GULF OF MAINE RESEARCH INSTITUTE

LabVenture Accessibility Report

OCTOBER 31, 2019

hello-upswell.com
971-244-0142

107 SE Washington St., Ste. 238
Portland, Oregon 97214

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Overview

This document serves as a high level overview of the GMRI LabVenture accessibility project undertaken by Upswell. It covers the existing implementation, learnings, and desired goals for future accessibility efforts.

Project Approach and Implementation

LabVenture serves as an introduction to the scientific process for students, and is likely the first encounter many students will have with research science. During their time at LabVenture students are presented with examples of actual scientists doing real scientific work, and then given an opportunity to experience a little of what goes into that work themselves. By participating in a recreation of scientist's work studying the students can begin to see themselves as scientists.

The accessibility effort sought to ensure that we met LabVenture goals as inclusively as possible. As much as possible, we applied existing accessibility best practices, but recognized that due to the unique format and use cases of the experience, some of these best practices were not applicable. More importantly, we sought to translate these moments into opportunities to push the boundaries of how inclusive an experience could be.

It's important to note that LabVenture is the result of a two-year long design and implementation process. The accessibility effort fell at the tail end of this process, with many decisions around application flow, types of interactions, and content having already been made. It only became clear after the work to make the design inclusive began that many decisions that were key to LabVenture's DNA simultaneously made it inaccessible. Features like time-based activities, frequently changing user interfaces, draggable elements, and multi-user experiences where a single user can take-over the entire experience pose unique challenges to the traditional screenreader model. Furthermore, many LabVenture activities require students to use their vision to identify plankton, find patterns in data, and plot points on graphs. All of these decisions make for an engaging and educational experience, but unfortunately not one in which all can participate.

The sheer size and range of the existing LabVenture experience required a very defined target for our effort. Our primary focus came to be improving the experience for visually impaired users, as the experience is a digital touchscreen, this is the population most underserved by the existing experience. Accommodations for visual deficits are also well documented and at a high level of maturity, due to the volume of research and prior work in this area. This thinking was also directed by advice from universal design consultants that most accomodations made for visually impaired users positively impact users with other levels of ability. However, only seeking to accomodate a narrow range of ability would be hardly any better than where we started, so while visual improvements formed the bulk of our work, attention was paid to the experience for hearing impaired users as well as users with motor disabilities. In cases where we found a change we made for visually impaired users was insufficient for other users we did our best to find solutions- captioned films, additional touch surfaces, and simple and forgiving gesture recognition.

In pursuit of those goals, and dealing with those limitations, we implemented the following key affordances.

Screen Reader

Central to the experience's accessibility is a screen reader. It provides readings of thousands of lines of text, descriptions of hundreds of images, and allows users to manipulate objects ranging from virtual black sea bass to graphs and charts in the multi-user application. Given the departure from traditional digital experiences like webpages or simple kiosks we needed to overhaul our existing screen reader. In addition to the textual content displayed on screen the screen reader is provided with additional context and descriptions of what is happening both in the room and on the table. As many of the activities in LabVenture are game-like, the ScreenReader is modified during these moments to behave in a similar manner. Moments where sighted users drag-and-drop items are translated onto the iPad one-to-one, and users can explore sonified data, all using the screen reader controls.

While modifying the behavior of the screen reader we were also aware of a need to keep the screen reader easy to use and easy to learn. This required us to design interactions to have only a few inputs while still remaining rich, but also to have a flexible controller for our screen reader.

Virtual Universal Key Pad

Traditional Universal Key Pad (UKP) devices rely on physical buttons attached to the kiosk in a rigid housing. This is usually targeting a public space, like a museum or wayfinding kiosk, which is usually single-user. As LabVenture is a multi user application which encourages students to reposition themselves during the course of the experience we wanted to support all students being free to move as they felt comfortable. A traditional UKP would require users to occupy the same position at the table for the several hour long duration of the experience, potentially isolating them in activities where the team moved around the table.

