



Supporting Simulation Use for Students with Intellectual and Developmental Disabilities

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Abstract

In this study, we explore how enhancing interactive science simulations with sonifications can scaffold interaction and learning for students with intellectual and developmental disabilities (I/DD). We added auditory cues to three PhET Interactive Simulations as additional feedback to highlight important concepts and relationships. Working with seventeen students who have I/DD, we evaluated the success of these cues in emphasizing science concepts, explored what additional help may be necessary to support successful inquiry-based learning for these students, and collected feedback on the auditory cues and the students' overall user experience.

Keywords

Sonification, intellectual and developmental disabilities, science education, simulations

Introduction

More than 800,000 K-12 students in the US have an intellectual or developmental disability (I/DD) (Snyder et al., Table 204.30). Students with I/DD are commonly taught in inclusive, general education classrooms (Snyder et al., Table 204.60). To support the inclusion of students with I/DD in science learning, the Georgia Tech Sonification Lab is working with PhET Interactive Simulations (phet.colorado.edu) to make their award-winning educational simulations (sims) more accessible. PhET sims provide interactive learning environments designed to support exploration and experimentation, and are frequently used for guided-inquiry activities in K-12 and college science classrooms (Moore, et al.).

Effective approaches to support understanding of science concepts for students with I/DD is an active area of research (Stavroussi, et al.). In this work, we seek to investigate the use of highly interactive and exploratory science learning simulations by students with I/DD and the benefits of sonification to support learning. Sonifications can provide additional presentation modalities beyond the visual for complex concepts, giving users the opportunity to learn in different ways (Low & Sweller), some of which may be particularly beneficial to students with I/DD. For example, sound can be used to draw additional attention to the most important representations on-screen or provide recognizable auditory cues that remind students of relevant contexts.

Sonified PhET Simulations

We enhanced three PhET simulations with prototype sonifications consisting of a combination of auditory cues (Table 1). The sounds were customized for each sim based on past research, pedagogical content, and structure and interactivity of each sim. Many of the sound design choices were informed by past auditory display research (e.g., Walker & Nees), and used

to highlight important state changes or relationships. We briefly describe each sim and the most pedagogically relevant sounds below. See Tables 2-4 for a complete list of sound descriptions, mappings, and rationale.

Table 1. Auditory Description Categories.

Auditory Display Type	Description	Example
Auditory Icons	Brief realistic representations of an action	An object being rubbed on a sweater
Earcons	Musical, learned auditory representations	A sound which plays after a reset button press
Mapped Sonifications	Modulated representations which vary based on the parameter changing	Increasing pitch as more electrons are transferred to a balloon

Table 2. Sound Design Table: John Travoltage.

Concept or Action	Visual Representation	Auditory Representation	Mapping	Reasoning for design
Foot Movement	Foot moves across carpet	Filtered noise, sounds like rubbing on clothing	Increasing speed = faster carpet rub, slower drag = louder	Auditory icon mimicking real-world sound
Transfer of charge	Blue electrons build up in his body	Short “popping” sounds, one for each electron grabbed	Pitch increases as the number of charges on him increase	His body is “filling up” with charge, following same auditory pattern a bottle has as its filled with water
Accumulated charge	Electrons move around body and distribute themselves	“Clanking” sound	Any amount of electrons cause volume > 0	Earcon evoking the feeling of particles moving
Hand Movement	Hand moves towards or away from doorknob	Short melodic tones	Pitch increases as hand approached doorknob, decreases as moved away	Parallels localization task, pitch represents closeness to the target
Being shocked	A bolt of electricity travels from hand to doorknob, electrons leave body and enter doorknob	“Bzzzt ouch!” followed by short melodic tones of electrons leaving	Pitch decreases as electrons discharge	Using auditory icon to evoke the feeling of being zapped; pitch decreases as electrons are ‘draining’ out (inverse of charge accumulation)

Table 3. Sound Design Table: Balloons and Static Electricity.

