant 3) provide feedback about directions, warnings, and hazard alerts overlapping or occuring when they are not supposed to.

Finally, the testers requested more frequent instructions throughout a GPS navigation route. The app gave instructions at each turn, but did not update them along the way to let users know they were still on the right path. The participants let us know that reminders of the direction every ten seconds or so would help them maintain an understanding of the path. For reference notes, see (OP | Participants 4 & 5), (OP | Task 1 | Participants 4 & 5) and (ORQ | Question 4 | Participants 4 & 5).

6.2 Second Key Demographic User Study

The second round of user testing helped us identify any bugs and accessibility issues in Low Vision Mode. Several volunteers participated in both rounds of user testing, and they reported that screen reader compatibility was much better in LVM. During GPS navigation, instructions were read out much more frequently, which was very well-received by the testers.

We learned of many small accessibility issues, but most of the feedback we received this time around was positive. The bugs we learned about were promptly fixed in version 1.1.0. Any larger suggestions we received but did not have time to implement are discussed in Section VII.

VII. Future Work

After finishing version 1.0.0 of the app, we worked together to develop a list of recommendations for future development teams. These recommendations cover improvements to app efficiency, new features to implement, and resources that may be of use. We hope that these suggestions will be able to guide future teams to improve EcoTarium Explorer.

7.1 General Enhancements

Our team determined a list of general enhancements that can make the app feel more customized towards the EcoTarium's brand, overall efficiency of the app, and other miscellaneous improvements.

1) Restructuring the general UI design of the app to better match the branding of the EcoTarium. This may enhance the overall end-user experience and create some cohesion between different aspects of the EcoTarium's existing products. We suggest asking the sponsor for materials to match the design to. With these materials, the next team should be able to create custom components (such as buttons) that can be used throughout the app. For inspiration, look at how we implemented various EcoTarium icons into the map markers.

2) Figure out how to prevent unnecessary re-renders on some screens of the app. While not a noticeable issue to the end-user, this fix should improve battery efficiency.

3) Determining where and when to use location services. As of now, we have extended location services to most of the screens on the app, to provide the user with a list of exhibits that they are currently close to. While this is a helpful feature, this may drain the battery unnecessarily, as it is relatively computationally complex.

7.2 Outdoor Navigation Enhancements

EcoTarium Explorer has a functional but basic navigational system. We suggest that future teams look into the following to improve the navigational experience.

1) Adding a rerouting feature into the navigation component. Currently, if a user makes a wrong turn, they will not be rerouted. While the EcoTarium campus is relatively small, we believe that this addition will make the navigation experience more whole.

2) Increasing sensitivity/precision of the algorithm that provides the voice and banner instructions. Rarely, there may be some instructions that are skipped over due to how close some steps are in relation to each other.

3) Prevent alerts and navigational instructions from interfering with each other. If the app starts telling the user multiple things at once, it can look unprofessional and create confusion.

7.3 Indoor Exhibits

The scope of our project was limited to just the outdoor exhibits at the EcoTarium. This allowed us to use GPS as our means of navigation between exhibits. The EcoTarium additionally has an indoor museum, with many more exhibits not found on the map of our app. GPS is likely too inaccurate to use to navigate the indoor exhibits, so an indoor navigation system will likely require significant research and testing.

Over the course of the project, we regularly met with another MQP team working on a similar accessibility app for the Worcester Art Museum (WAM). The WAM MQP team was tasked with creating a navigation system to help visitors find their way around the indoor museum without using GPS. Their solution was to use a system of bluetooth beacons that are

used to triangulate the position of a visitor's phone. This is a potential path for the EcoTarium to take to implement navigation indoors (Connors et al., 2024).

The EcoTarium building is a large, open area spanning three floors. Most bluetooth navigation systems use signal strength to triangulate the user, and assume the beacons with strong signal strength are on the same floor as the user. With the EcoTarium having semi-open floors, triangulation becomes extremely challenging since there may not be a solid floor to block beacon signals coming from other floors, thus interfering with triangulation calculations. We anticipate that a significant amount of research will be required to implement indoor navigation. If stakeholders request indoor navigation as the next major feature of EcoTarium Explorer, the next development team should expect to spend most of their time working on solving this problem.

7.4 Guided Tour

During one of our user testing sessions, one of the testers suggested a "guided tour" feature. This feature would take the user through a curated path showcasing the significant exhibits that can be found at the EcoTarium. We believe that this could be a great feature to those that are visiting the museum for the first time and to those that are visually impaired. This could even be expanded to allow users to create their own custom path, making for a more flexible experience.

7.5 Application Statistics

It would be useful for the EcoTarium to be able to easily track application usage. Since the app is using a developer build of Expo, integration with most analytic providers is possible.

One example of such is Google Firebase Analytics, which would allow the EcoTarium to track a number of key statistics of the app (i.e. active user count, crash analytics). This would be a useful addition to perform more data-driven analyses of the app.

VIII. Conclusions

8.1 Outcomes

At the end of the MQP, we released EcoTarium Explorer to both the Apple App Store and Google Play Store. The submission process required building the app for production, submitting necessary screenshots and information, and waiting for review from both marketplaces before the app went live.

8.1.1 Preparation work

Our sponsor at the EcoTarium provided us access to Apple Developer and Play Console accounts, which are Apple and Google's web applications that allow developers to submit apps. We did not undertake any work with getting verified for publishing on both app stores. Our sponsor also provided us with the app name, description, and icon for usage when publishing.

Before releasing the app to both stores, we made a production build of the app that was able to be submitted to both stores. This was done locally on the computer of one of our team members, but could also have been done via Expo App Services (EAS) Build.