The solution we found to this was a mobile, Virtual UKP implemented as an application running on an iPad. Users can swipe and tap on the ipad to control the experience, similar to a remote control, or a game console controller. The Virtual UKP is a persistent interface for the user, even when they are sent to use another interactive station.

We ensured that all activities use a basic set of swipes and taps, with no complicated gestures, or targeting being needed. Context is always given via TTS prior to the switch in behavior, and the user is constantly provided with context and instruction while the UKP is in a different mode. In order to accommodate different levels of physical ability we ensured that movements can be small or large and still get the desired result. In this way the Virtual UKP is not just a solution for visually impaired users, but is also an affordance for users who would have difficulty using the full scale table touchscreen.

As an example, one activity requires users to sort the catch from lobster traps. This activity requires users to sort trash, black sea bass, lobsters, and bycatch such as other fish and sea life into four separate categories. A traditional screen reader approach would require the user to navigate to each item, select it, and then navigate through a sublist to select the desired bucket. All while their teammates are rapidly dragging trap contents around on screen! Instead we present the UKP user with items in the trap one at a time, starting at the bottom. When an item in the trap becomes active the user can swipe or drag it in one of four directions- each corresponding to a given sorting ‘bucket’. Starting from the bottom gives the user a chance to sort a good number of their own catch before they compete with their teammates for trap items. The UKP can sort items that a user on the table is currently holding, and vice-versa.

As there are as many different interactions as there are activities in LabVenture, it could have easily gotten out of hand if we had invented a new set of UKP gestures for each activity. Instead we continued with the same set of controls the user already learned for the screen reader. The sorting method above was repurposed later for sorting traits into lists that described habitat, appearance, and behavior, as well as for selecting supporting evidence to make scientific claims. We found that states where users had immediate access to dragging elements on screen made sense to streamline in this way, and were simple enough that they could be broken down into simple gestures. This would evolve into the control scheme for sonification.

Sonification

A key component of LabVenture is interaction with real data, and understanding how scientists look for patterns within that data. Since most data is presented in a visual format, blind and low-vision users, as well as users with disabilities that impact spatial reasoning are unable to get the same takeaways as their sighted teammates without modification of that data.

As a solution to this we have taken the data presented to students and given it two treatments so that it can be easily understood from audio alone. First, each data point is read by the screen reader, and given concrete values to the data. Then each data point is represented by a musical tone, ambient audio loop of varying amplitude, or a sliding tone. Students are then able to compare tones by pitch and amplitude to quickly identify shapes and patterns in the data.

As has been mentioned previously- the breadth and depth of activities in LabVenture present difficulties in making a screen reader / UKP based experience. In order to limit the number of possible operations we expected of the UKP user we limited exploring the sonified data set to a single axis of data. The most straightforward of these being graphs, as a user moves left to right they hear the x label at that location, as well as the y value. For image based activities we chose a critical strip of information in that image, and transposed that data onto a line. Though this simplified the image data, it still presented sufficient challenge to interpreting the data, and gave an anchor point that made the activity usable, and understandable within the given time limit.

The content for a given sonification activity is dependent on the desired takeaway for the students, as well as the content of the data. Presence / absence is easily translated to volume, non-binary changes in a value are also communicable by volume, or more distinguishably by pitch. Two changing values can be presented at the same time by varying the volume of one and the pitch of the other, as those changes can be distinguished from another. Two signals both changing in the same way are harder to pull meaningful information from.

The chosen timbre of tones for sonification is important, and often overlooked in examples from other researchers. Due to the different ways that hearing loss can manifest we found that a single sinusoidal waveform should never be used, as it represents a pure tone that might fall outside the user’s hearing range, nevertheless it is the most commonly used timbre in most examples of sonification. For content requiring both change in volume and change in pitch we used a complex timbre with many harmonics that was not only audible but also more pleasant to listen to. This means that as we shift the pitch some harmonics or even the fundamental might fall outside the user’s hearing range, but other frequencies will shift to fall inside their hearing it. A shepard tone is an interesting example of perceived pitch movement being maintained despite component frequencies dropping out and being added in.