Concept or Action	Visual Representation	Auditory Representation	Mapping	Reasoning for design
User-controlled balloon movement	Location in the play area	“Buzzing” musical loop when negatively charged	Increasing volume as it’s moved further away from the sweater	Polarity mapping between distance from the sweater, changes based on number of charges on it.
Non-controlled balloon movement	Velocity of Balloon movement	Filtered noise, sounds like “whoosh”	Increased volume as the balloon velocity increases	Sonification paralleling realistic drifting sounds
Induced Charge	Electrons in wall are repelled	“Buzzing” musical loop	Playback rate increases (higher pitch = more deflection of electrons in the wall)	Sonification from polarity mapping research, objects with more energy have increasing tempo (and higher pitch from playback rate)
Balloon pick up/drop	N/A	Two tones in succession	Ascending tones for pickup, descending for drop off	Earcon representing z spatial position (selected is ‘higher’ than dropped)
Hitting Wall	Balloon touches wall	“Bumping” sound	N/A	Auditory icon mimicking real-world sound
Rubbing on sweater	Balloon moving back and forth along sweater	Filtered noise, sounds like rubbing on clothing	Volume increases with faster & longer rubs, plays during any movement on the sweater	Auditory icon mimicking real-world sound

Table 4. Sound Design Table: Build an Atom.

Concept or Action	Visual Representation	Auditory Representation	Mapping	Reasoning for design
Pick up/drop particles	Particle is removed/added from bin	Two tones in succession	Ascending tones for pickup, descending for drop off	Earcon representing z spatial position (selected is 'higher' than dropped)
New element type built	Proton added to center of the atom, element name shown, element abbreviation updated in table	Two note chord plays after proton drop sound	Higher pitch for lighter elements, lower pitch for heavier (more massive) elements	Earcon from polarity mapping 'mass' or 'weight'
Neutral/ion	Label shows: + Ion, - Ion, or Neutral Atom	Three note glissando	Rising pitch for positive ion, descending pitch for negative ion, no sound for neutral	Earcon from auditory graph research (pitch change in direction of positive or negative)
Stable/Unstable	Label shows unstable or unstable; atom nucleus vibrates when unstable, static when stable	Pulsing constant tone when unstable	Sine and triangle wave with a low frequency oscillator at 10 Hz	Earcon, informed by alert and warning research

John Travoltage

The *John Travoltage* sim can be used to support exploration of static electricity. It opens with a man, John, standing on a carpet next to a doorknob. Students can move John's leg to accumulate negative charges, and move his arm towards or away from a doorknob to discharge the charges - resulting in a "zap." The farther John's hand is away from the doorknob, the more

charge must be accumulated on his body before a discharge occurs (Figure 1). John's hand movements are mapped to the pitch of a sound: pitch increases as his hand approaches the doorknob. When his foot is rubbed on the carpet, an auditory icon plays a realistic "rubbing" sound; the appearance of each negative charge on John's body results in a short tone with ascending pitches to represent the accumulation of electrical charge. A gentle "clanking" sound represents the movement of accumulated charges on John's body.



Fig. 1. Screenshot of PhET sim John Travoltage. Left panel: Hand away from doorknob, many charges have built up before discharge, discharge occurring. Right panel: Hand near doorknob, few charges have built up before discharge, discharge occurring

Balloons and Static Electricity

The *Balloons and Static Electricity* sim can also be used to support exploration of static electricity. The sim consists of a balloon, a sweater, and a wall; all three of these start with a net neutral charge. The balloon can be moved around the play area, and can collect negative charges when rubbed on the sweater. If the balloon has a net negative charge, upon release it will move to and stick to the (positively-charged) sweater. Moving the negatively-charged balloon near the wall results in an induced charge effect. Negative charges in the wall are repelled by the negative

charges on the balloon resulting in a slight induced positive charge of the wall near the balloon. The more negatively charged the balloon, the greater the induced charge that occurs along the wall (Figure 2).

