8803 SRD: PhET Simulation Accessible UI & Sonification End-of-Semester Report

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1 Introduction

PhET is a collection of web applications that use interactive and gamified simulations to help students learn scientific/mathematical concepts. The simulations have target audiences ranging from elementary school students to college students. Currently, most of the simulations rely on visual representations to convey their (change of) content, limiting its usability and accessibility to certain users. This semester, the team's work has been researching about and design sounds that sonify PhET simulations and we chose to start with one simulation Build an Atom because it is relatively simple and standard.

2 Research

In preparation for the sound design, the team conducted a two-phase research process to understand how users are currently using the simulation Build an Atom.

2.1 Task Breakdown

The team first interacted with the simulation and broke down the simulations by listing all the changes on the interface based on the steps in carrying out specific tasks. For example, in building a Lithium atom, one step is

3. Move a proton to the nucleus
    - 3.1. A proton is added to the nucleus
    - 3.2. Element (becomes hydrogen)
    - 3.3. Neutrality (becomes cation)
    - 3.4. Stability (becomes stable)
    - 3.5. Options for complementary information
        - 3.5.1. Net charge (+1)

The step is decomposed based on the action and the change on the screen, both of which are listed in a hierarchical manner. The task breakdown helped the team understand the simulation and what's most important in terms of information to present to the user.

2.2 Cognitive Walkthrough

The team then conducted a cognitive walkthrough with Amy, a high school chemistry teacher that has been using Build an Atom to teach the concept of atom. She walked us through her usage of the simulation in classroom and observations of her students using it. She gave us valuable information about how the students are currently using the simulation and the pain points in their usage. For example, one important finding is that a sound without proper explanation of its meaning often confuses the student.

3.Sound Design

3.1 Theory

Kramer has described several level of relationship between the sound and its referent (Diagram 3.1[1]). The most intuitive sound is to use direct ecologic sound (e.g. the creak of a door to represent the door opening). The second level is to use indirect ecological sound (e.g.the mixture of leaves rustling, thunder and the sound of rain hitting the ground to represent a storm). The third level is to use indirect metaphorical sound (e.g. the buzzing sound of bees to represent helicopter.). Based on this theory we analyze the characteristics of the elements which we need to sonify and come up with our design idea.

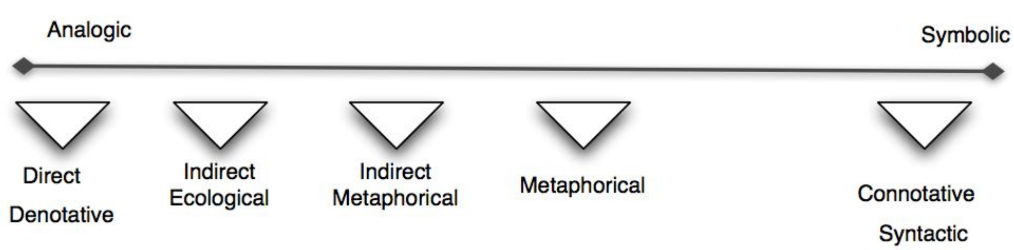


Diagram 3.1 levels of representation continuum

3.2 Design

General design:
Unlike sonify weather or the buzz sound from a bee that are exist in everyday life, the particle within an element does not have any ecological sound in the real world, so the focus of sonifying elements is mainly about creating an engaging experience to the users. To achieve this, we decide to use rhythm to describe the atom. We divide one measure into eight time slots, the sound that stands for different particles are triggered in different time slot within a measure, the time slot is chosen randomly each time the user add a particle, which means the complexity

[1] Kramer, Gregory. *Auditory display: Sonification, audification, and auditory interfaces*. Perseus Publishing, 1993.