In activities where communication about a specific region of the data is important, the sighted users are presented with a visual representation of what portion of the data the UKP user is exploring. This means that the team can come to a consensus about the data, where previously visually impaired users would have to have the activity, data, and conclusion explained to them.

During their time at LabVenture students are given a variety of challenges, one of which is counting the rings in an image of an otolith. The activity starts off simply, and then increases in complexity, with rings becoming more numerous and vague. Students are asked to count the rings in order to estimate the age of the fish. We found an exciting application of sonification was to turn that image into a volume control for a musical loop, with the volume increasing when the user had their finger over a ring, and decreasing when it was off the ring. The variance in the size, and placement of the rings means that the user has to do the same searching as their sighted teammates. At the same time, the location in the image they are touching is displayed on the table, so that their team could see what region they were talking about. This approach maintained what was fun and exciting about the activity- the challenge of searching for the rings of the otolith. As accessibility researchers have learned- we should not seek to remove all challenge, but we should instead seek to remove frustration. Simply giving the user an answer, or bypassing a challenge is not parity of experience.

Another experience requires students to find the optimal habitat for lobsters on a map. Over time the optimal habitat slowly shifts north as the water temperature increases. This presented several challenges. How can a user know where they are in a 2d map? How can a user know that the temperature is changing? How can a user know and remember the optimal range for lobster habitats while examining the data? The approach we settled on was presenting all three at the same time when they changed, or became important. As a user drags their finger from north to south they hear the name of a location they are over. If the temperature changes they hear a musical note play that is mapped to the temperatures in the map. Finally they hear a sound that represents the population of the species they are looking for. They are asked to select the region of the map for a given year where the population is loudest. The important takeaway for students is the change over time in temperature and population location, rather than what those specific temperatures are.

The choice to use musical tones and representational sounds rather than spoken data points also serves to recreate the ambiguity that a scientist experiences when examining data. In many instances, sonification can improve the experience for all learners, creating a richer more multi-sensory experience.

Audio Delivery

As audio is crucial to the labventure experience, a variety of audio delivery methods are provided for the user. Text to speech, screen reader sound effects, and sonification audio are routed to a separate audio output for the UKP user. This accomplishes several goals- the actual delivery device can be tailored to the user and their level of hearing. Users with conductive hearing loss can benefit from bone conduction headphones which are shown on audiograms to be better for hearing loss caused by deformities of the inner or outer ear. Similarly users with profound hearing loss or sensory processing issues can benefit from over-ear headphones and the ability to control their volume independently of the rest of the audio routing in the experience. When possible, bone conduction headphones are the preferred audio delivery method, as they allow the user to hear both the audio stream they are controlling with the UKP, as well as their teammates' conversations as bone conducting headphones do not block the ear canal.

In allowing users to select their preferred mode of audio delivery (over ear headphones, bone conduction headphones, or speakers) a broader range of people are accommodated.

Collaboration

LabVenture is structured around collaboration. Students are presented with videos detailing how scientists and lobstermen collaborate in the Gulf of Maine and activities are arranged so that students must work as a scientific team to complete a goal. Modifying activities to support Accessibility inherently presents a challenge here, as students have to be kept on the same page in order to collaborate, and the speeds at which users can experience a variety of types of content varies.

To account for this we present constant reminders to users to collaborate and work with their team. Users are shown a highlight around elements that the UKP user is interacting with, so they are able to understand what that user is doing, as well as not interfere with their actions.

Similarly, the UKP user is given notice when a teammate selects certain buttons, or manipulates an element that they might have selected. During activities where students are meant to perform different roles the UKP user is given a role. This portion of the table is highlighted, facilitating the shuffling that has to take place.