8.1.2 Releasing EcoTarium Explorer to the Apple App Store

Releasing apps on the App Store requires developers to submit their app through App Store Connect. Initially, we had to create the app's listing in App Store Connect, and fill out information about the app, including its name, screenshots, description, etc. Due to Apple's more locked down nature of submitting apps, we had two viable ways to submit the app binary (the final app package) - the Transporter app on Mac, or EAS Submit.

Initially, we used EAS Submit, but the app ultimately didn't process correctly due to missing permission strings. To reduce the feedback loop time, we switched to using the Transporter app on a team member's Mac, and we were able to submit the app binary to Apple for review.

At first, Apple rejected the app upon review, but only due to permission strings that did not accurately explain why we needed end-user location data. Once we made the permission strings more verbose, the app was rebuilt and resubmitted. Apple approved the app for release on the App Store within 24 hours, and was publicly available for iOS users shortly thereafter.

8.1.3 Releasing EcoTarium Explorer to the Google Play Store

Releasing the app to the Google Play Store followed a similar process to the App Store. Upon getting access to the Play Console (the web app used to submit apps to the Play Store), we filled out about a dozen forms that clearly informed Google of the purpose of the app. We then had to fill out the Play Store's listing, including the app description, name, and screenshots. From this web console, we were able to upload the .aab (Android App Binary) file that contained the EcoTarium Explorer. It's important to note that EAS Submit is also able to submit binaries to the Play Console, but we found it a lot easier to drag-and-drop the file into the web app instead.

Google allows apps to go through 3 testing tracks - Internal Testing, Closed Testing, and Open Testing. We decided to skip these three tracks after seeing that Google's review times were much higher than Apple's and went straight to the production track, especially given that we had no existing user testing base and had internally tested the app. Upon a successful review, we released the app to the Play Store.

8.2 Impact

Much of the work for this project came from our individual passions and self-motivation. Following the first user study with Audio Journal, we had the chance to see what our efforts meant to the low-vision community in Worcester. One of the impacts this project had on us was hearing how much the study participants appreciated that our work catered to their experience. With the app's live release, we hope individuals of all abilities and backgrounds can feel similarly included in the EcoTarium experience.

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Zeolla, M., & Vila, M. (2023, April 25). *Increasing Accessibility at the Worcester Art Museum*