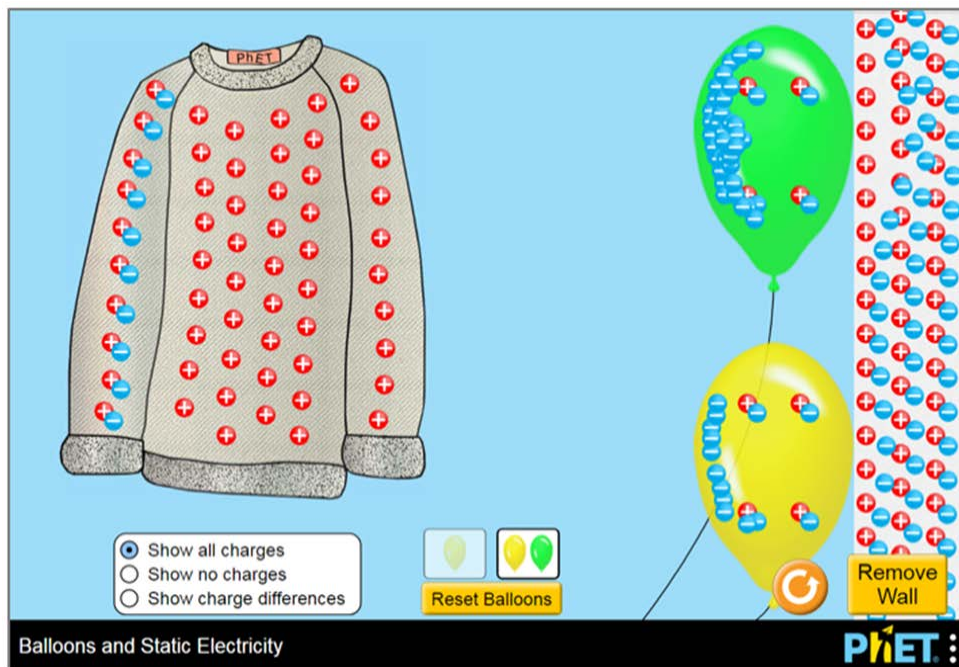


Fig. 2. Screenshot of the PhET sim Balloons and Static Electricity. Upper balloon has a large number of negative charges and results in a large induced charge along the wall. Lower balloon has fewer negative charges and results in a smaller induced charge along the wall.

Ascending and descending tones represent selecting and releasing the balloon. The volume of a pulsing tone represents the charge on the balloon (more charge results in a louder volume). Another short tone increases in frequency as more charges are transferred. The balloon's movement when released is represented by a consistently increasing tone, played at a speed determined by the amount of charge on the balloon.

Build an Atom

Build an Atom is a chemistry sim that allows exploration of a model of an atom, represented by a nucleus with two electron orbits, with buckets of protons, neutrons, and

electrons. Students can drag the protons, neutrons, and electrons into the atom model and receive feedback indicating what atom they have built, its overall charge, and its location in the periodic table. Some of the feedback is provided as text labels on the atom model, and other feedback is provided in boxes beside the atom model (Figure 3). Ascending and descending tones represent selecting and releasing protons, neutrons, or electrons. The most notable sonification was the representation for element type: when a new element type is built, two tones play together; decreasing pitch of the pair represents heavier elements.

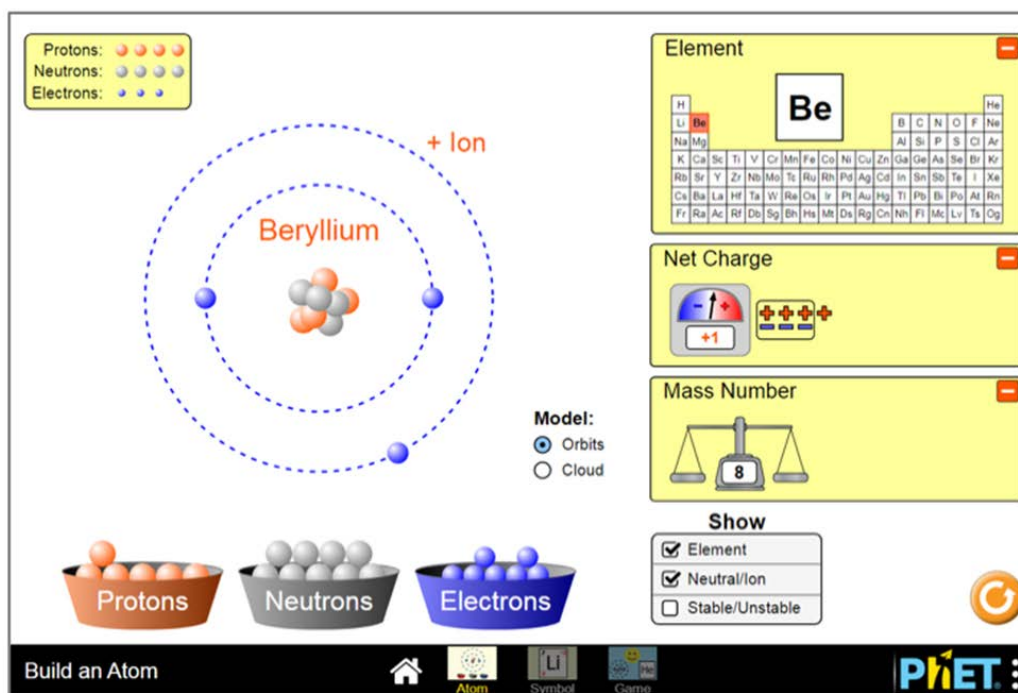


Fig. 3. Screenshot of the PhET sim Build an Atom. Atom model shows Beryllium with four protons, four neutrons, and three electrons. Readouts along the side indicating element, location in the periodic table, net charge, and mass number.