Project Takeaways

Accessibility is not a single problem with a single solution. It requires dedicated effort to accommodate a diverse range of abilities, and constant iteration and testing. Existing implementations and best practices are not sufficient for complex applications, real time games, or multi-user experiences. Games are a great space to watch for ongoing research into accessibility as games have a high concentration of interesting challenges and impassioned implementations of affordances. While technology can be an attractive approach in some cases it may not always present the best answer. Large gains can be made from the physical design of a space to accommodate mobility aids, conversations in sign language, or more sterile acoustics. Similarly tactile tables, charts and maps can provide intuitive understanding of data.

Disparity of experience is necessary to avoid, but completely aligned experiences are difficult to achieve, especially when modifying an existing experience. Time delineated activities are inherently not accessible, even more so when they are only calibrated to an able-bodied user’s ability. The rates at which different types of information can be communicated to different users vary. A sighted user can easily differentiate from a change in state where the whole screen changes vs only a portion of it, while describing this to screen reader users would take enough time that they would end up too far behind their team. Contrary to that, some screen reader users may be able to process textual information much more quickly than their teammates due to the screen reader being able to speak at a constant accelerated rate. Information cannot be presented to a user just once. Visual information can be revisited, so should audio information. This conflicts with activities being time delineated. At times the screen reader had to be modified to read, and reread elements that were not currently on screen.

LabVenture's focus on collaboration might pose difficulty for deaf or hard of hearing students. While videos are subtitled, and anything read by voiceover is also written onscreen, the room itself is loud. Communicating verbally with other students will be difficult. Students record their observations after discussing them, so hearing impaired students will have an opportunity to communicate about the activity via writing, but it is not ideal.

Users with low vision are a prime example of why simply following best practices is not sufficient. We have to thoroughly test with a variety of users. For users with low vision the accessibility features on devices are less intuitive than the sighted UI. LabVenture, and our implementation of a separate screen reader further complicates this. A user with profound or total vision loss might find that the UKP allows them to feel more a part of the group, as they are able to read and manipulate the user interface where they previously could not. However users with low vision, who can rely on that vision a portion of the time, may not need to use the UKP and could be more hesitant to use the UKP as they feel it is differentiating them from the team. We also found that low-vision users need physical proximity to the screen to see the content, the flat, static orientation of the table can present a problem, as it is difficult to bend over for very long periods of time.

Many typical accessibility tones or sounds can be "annoying" and people prefer content-based sounds or pleasant/more musical sounds for sonification. Each sonification implementation requires a different approach. It has many parallels with data visualization in that the method used has to be fit to the data. The wrong representation can hide patterns in the data, and the right method can make them more obvious.

Future Directions

This solution was a retrofit, meaning that there were many compromises that came out of trying to add to the experience without modifying the underlying structure. Future versions of LabVenture present an opportunity to integrate inclusive design as part of the process from its inception.

The infrastructure that is in place now is production ready, and is the result of constant iteration to improve the user's experience. However there are opportunities for improvements to streamline set-up, allow for more flexibility in the screen reader, and reduce opportunities for mistakes in the activity creation process. All of which would allow for a better experience as time and effort could be spent elsewhere.

Sonification was a task with many difficulties that are more-or-less solved now. Implementing sonified experiences in the future will be less time-intensive. We look forward to the opportunity to sonify more types of data in the future, and even begin using said data outside of accessibility solutions. We also now have a basic vocabulary and body of work to draw from when working on future sonification efforts.

For this effort we primarily targeted visual and hearing impairment. Future experiences pose an opportunity to investigate how to better serve all users.

Appendix 1.A

The following is an excerpt from our sonification prototyping phase. This round of prototyping helped to solidify the simplification of user inputs as it brought about the method of interpreting an image as a single line of critical data.