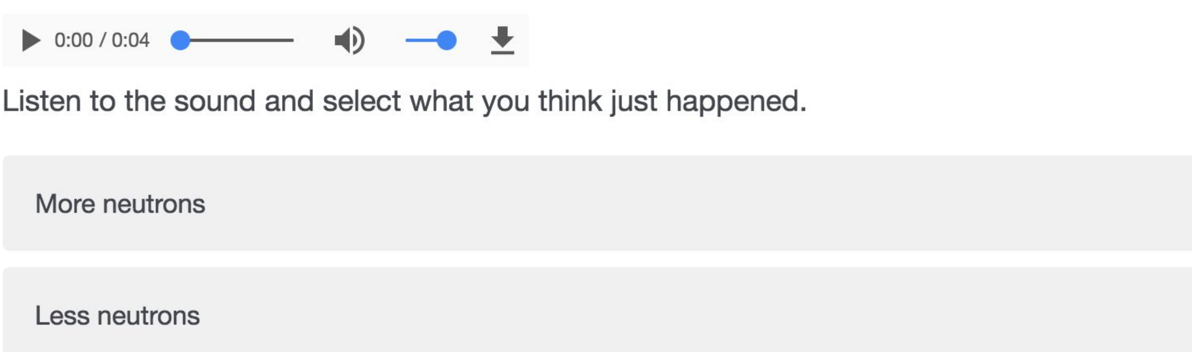
of the rhythm pattern are increased with the number of particles increases within an atom. The randomness of time slot chosen enforced the gaming experience which made the pattern different every time the user build it.

Elements	Previous Design	Current Design	Rationale
Proton	A snare drum sound that is generated by pink noise added with a klank resonate filter	Based on previous design, we add another snare drum sound by add a resonant filter whose resonant frequency is higher than previous sound.	The proton has charge, so we want to map the noise with charge in this application. Two sounds are representing proton, because we total number to be added is 10, it would be massy by using only one rhythm line. The lower sound stands for the elements in the first row of element table.
Neutron	A bass drum sound that is generated by a sine tone with a low frequency around 120Hz added with a little portion of noise which compensate the higher frequency and create a colliding sound. A percussion envelop is added to amplitude.	Based on previous design, we add another sound by raising the frequency of previous sound.	The neutron is without charge, so we use pure tone to represent it. And to separate this with proton sound, we use lower frequency space. Two sounds are representing neutron, the first three neutron has a lower sound which acting like a cue in one measure.
Electron	A stand alone sine tone add with a LFO, the sine tone is with high frequency, and the LFO on amplitude conveys the rotating behaviour of electron, the sound is not in sync with rhythm.	A buzzing electric sound that is generated by two saw wave with slightly different frequency which create beating frequency. The sound is at the first beat of one measure and may raise the frequency when increasing in number	The previous design works well when there is only electron happening, however when working with the rhythm generated by proton and neutron, is become quite annoying and distracting because not in sync. The current design sounds more like a electron but conveys no rotating behaviour. But working with rhythm is the first concern.
Mass	A sine tone with a huge reverb, and decrease in pitch with increase in number. A stand alone a sound that is not in sync with rhythm.	Use the tempo of rhythm to convey, the tempo of rhythm decrease with increase of mass number.	The first sound is not intuitive enough, and the tempo has larger the influence on rhythm.
Net	A white noise with a broad	Two sounds stands for	The second design conveys better

charge	band pass filter, the cutoff frequency increase as net charge increase	net charge, one for positive, the other for negative. Generated by sine wave added with pink noise. For positive charge, the sine wave's frequency is added with an increasing envelop, for negative sound, the sine wave's frequency is added with decreasing envelop.	with the difference between negative and positive sound.
Stability	Two sine wave sound that are slightly different in frequency which creates a impalsing sound.	The sine wave that modulate the whole output of rhythm sound, which shake the hearing.	The first designs sounds distracting when working with rhythm. The second sound combines with rhythm which saves sound space, and make the rhythm sounds more interesting.

Evaluation

After finishing designing sounds, the team came up with a Qualtrics survey to evaluate the sound design. An example question in the survey is



The goal of the survey is to evaluate

1. How well the user can match the sound to the particle in action (neutron, electron, electron).
2. How well the user can match the sound to the change of property (mass number, net charge, stability).
3. How engaging the sounds are.

Future Work

Next, the evaluation will be executed and the feedback will be analyzed and applied to the redesign of sound. The ultimate goal is to generalize the sound designs to other PhET simulations.