Methods

Participants included 17 students from the summer component of the EXCEL Program at the Georgia Institute of Technology. The EXCEL Program is a four-year college program for

students with intellectual and developmental disabilities, and the summer component includes both current high school students and recent high school graduates. Students reported daily use and familiarity with smartphones, tablets, and computers. Five students reported that they play video games on consoles, computers, or handheld devices. Multiple students stated they had trouble reading familiar and unfamiliar words, remembering content from lessons, and focusing on school or schoolwork.

Of the 17 students, twelve used *John Travoltage*, eight used *Balloons and Static Electricity*, and four used *Build an Atom*. Each student had up to five minutes of free exploration time where they could play with the sim to gain familiarity. Next, students answered sim-specific task questions to explore whether or not they were understanding the audio and visual representations. Students were encouraged to use the sim to answer the task questions. Total time spent using the sims ranged from 5-12 minutes (*John Travoltage*), 7-18 minutes (*Balloons and Static Electricity*), and 11-25 minutes (*Build an Atom*). After sim use, we collected survey responses on general user experience (Finstad; Watson, Clark & Tellegen) and asked for open-ended feedback about the sonifications. A complete list of task and survey questions can be found at bit.ly/csun2018-methods. Screen capture recordings and verbalizations were analyzed for trends in successful and unsuccessful student interactions with the sims in conjunction with their survey responses.

Results

Student Exploration

These interactive simulations are designed to support student exploration as a part of an inquiry learning process. During the free exploration portion of the interviews, all of the students explored the sims on their own, though some students (five with *John Travoltage*, three with

Balloons and Static Electricity, and two with *Build an Atom*) needed additional encouragement to start. Some of the students consistently continued to use the sim (without prompting) to answer the questions (seven using *John Travoltage* and *Balloons and Static Electricity*, four using *Build an Atom*), while the rest attempted to respond from memory of their free-exploration experience. With prompting from the researcher, these students would utilize the sim to respond more thoroughly to questions.

Student Use of the Sonified PhET Simulations

All of the students interacted, engaged in successful exploration, and also encountered challenges while using the sims. Here we describe student interpretations of the sound and visuals, and common challenges.

John Travoltage Simulation

Eleven of the twelve students who used *John Travoltage* correctly interpreted what happened when they rubbed John's foot on the carpet; all of them referenced seeing the charges appear, and two mentioned hearing the sonification representing transfer of charge from the carpet to his foot. After adding electrons to John's body, six students correctly interpreted the resulting "clanking" sound, representing the electrons dispersing throughout John's body. Nine students correctly interpreted the "zap" sound and described (when asked) that the spark moved from John's hand to the doorknob.

During sim use, we asked what happened to John in the sim when they moved his hand towards the doorknob. Four students responded correctly that John had to have a certain amount of charge on his body to be shocked, and five other students thought he would be shocked all the time. As a follow-up, we asked the students to generate 4, 6, 10, and more than 12 electrons, and then tell us what happened; nine students correctly described the overall phenomenon, and three

referred to the “zap” sound later in the interview. When asked to provide additional feedback about the sounds, students indicated they liked the discharge “zap” sound, the “clanking” charge sound, and the sound when moving John’s arm.

Two common challenges were encountered with this sim. Three students had difficulty during initial exploration getting John’s leg to move, which is required to begin picking up negative charges. Students would use the mouse to ‘click’ on the leg (which does not result in leg motion) rather than using a ‘click and drag’ interaction. With prompting from the interviewer, students encountering this issue were able to successfully move the leg. A second common challenge, encountered by seven students, starts with the successful collection of charges on John’s body, and successfully moving John’s arm to result in a discharge event; however, then some students did not move John’s arm again without prompting, resulting in a narrowing of the exploration students engaged in. Leaving John’s hand near the doorknob results in repetitive discharge events when rubbing the foot on the carpet, and does not allow for exploration of how the amount of charge on John’s body relates to the distance John’s hand needs to be from the doorknob to discharge.