Sonification Prototyping — Round 1: Otolith

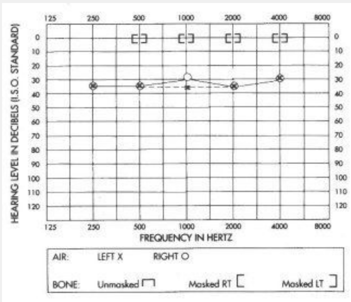
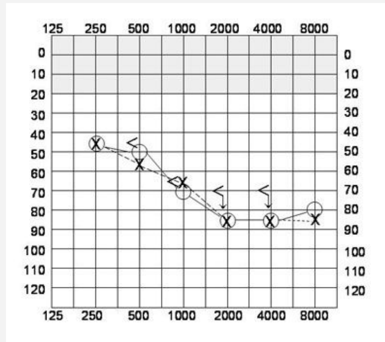
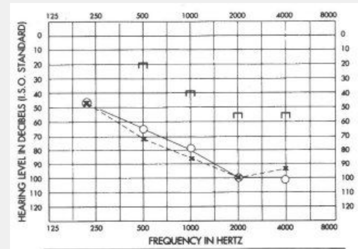
Motivation

- Provide an interface for aging Otoliths to the UKP user
- Communicate the challenges that QT based audio presents to sonification
- Present a possible solution that still provides a worthwhile experience
- Explore the quality of experience provided by the technical solution
- Explore the possibility of sonification that is not based on change in pitch detection to accommodate for hearing loss that might affect portions of the audio spectrum.

Limitations

QT's raw C++ audio output is being used for the UKP audio stream as it supports custom selectable outputs. The audio output is low level, so it is extremely flexible, but also difficult to work with as higher level functionality is not supported. EG: developer needs to know what file format they are providing the output, there is no built in synthesis.

Frequency based sonification is likely not sufficient. Hearing loss is not a dampening across the entire audio spectrum but instead can attenuate different frequencies by varying amounts. The audiograms below represent three different types of hearing loss and show their relation to frequency. These illustrate that a user would have moderate to severe difficulty differentiating tones above 500 hz. It is noteworthy that while the user with conductive hearing loss appears to suffer no loss of bone conduction hearing (marked with bracket shapes in leftmost graph), the user with mixed hearing loss sees similar patterns of attenuation in hearing for both types of transducer. What this means is that even though we are potentially using a bone conduction transducer for the user they will still have an attenuation of higher frequencies.

		
Conductive Loss (Deformation of inner or outer ear)	Sensorineural hearing loss (Age, sound exposure, neurological morbidity)	Mixed Hearing loss (Variable combination of conductive and sensorineural hearing loss)

Solution / Prototype

A common approach to user-controlled audio is mixing 'stems'. A stem is a pre-recorded audio track that an application (typically a game or interactive art software) controls based on the current state of the system. While a full explanation of audio stems is beyond the scope of this document we'll be exploiting the following common features of audio stems:

- Stems can loop (Stems are stateful, and should support maintaining a constant state)
- Stems can be manipulated (volume, filtering)
- Stems are designed to play at the same time as other stems (Layering)

The solution this round of prototyping explored was varying the amplitude of an audio stem based on the brightness of a prepared data image.

Takeaways

- Limiting the interaction to just a single dimension is fine, as it makes the activity more understandable.
- Volume should be threshold-based (no gradations in brightness, just on or off with some transitional fading)

Appendix 2.A

The following is an excerpt of our screen reader technical documentation, which serves as an introduction for developers to our screen reader.

Screen Reader Reference

The screen reader used in GMRI works with a separate TTS engine and remote UKP in order to make Labventure more accessible. For an activity to be made compatible with the screen reader it needs to be split into separate accessible states. These accessible states represent the different stages that an activity can be in, and make certain UI elements available and unavailable.

UI elements are made interactive via the UKP by implementing a few properties.