Via A Mobile Application. https://digital.wpi.edu/pdfviewer/s1784q40p

Appendix A: User Interface Storyboards

A.1 Low-Fidelity Wireframe (Hand-Drawn)
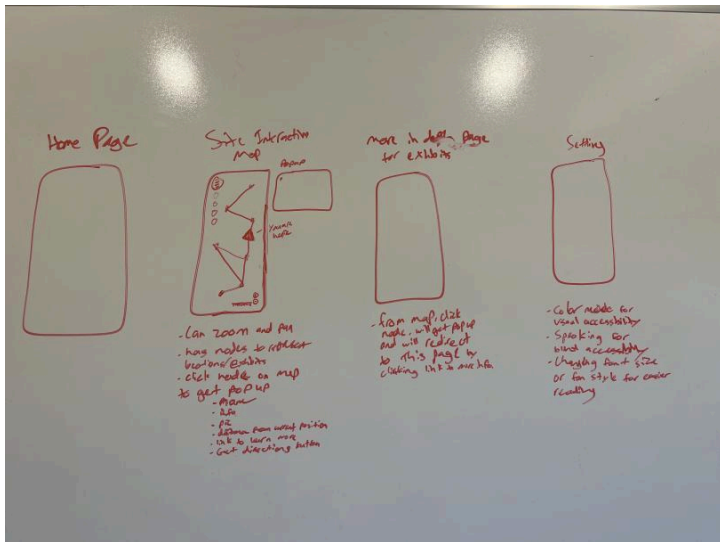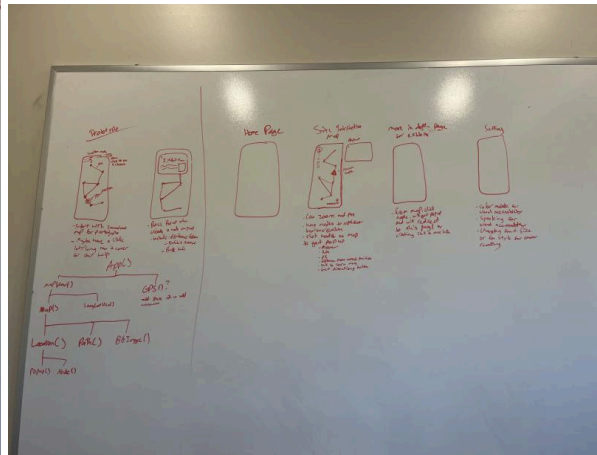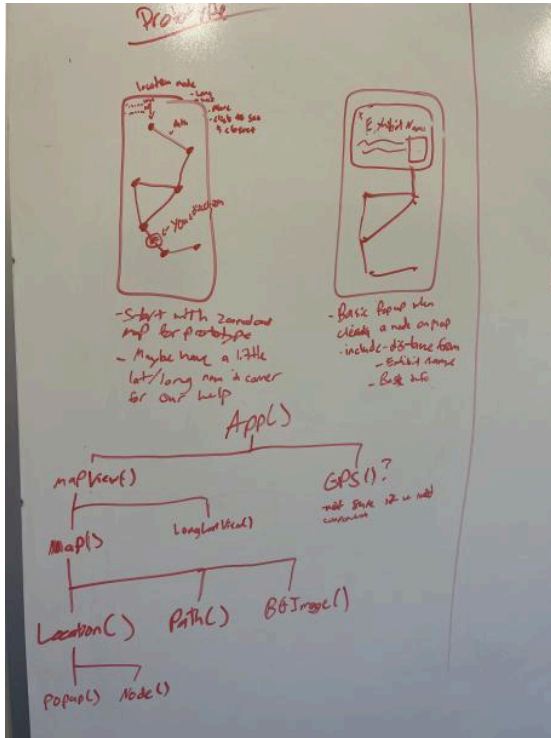
A.2 High-Fidelity Digital Wireframe (LucidChart)
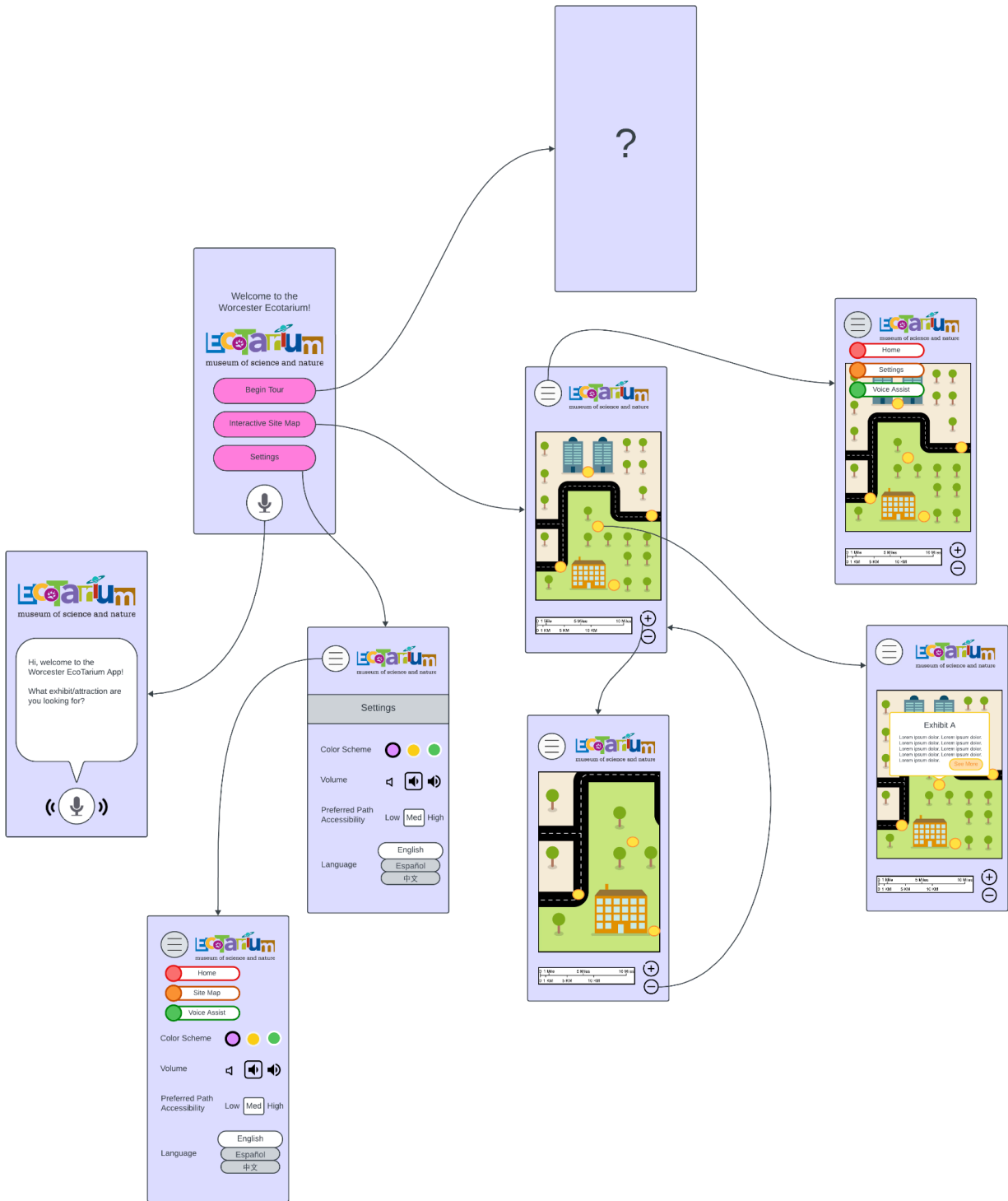
A.3 Interactive Figma Mockups

A.3.1 Gallery Interactions

A.3.2 Exhibit Page Interactions

Panel 1:

Siegfried Statue

Navigate to this exhibit

Detailed Description (off)

Siegfried Statue

This is a statue of a dinosaur. It was designed and built ~60 years ago. He's visited a few other museums over the years, including the Bruce Museum in Connecticut. We're glad to have him staying here with us.

He's the star of two books that tell the story of his adventures around the City of Worcester.

Additional Media

All about Siegfried

Stegosaurus Facts

Panel 2:

Siegfried Statue

Navigate to this exhibit

Detailed Description (off)

Siegfried Statue

This is a statue of a dinosaur. It was designed and built ~60 years ago. He's visited a few other museums over the years, including the Bruce Museum in Connecticut. We're glad to have him staying here with us.

He's the star of two books that tell the story of his adventures around the City of Worcester.

Additional Media

1.00x
00:04 — 00:54

Panel 3:

Siegfried Statue

Navigate to this exhibit

Detailed Description (on)

Siegfried Statue

Since the Stegosaurus became extinct millions of years ago, ours is not live. He's a statue. Siegfried was commissioned in 1963 and built at the Louis Paul Jonas Studios in Hudson, New York. The Jonas Studio has produced life-size fiberglass dinosaurs for more than 50 museums and parks and also created nine famous dinosaur sculptures for the New York World's Fair.