Balloons and Static Electricity Simulation

All eight students who used *Balloons and Static Electricity* correctly described what happens to the balloon when it has charges and is released away from the sweater (i.e., it drifts towards the sweater), and all correctly described that the negative charges in the wall move away from a negatively charged balloon. Five students later referred to hearing the sound that represented this induced charge on the wall. In the user experience questions, four students mentioned their favorite sounds related to the behavior of the balloon, for example, the “think”

sound of the balloon hitting the wall, or the “swooshing” sound of the balloon being attracted to the sweater.

A common challenge, encountered by six of eight students, involved the successful transfer of all of the available negative charges from the sweater onto the balloon. Transferring all of the charges is a useful exploration, and allows students to set up scenarios to observe the most extreme behaviors in the sim. For example, when all of the available negative charges are on the balloon, moving the balloon to the wall results in the largest induced charge, and releasing the balloon results in the balloon moving to the sweater with its highest velocity. Once this has been accomplished, students need to use one of the two reset buttons (‘reset’ the full sim, or ‘reset balloon’) to remove the charges from the balloon. Without resetting the balloon, students cannot contrast the large induced charge and the high balloon velocity with other cases, narrowing the available opportunities for making comparisons with the sim.

Build an Atom Simulation

All four of the students who used *Build an Atom* recognized that adding particles to the atom model resulted in changes to the atom labels for element name, stability, and atom properties such as atomic mass, but three of the students struggled to read and understand these label changes. Labels included discipline specific terms, such as element names (e.g., “Helium,” “Lithium,” or “Oxygen”) and state information (e.g., “Ion” and “Neutral Atom”). The only student who did not have difficulty interpreting the label changes had previously taken a chemistry class. Three students reported their favorite sounds were the earcons representing selecting and dropping particles, and the decreasing pitch sound representing increasing mass.

In addition to challenges reading and interpreting the sim’s labels, students had difficulty relating the changes that occur in the atom model at the center of the screen and the readout

boxes along the right side of the screen. For example, one student, with the ‘Mass Number’ box open, did not notice the update in the mass number on the scale while adding neutrons, and thought that “neutrons don’t do anything.” Another student used the stable/unstable checkbox during the free explore portion, but did not refer to it again even when directly asked which particles affect stability. Similarly, none of the students referred to the net charge box when describing what makes an atom neutral or an ion, although two students opened it during the free explore time.

Discussion

Accessing Unique Exploration Pathways and Supporting Comparisons

Consistently across all sims, we observed a trend in students initiating effective sim use by setting up scenarios which would help them explore different ideas in the sim. However, many students limited the number of comparisons between scenarios (e.g., not resetting the amount of charge on the balloon in *Balloons and Static Electricity* to compare scenarios with a few, a few more, and many negative charges), and needed encouragement to try more comprehensive different interactions. Cueing for students to choose a specific new interaction pathway could be provided by a teacher facilitator, peer, activity prompt, or by a learning environment that the sim is embedded within.

Supporting Exploration and Interpretation of Peripheral Simulation Features

Students tended to focus directly on the content in the center of the screen, where the majority of their interactions were, posing a challenge for sims which provide additional details through peripheral displays (e.g., expandable boxes) or interface controls (e.g., reset buttons or radio buttons to change views). Auditory or visual cues that highlight relationships between central and peripheral representations may help address this challenge. Prompting further

exploration of these details, through built-in scaffolding or additional instructional support, can also be used to help direct attention to these peripheral displays and controls when needed, and encourage more comprehensive exploration for students.

Conclusion

In these interviews, students explored the sims, and enjoyed and made use of the sound representations. Many students indicated understanding some of the primary learning goals of the sims, particularly after completing the prompted tasks. Modifications of the tasks used in this work could be utilized by teachers to support students with I/DD in the classroom.

To address the apparent print disabilities observed, we are investigating the addition of text-to-speech to support students with interpretation of on-screen text. We have also begun including description content into multiple PhET sims, to support students with visual impairments, and noted that providing this content to students with I/DD could be beneficial. We are also investigating the use of visual cues, in the form of arrows, to support ‘click and drag’ interactions. Increased visual and auditory support to highlight coordinated changes across the whole screen, including relevant peripheral features, could better support and scaffold self-driven exploration and understanding.

Overall, the sonifications supported understanding for students with I/DD, and the students referenced these sounds while answering questions in the interviews. Future work will explore how text description and sonifications could work together to support diverse learner needs and scaffold sim exploration.

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