Accessible Elements: Common Properties

Previous and Next elements
If an element is meant to be a part of a list, its previous and next elements let the screen reader know how to travel through the list.
Press Action
Elements that perform an action on press need to define that action themselves.
Moving between Options / Modifiers
Some items have multiple options that can be set, or can have their values modified. Because these actions are specific to an object it is implemented on the object itself.
Custom interaction / games
Some elements don't have neighbors in a list. Instead they are set up to perform other actions on left and right navigation. An example is the trap sorting race. Elements supporting directional actions do not support list navigation

Connecting Elements

In order for elements to be assembled into a list they have to be connected. You should never manually or declaratively make this connection, instead favoring the ScreenReader.clearAndConnect() function. This function takes an arbitrary length list of arguments and sets their accessibleNext and accessiblePrev values to order the list as a linked list. When two elements are connected their accessible next, and accessible previous properties are pointed at one another. This means that the screen reader can now move from one item to the next and back.

Navigation Behavior

In addition to elements being accessible in the current activity there is also a persistent meta navigation. The meta navigation holds elements that pertain to the entire activity. At the time of this writing this includes a summary of the current state, and a speed control for text to speech text. The meta navigation has no visible on screen elements associated with it, instead it always appears at the end of the list of accessible items. It is automatically added to the list when using clearAndConnect.

There are a few other navigation behaviors:

- The screen reader list loops around when the end of content / meta nav items are reached.
- Offscreen items that appear after an action takes place are skipped while offscreen, the screen reader simply jumps to the next available element. A chime plays when they become available again.
- Invisible, but interactive elements are not skipped. This includes things like additional text that have no onscreen element, and 'accessible decisions' where a user can choose yes or no.

The Screen Reader Can:

- 'Focus' on a single QML element 'lastSelected'
- Maintain minimal state info about the current 'list'
- Automatically read the selected item's description
- Be set to inactive (during choreographed moments)
- highlight selected elements (used during collaborative multitouch states)
- Call prescribed functions that implicitly reference that element
    - readDescription() - Read the element's description, followed by auto appended global instruction based on element's properties
    - selectAccessiblePrev() - Move to the 'previous' element in the list, defined by the element's accessiblePrev
    - selectAccessibleNext() - Move to the 'next' element in the list, defined by the element's accessibleNext
- Call prescribed functions defined by the element.
    - element.accessibleRight() - tell the element the user has swiped right (trap sorting etc)
    - element.accessibleLeft() - tell the element the user has swiped left (trap sorting etc)
    - element.accessibleUp() - tell the element the user has swiped up (counters, etc)
    - element.accessibleDown() - tell the element the user has swiped down (counters, etc)
    - element.accessiblePress() - tell the element the user has tapped (buttons)

Setup

Because the number or ordering of list elements might change each State has multiple 'accessible states', these are setup with a function.

An accessible state function should do the following:

1. Reset connections,
   This sets our list size to 0. This is useful for elements that know their order in their own list.

2. Set the callback used when 'back' is called by the user.
   This should always be an accessible state, either another state or the same state.

   Example:

   A user is looking at a species guide, they are in the state 'accTopLevel'.
   They then select the images at the top of the screen to look at them as a gallery.
   Selecting it calls 'accStateImageGallery'.
   The user is now in a list of three elements. If 'accStateImageGallery' set 'navigateBackCallback' to be the top level function the user can hit back to return to the top level list.
   For safety the top level state should set this to itself to allow recovery from broken states.

3. Connect elements.
   This makes the accessibleNext and accessiblePrev properties of logically adjacent elements reference one another. This is how the screen reader knows what elements it can visit in what order. 'clearAndConnect' also sets the accessibleNext/Prev properties to null on elements on the two ends of the list. ClearAndConnect uses the arguments array, meaning the number of arguments you can pass it is flexible. Some states use an outdated 'connect' call, rather than the newer clearAndConnect- this is deprecated and subject to change

4. Call 'begin'
   This sets the screen reader's focussed element to the passed element and sets the screen reader as active.


fish?
image to determine the age in years.