"Siggy" was the centerpiece at the Great Excavation of 1964, a fund-raising drive for the EcoTarium (then the Worcester Science Center). He has had some adventures off the property since his arrival in 1964. In 1997, Siegfried lived at the Bruce Museum in Connecticut on loan for three years. He made quite a few friends before returning home to Worcester. He's also starred in two storybooks where he's made the rounds in Worcester, traveling to Mechanics Hall, Worcester Art Museum, and other local hot spots, and being treated by the physicians at the University of Massachusetts Medical Center.

A Stegosaurus was a plant-eating dinosaur that lived during the later Jurassic Period (about 140-156 million years ago). It was named in 1877 for the 17 bony plates along its back and tail - Stegosaurus means 'armored' or 'plated roof lizard'. They had long spikes at the end of their flexible tails that could be used as weapons. These dinosaurs grew up to 30 feet long and weighed as much as 6,800 pounds! While a Stegosaurus could grow to the size of a school bus, its brain remained the size of a walnut.

Stegosaurus fossils have been found in Colorado, Utah and Wyoming. Since we only have bones to understand how these dinosaurs looked, sometimes mistakes are made in putting them together. At first, scientists thought the plats were flat along the back like scaly armor or sticking out to the side. Then they realized they are upright and form two rows on the back. Scientists today are still debating the purpose served by these plates.

Additional Media

All about Siegfried

Stegosaurus Facts

Panel 4:

Siegfried Statue

Navigate to this exhibit

Detailed Description (on)

Siegfried Statue

Since the Stegosaurus became extinct millions of years ago, ours is not live. He's a statue. Siegfried was commissioned in 1963 and built at the Louis Paul Jonas Studios in Hudson, New York. The Jonas Studio has produced life-size fiberglass dinosaurs for more than 50 museums and parks and also created nine famous dinosaur sculptures for the New York World's Fair.

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A Stegosaurus was a plant-eating dinosaur that lived during the later Jurassic Period (about 140-156 million years ago). It was named in 1877 for the 17 bony plates along its back and tail - Stegosaurus means 'armored' or 'plated roof lizard'. They had long spikes at the end of their flexible tails that could be used as weapons. These dinosaurs grew up to 30 feet long and weighed as much as 6,800 pounds! While a Stegosaurus could grow to the size of a school bus, its brain remained the size of a walnut.

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Additional Media

1.00x
00:04 — 00:54

A.3.3 Voice Assistant Interactions
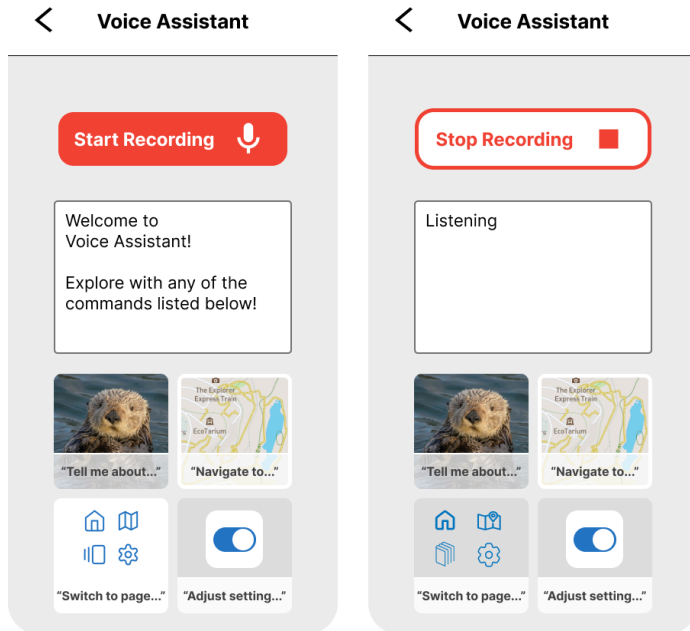
A.3.4 Onboarding Interactions

Hello!
Welcome to the EcoTarium App.

CONTINUE

This app is designed for all visitors
of the Worcester EcoTarium.

It has the option for
Enhanced Accessibility Mode to
accommodate visual impairments.

It does so with clear, contrasting
elements.

CONTINUE

Please click the appropriate button
to begin in Enhanced Accessibility
Mode or Standard Mode

Enhanced Accessibility
Mode

Standard Mode

A.3.5 Map Help Page Interactions
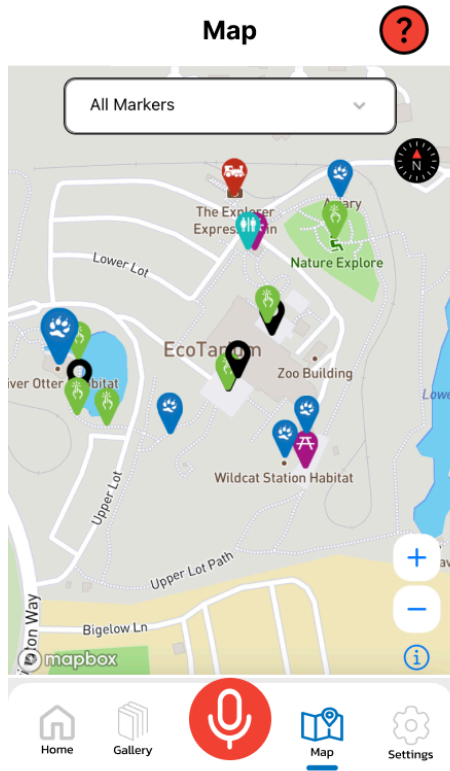
Appendix B: User Study Informed Consent Form

Informed Consent Agreement for

Participation in Increasing Accessibility at the Worcester Ecotarium App Study

Student Investigators:

Dylan Phillips, Joseph Fox, Owen McGinley, Dylan Olmsted, and Brandon Vuong

WPI Faculty Advisor(s): Rodica Neamtu, Email: rneamtu@wpi.edu

Student Investigators Alias: gr-ecotarium-mqp-23@wpi.edu

Title of Research Study: Worcester EcoTarium App User Study

Sponsor: Worcester EcoTarium

Introduction:

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the Study:

The Worcester EcoTarium is working with WPI to enhance their existing mobile app and make the museum more accessible to navigate for visually-impaired or otherwise-impaired visitors. We are the student team responsible for developing and testing the application on Apple

iOS and Android devices. Our overall goal is for users to use the app effectively, and ensure that our new museum navigation feature works as intended. Visually impaired people are the focus of this study, but we would also like people with no or minimal visual impairments, as well as other forms of impairments to participate in the study. We will be writing a report and analysis of our findings.

Procedures to be followed:

- For participants with significant visual impairments, we will provide read-aloud service for all study materials, including this consent form. This service will be conducted by a qualified individual who will read the content aloud to you in a clear and understandable manner.

- You will be given the opportunity to ask any questions you may have during the read-aloud session. Our team is here to address any concerns and provide additional information as needed.

- By participating in this user study, you acknowledge that the expected duration of the study is approximately 1.5 hours or less. We value your time, and every effort will be made to ensure that the study is conducted efficiently while still obtaining valuable insights.

- We will provide iOS and Android devices to use in-person, as well as instructions on how to open and use the test version of the app.

- You will be asked to perform some tasks regarding using the app while navigating our test area. The test area is three of the EcoTarium's outdoor exhibits, which are three wheelchair-accessible locations in close proximity to the starting point, the parking lot.

- Testing will involve physically walking through the grounds with an escort while using the app. It will also involve using the app while seated in-place

- You will be asked to state out loud your thought process when using the app, as well as your opinions on various features of the app.

- At the end, you will be asked to answer a set of questions.

- Your identity and responses to individual questions will be kept confidential.

Risks to study participants:

- Standard risks associated with using smartphones and navigating rooms.

- Standard risks involved with navigating outdoor, ADA-compliant walkways.

Benefits to research participants and others:

You will help the Worcester EcoTarium be more accessible and engaging for all visitors.

Your participation in this research is voluntary.

Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

Record keeping and confidentiality:

Our report will be made available online at digital.wpi.edu. It will include analysis and statistics of the intuitiveness and user satisfaction of our app. Only the student investigators will

have access to the data collected in the questionnaire, which will be securely stored on a secure Worcester Polytechnic Institute OneDrive server. The answers to the questionnaire will be destroyed within a month after the completion of our report. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury:

This study involves minimal risk of injury. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

WPI Faculty Advisor: Rodica Neamtu, Email: rneamtu@wpi.edu or

WPI IRB Manager: Ruth McKeogh, Tel. 508 831-6699, Email: irb@wpi.edu or

WPI Human Protections Administrator: Gabriel Johnson, Tel. 508 831-4989, Email:

gjohnson@wpi.edu

By signing below, you acknowledge that you have been informed about the study, and consent to be a participant in the study described above. By signing this consent form, you affirm that you are 18 years of age or older. Participation in this study is limited to individuals who meet this age requirement. If you do not meet the age requirement, please do not proceed with participation.

Make sure that all of your questions are answered before signing this form. You are entitled to retain a copy of this consent agreement.

_____

Study Participant Printed Name

_____   **Date: _____**

Study Participant Signature

_____ **Date:** _____

Witness Signature (as applicable)

_____ **Date:** _____

Investigator Signature

Appendix C: Key Demographic User Study Guided Procedures

INCREASING ACCESSIBILITY AT THE WORCESTER ECOTARIUM

GUIDED PROCEDURES

Indoor App Testing

Introduce Ourselves and Our Purpose

Hello! We hope you have enjoyed your day so far working with WPI's WAM team!

We are the members of WPI's EcoTarium MQP team: Myself (Dylan Phillips), Joe Fox, Owen McGinley, Dylan Olmsted, and Brandon Vuong.

We'll each say a bit about ourselves.

[We each say a bit about ourselves, our majors, interests, excitement for this project, etc.]

Great! Now, we will get into the purpose of our study, which is similar in many ways to the WAM team's study, but different in a few key areas…

Our team of Computer & Data Science engineers is working to increase accessibility at the Worcester EcoTarium through the use of the personal tool that everybody carries these days: their Smartphone. We aim to enhance the EcoTarium experience for all visitors, with a particular goal of unveiling that experience to those with visual impairments.

We truly appreciate your attending today, as our goal with this study is to understand your perspectives for the app's functionality. Your inputs for the EcoTarium App's User Interface, Navigation Assistance, and Overall Engagement will directly inform our team's future development and will further enhance the EcoTarium experience for guests of all capabilities.

Informed Consent

General App Testing

EcoTarium Outdoor Navigation Testing

General App Testing Procedures

Brief Intro

Before we get started, we would like to record audio for later analysis. All audio we capture,

as well as any analysis we conduct, will not contain any identifiable information and will be

promptly destroyed after our analysis is complete.

Does everyone grant their permission for us to record your responses to our prompts for

General App Testing?

Now, we will give you a brief intro to our General App Testing Procedures…

With these procedures, we will provide prompts and later ask questions about the

EcoTarium App's **User Interface**, namely, its **App Navigability** and its **Text & Icon Accessibility**.

Please do your best to explain your thoughts out loud as you are going through each

prompt.

Task List

The following tasks will target either App Accessibility or Text & Icon Accessibility…

- Start on Home Page

- Task 1 – Identify All Home Page Components

    - If you are using Screen Reader,

        - Use your Screen Reader to read aloud all Home Screen components

          and their alt tags.

- - ○ Otherwise,

    - ■ Describe all Home Screen components.

- Task 2 - Navigate Around the Carousel

  - ○ List the five exhibits in the Featured Exhibits carousel

  - ○ Use the microphone icon (i.e., voice command) to access one of those components

- Task 3 - Find an Exhibit on the Map Screen

  - ○ Within the Featured Exhibit's page you selected, press the button to show you the exhibit on the map screen

- Task 4 - Access Specific Exhibit (Adult Description)

  - ○ Navigate to a featured exhibit "more info screen" from the map screen.

  - ○ If you are using Screen reader,

    - ■ Use your Screen Reader to read aloud all Exhibit Screen components and their alt tags.

  - ○ Otherwise,

    - ■ Read aloud—or play audio for—descriptions and images.

  - ○ Play an audio component

  - ○ Navigate back to the home page

- Task 5 - Adjust Accessibility Settings

  - ○ Navigate to the Settings Page.

  - ○ Change the default description level from "Adult" to "Teen".

  - ○ If you would like to experiment with different color schemes, please do so.

  - ○ Navigate back to the Home Page.

- Task 6 - Access Specific Exhibit (Teen Description)

  ○ Please navigate to the Gallery Page

  ○ Please use the search bar to find the same exhibit you looked at before

  ○ If you are using Screen reader,

    ■ Please use your Screen Reader to read aloud all Exhibit Screen components and their alt tags.

  ○ Otherwise,

    ■ Please read aloud descriptions and describe images.

  ○ Adjust the slider on the exhibit page from "Teen" to "Kid" and read descriptions again

- Please navigate back to the Home Page

Reflection Questions

App Accessibility

1. How would you rate the overall accessibility of the EcoTarium App on a scale from 1 to 5?

2. Were you able to easily identify and interact with all Home Page components? If not, which components posed challenges?

3. After changing the description level slider, did you notice significant differences in the exhibit description? Please describe any differences.

4. If applicable, how would you rate the app's compatibility with screen readers?

5. Were you able to access specific gallery pages and read descriptions and alt tags effectively? Were there any gallery pages that posed challenges?

6. How user-friendly was the search feature when looking for specific exhibits?

7. How effective was the speech-to-text (i.e., voice command) feature? Were you able to find all desired information with your voice alone?

8. Are there features you see in other apps you use which you think could be useful to the EcoTarium app? If so, please describe.

Text & Icon Accessibility

1. How would you rate the visibility and clarity of text and icons throughout the app on a scale of 1 to 5?

2. Were there any instances where the text or icons were difficult to read or understand? Please provide examples.

3. Did the accessibility settings—and if applicable, the color schemes—enhance the visibility of text and icons for you? If so, in what ways?

4. Were you able to distinguish between different images and their descriptions effectively?

5. How could the EcoTarium App further improve text and icon accessibility for all users?

EcoTarium On-Site Navigation Testing

On-Site Navigation Testing Procedures

Brief Intro

Before we get started, we would like to record audio for later analysis. All audio we capture, as well as any analysis we conduct, will not contain any identifiable information and will be promptly destroyed after our analysis is complete.

Does everyone grant their permission for us to record your responses to our prompts for On-Site Navigation Testing?

Now, we will give you a brief intro to our On-Site Navigation Testing Procedures...

With these procedures, we will provide prompts and later ask questions about the EcoTarium App's **Navigation**, namely, its **Accessibility Considerations** and its **Clarity**.

Please do your best to explain your thoughts out loud as you are going through each prompt.

Task List

[Disclaimer: Any and all visually-impaired persons will be assisted by an escorting assistant as they navigate the grounds, and all navigated paths will be fully accessible for safety precautions.]

Throughout all tasks, make note of the following issues which we were tracking in our own app testing: (1) GPS drift, which may or may not be the cause for (2) navigation not recognizing path checkpoints, and never moving on to the next checkpoint.

- Start in the Parking Lot

- Navigate to Siegfried Plaza

  Are participants able to intuitively use the microphone button?

  If so, does their first voice command work? Do they give a valid voice command?

  If not, how do they use the app to navigate to the exhibit?

  Do participants get a warning for the curvy path?

  Is the warning useful for alerting the participants? How so?

- Go inside the EcoTarium, use the elevator, escort participants to Sundial Plaza

  Is inside the EcoTarium easy to navigate for the visually impaired?

- From Sundial Plaza, navigate to the river otter exhibit (**explain longer walk goals**)

  For each of the following alerts, check

  (a) that they occur, and (b) how the participants feel about them:

    Bird Exhibits

    Street Crossing

    Living Exhibits Outdoor Kiosk

    How Can a Meadow Protect a Pond

    Hazard: Curvy Path

    What Happens when Pollution Runs into a Pond

    River Otter Pavillion

- From the river otter exhibit, navigate to the outdoor rest area (down hill from Siegfried)

  Is there a clear danger for participants as they navigate around the parking lot?

- [Find benches to sit on as we ask reflection questions]

Reflection Questions

Accessibility Considerations

1. How would you rate the app's on-site navigation on a scale from 1 to 5?

2. Did you receive appropriate navigation paths to Siegfried Plaza, the Lower Pond, and the Train Station as requested? Were there any imperfections in the EcoTarium App's navigation responses?

3. What challenges, if any, did you encounter in using voice commands and requesting guidance within the app?

4. How could the app better address accessibility considerations for on-site navigation?

Clarity

1. How clear and easy to understand was the map's interface on a scale from 1 to 5?

2. What could be improved about the map's interface?

3. Did you feel that the map provided sufficient guidance and clarity in turn-by-turn navigation instructions?

4. Did you appreciate the hazard warnings and nearby exhibit alerts?

5. Were there too many en-route alerts? Were there opportunities for more?

6. What suggestions do you have for enhancing the EcoTarium app's turn-by-turn navigation instruction clarity?

Concluding Remarks

- And finally, please share any final comments or questions you have about your experience with the Worcester EcoTarium app.

Thank you all for participating, and thank you to the Audio Journal for being such a great partner in this endeavor. We hope you enjoyed your time today at Worcester's Art Museum and EcoTarium; your insights today will help individuals of all abilities enjoy these one-of-a-kind Worcester experiences.

Appendix D: Data from the First Key Demographic User Study

First Key Demographic User Study

Task	Participant			
	Participant 1	**Participant 2**	**Participant 3**	**Participants 4 & 5**
Indoor Procedures		VoiceOver controls were difficult for Participant 2, which hindered their ability to use the app effectively	Home Screen: Make the pagination in VoiceOver/TalkBack read out what the user is currently on, it was also confusing for the user to have the carousel wrap around. When swapping pages on the carousel, the page that was swapped to does not get read out to the user through TalkBack/VoiceOver.	Overall: - Cannot access "Learn More" through screen reader when it is a hyperlink within short description - Voice command was buggy; wouldn't register mic input AT THE START
Task 1 - Identify all home page components:	Cut out ellipses from words, screen reader reads it out loud	Swiping on VoiceOver interferes with carousel, screen reader was confusing on home page	Drop down is labeled as a menu in VoiceOver/TalkBack Modal text (Learn More) is inaccessible with VoiceOver/TalkBack features	- Participant prefers top navigation bars to bottom navigation bars
Task 2 - Navigate around the carousel:	Able to get to next exhibit on carousel	Participant did not understand direction	Swiping on the carousel when trying to swap elements with VoiceOver swaps the currently displayed exhibit and breaks whatever exhibit is currently being shown. For example, if the user is on the Siegfried Exhibit and tries to swipe to get to either of the carousel buttons, it will change the currently selected exhibit, but not update the state.	- In featured exhibits, sundial image is read aloud as "Sundial," not a gallery item; suggested fix is to label all images as "[Item] Image" within the carousel - Participant doesn't understand what "previous gallery item" refers to when scrolling over the featured exhibit carousel; Suggested fix is to label it as a button
Task 3 - Find an Exhibit on the Map Screen:	Delete the ">>" reads as greater than greater than on screen reader	Went to map screen, which did not seem helpful for the participant	Map (Exhibits) Screen: Drop down does not read out currently selected option and also does not read out any options that can be selected within the dropdown This screen is just too confusing to navigate as someone with visual impairments	- Participant is unclear on what the marker selection drop-down does, as when they scroll over using screen reader, the alt tag says "all markers;" suggested solution is to call it "filter waypoints drop-down button"
Task 4 - Access Specific Exhibit (Adult Description):	Make the learn more button into its own button and out of the description, it gets lost in the description // Need to add better alt descriptions for images // "Learn more about the exhibit" rephrase to this // describe color and better descriptions of visuals //	Used gallery tab instead of more info button. Screen reader was very helpful on specific exhibit screen		- Some audio files are very quiet; suggested solution is to standardize volume across all audio files

	update the audio alt tag to be "Listen to audio about ..." // the page reader voice over was speaking over eric in the audio clip			
Task 5 - Adjust Accessibility Settings:	Need to reorder the buttons, it was confusing using the screen reader with the options being read before the label	Screen reader reads switches and options before labels		- When trying to toggle haptic feedback, screen reader announces "Haptic feedback toggle switch; Haptic feedback set to 1"; suggested solution is to say instead, "Haptic feedback toggle switch; Haptic feedback currently set to 'on'"
Task 6 - Access Specific Exhibit (Teen Description):	Always having a back button no matter where you are // gives updates if museum is in a special state, snowing, events, etc			- Participant tries to adjust accessibility setting by pressing the "adult" label rather than interacting with the age level slider; suggested solution is to make 3 buttons rather than a slider - Labels on age level slider are read aloud, causes confusion since they have no interaction; suggested fix is to replace the slider with buttons
Indoor Reflection Questions				
1 - Overall accessibility rating:	4, images need description, voice commands wasn't working at the time, navigation not as description	5	1) 4, certain buttons should be labed to the point where they are described to by the screen readers. Screen readers will say the type of touchable something is, for example button. Delay on navigation Voice Commands not working off the bat	- (4); Participant gives reasons for their score: voice command was iffy; directions were only read once (not enough reminders for navigation); no way to re-read instructions after they were first mentioned
2 - Easily identify home page components:	5	4	2) Yes home page components were easy to identify	- Able to ID all except voice command - Voice command needs to be clearer to use - Tabs were good (pages were well labeled, easy to understand on the nav bar)
3 - Notice differences in exhibit description:	Take away the slider and change to 3 buttons for age level // voice is a little fast		3) Yes they were noticeable differences. Maybe get rid of the slider and have selectable options	
4 - Rate the app's compatibility with screen readers:	3	"very good"	4) There were a couple of components that were inaccessible to the screen reader due to component hierarchy	- (3); Other than directions, not bad
5 - Access specific gallery pages:	Yes, screen reader spoke over audio	yes	5) Yes, but we should label the carousel items. Something like 1/7	- Yes

6 - User-friendliness of search feature:	would be voice navigation / add a voice button on search // when using voice commands, "microphone, please speak" then record, "Try again" if it failed		6) Dictate is not working for the search feature	- N/A - Did not use the search feature; Participant mentions that a search tab is good if you know what to look for, but otherwise not so useful
7 - Voice command effectiveness:	1, wasn't working for us at site		7) Dark Mode	- Voice command was not very responsive; suggested solution is to clean up the look and feel of the voice command modal
8 - Features in other apps that could be in EcoTarium app:	2 finger double tap to pause audio, maybe download the media to share with friends // scanner plus	no		- Have a general "search bar" instead of voice command; Users can use dictation to convert speech to text, which would then be searched on (this would allow us to not use React Native Voice) - Nav bar on the top is better - Home screen is really important for exploring (no suggested fixes here, just emphasized that point) - "How to Use" feature/page would be SUPER helpful
9 - Rating of visibility and clarity of text and icons:	4, slow down voice // even clearer directions // follow grass line // hazards // pickup spot	5	N/A	- Label every component as its type---e.g., "button", "label", "header", etc. - On/Off instead of 0/1 for haptics feedback setting alt tab
10 - Instances where text/icons were difficult to read or understand:		no	N/A	
11 - Did accessibility settings/color schemes enhance visibility of text & icons:	4/5 images need to have better alt text than "image"		N/A	- Haptic feedback and hazard/exhibit alerts are good IFF they are informative
12 - Distinguish between different images & descriptions:	yes but needs work	yes	N/A	- Give alt tag accessible descriptions for images; increase engagement for low-vision users
13 - How could the app further improve text/icon accessibility:		no		

Outdoor Procedures			Navigation Screen: Directions cannot be read out by screen readers (header) Hierarchy of the components causes bugs where the user cannot even reach the end navigation button Directions are not being read when starting navigation	Overall: - Users would prefer NEAR CONSTANT VERBAL INSTRUCTIONS for navigation, since they need that constant reassurance that they are walking the right way; suggested frequency of instructions: once every 5-10 seconds - Instead of using compass directions (e.g., North, South, Northwest, etc.), could consider telling the user to visualize a clock (e.g., turn to your 3:00), then once they complete the turn (verify their bearing), they can walk straight forward and continue their path - GPS drift causes alerts and navigation instructions to happen early or late - Participant mentions that street names do not help them navigate places in general
		Voice command button was difficult for the participant, who appeared to have some sort of speech impediment		
Task 1 - Start in Parking Lot, navigate to Siegfried Plaza:				- Participant suggests that when navigation is instantiated, there should be text directions on the screen which the user can read aloud (when scrolling over the navigation banner with text instructions, the screen reader says "navigation banner," doesn't provide instructions) - Participant doesn't appreciate how immediately on navigation start, the app doesn't introduce the path with any directions; the user has to walk a bit before the first direction presents
	Upon arrival, describe the surrounding area to help get their groundings	good instruction, helpful alerts		
Task 2 - Go inside EcoTarium, use the elevator, escort to Sundial:				
Task 3 - Navigate to River Otter Exhibit from Sundial:			VoiceOver should have priority over Expo Speech Hazard alerts are helpful Hazard alerts overlap upon themselves sometimes, causing there to be 2+ alerts open on top of one another Navigation does not end correctly (ends on "undefined in X feet" as the direction header) Have alerts for stairs and other obstacles for visually	- Warning doesn't tell you how to adjust your path, just tells you that there is a hazard nearby; suggested solution: more descriptions for warnings - Modal for disable hazard alerts stays on screen infinitely, blocks further instruction; suggested solution is to remove the alert after five seconds of the user not pressing "ok" - Hazard alert says "undefined in 25 feet" - Alerts come back 3 times
	For those using a cane, being able to describe the sides of paths, grass line, curb, etc	No stairs alert before road cross by owl exhibit, Alert modal should auto close	impaired persons	after user presses ok

Task 4 - Navigate from River Otter to Siegfried:	More frequent navigation updates, every fifteen steps or so, hazard alerts are huge to have	Navigate based on signs?	
Outdoor Reflection Questions			Overall: - Participant describes the two sets of users: those who want to quietly enjoy the app and those who want to engage as much as possible with the app, exhibits, etc.
1 - Rate app's navigation on a scale from 1 to 5:		5	1) 3 Unclear, does not start immediately	- (2); - Don't give directions in N-E-W-S - Don't make the user have to walk before they get the first direction of the path - Don't just give warnings, explain what the hazard is and HOW to avoid it - Alerts were not timely
2 - Receive appropriate navigation paths, imperfections in nav responses:		yes	2) Yes	- Participant did not notice any directions that were completely wrong, just the communication of the instructions was hard to follow
3 - Challenges, if any, w/ encountering voice commands & requesting guidance:		Did not always understand the participant	3) Send alerts for stairs and other obstacles such as that	- Voice command just says "Listening, ellipses," but does not tell you the commands, or that you should "start speaking"
4 - How could app better address accessibility for navigation:		Alert for all stairs, with an exact number of stairs	4) It could read the initial instruction out faster	- More frequent audio updates to MAINTAIN the provided routes
5 - Clear/easy to understand map, scale 1 to 5:			N/A	
6 - What could be improved about map interface:			N/A	
7 - Map provided sufficient guidance and clarity in turn-by-turn:		yes	7) Long periods of silence are difficult for the visually impaired	
8 - Appreciate hazard warnings/nearby exhibit alerts:		yes	8) Very helpful	
9 - Too many en-route alerts? Opportunities for more?		no	9) Sometimes the hazard warnings overlap upon themselves	
10 - Suggestions you have for enhancing navigation instruction clarity:		nothing	10) Good Maps, Navigator are two examples of apps that we can take inspiration from for navigation	