Design and Evaluation of a Multimodal Science Simulation

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ABSTRACT

We present a multimodal science simulation, including visual and auditory (descriptions, sound effects, and sonifications) display. The design of each modality is described, as well as evaluation with learners with and without visual impairments. We conclude with challenges and opportunities at the intersection of multiple modalities.

Author Keywords

Multimodal; evaluation; interactive simulation; learning; visual impairment.

INTRODUCTION

The use of multiple modalities within a single interactive learning experience can support diverse learners [9]. In this demonstration we use visual display and auditory display – verbal description, sound effects, and sonifications – within an interactive simulation (sim) to support exploration of the physics concept static electricity for learners with and without visual impairments.

Our aim was to create a single sim with multiple modality ‘layers’ capable of being accessed at once or in different combinations to meet the needs of individual users in the moment. We built upon prior work on interactive sims [7,13], description of interactives [6,14], and auditory display of learning tools [18,19,20], and evaluated the sim from the perspective of providing universal access [2].

MULTIMODAL DESIGN OF JOHN TRAVOLTAGE SIM

The PhET physics sim John Travoltage [10,11] consists of a man, John, standing on a rug with his hand reaching out towards a door. Rubbing his foot on the rug results in the transfer of negative charges from the rug onto John’s body. John’s arm can be moved in a 360-degree circle, resulting in his hand being closer or farther from the doorknob. Depending on the amount of negative charges on John’s body and the distance of his hand from the doorknob, the

electrons can discharge – transferring to the doorknob and ‘shocking’ John. Science learners from upper elementary school through college can explore the relationship between the amount of charge on John’s body and the distance of his hand from the doorknob that results in discharge/shock. Learners can navigate the sim using a mouse, touchscreen, touchpad, keyboard, or other input devices, and access descriptions with screen reader software.

Visual Display

John is a black-and-white semi-realistic character striking a playful pose (arm and leg appearing poised for action) in a room. John, the small rug he’s standing on, and the door are central. A small window looking out onto a tree are off to the left. Negative charges are shown as small blue balls.

Auditory Display

Sound Effects & Sonifications

Multiple types of sound effects and sonifications [19] listed in Table 1, were designed [11], to support visual and non-visual sim experiences. Sound is played using Web Audio [1] and PhET’s sound library Tambo [12].

Sim Feature	Mapping
Foot Rubbing	Carpet rubbing sound (Auditory Icon)
Charge Transfer	Number, pitch increases/decreases as number increases/decreases (Sonified Earcon)
Charges on Body	Static-like, increasing number increases volume and playback rate (Sonification)
Arm Rotation	Ratchet, pitch increases as hand-doorknob distance decreases (Sonified Auditory Icon)
Discharge	Electrical Zap (Auditory Icon)
Shock	“Gazouch” (Speech)

Table 1. Sound mappings in John Travoltage sim.

Description

Description can be accessed using screen reader software to support non-visual learning experiences. Dynamic description provides an always-available description of the current state of the sim. As learners interact with John’s arm or leg, they are provided with position values and real-time alerts. Descriptions highlight the key relationships: amount of charge and hand’s distance from doorknob. With John’s leg, position values indicate when “Foot rubbing on

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rug” and when “Foot off rug,” and alerts indicate charge transfer, e.g., “Electrons on body: 3.” For the arm, position values indicate distance from doorknob, and regions and landmark positions, as well as changes in direction and progress toward or away from doorknob. Description is structured using PhET’s description framework [14], designed [5,8] and implemented using a Parallel DOM [15].

EVALUATION OF MULTIMODAL DESIGN

As part of an iterative design process, we utilized rounds of think-aloud interviews [3,8,17] with learners with disabilities (visual impairments or intellectual and developmental disabilities (I/DD)) and without disabilities from primary school age to adult, to inform design of all sim features. We also included feedback from teachers, content experts, and expert screen reader users. To evaluate later design stages, we conducted semi-structured interviews of adult learners with visual impairments (n=5) and think-aloud interviews with children (n=3) and college students (n=3) without visual impairments.

Semi-structured Interviews

Interviews began with 10 minutes of free exploration of the sim. Then, participants answered a series of open-ended questions about their experiences and interpretation of: sim navigation, description, and sound. Last, participants completed three surveys: A subset of questions from the BUZZ [16] audio user experience scale, eliciting feedback on the sound aesthetics; a 4-question usability scale, UMUX, eliciting feedback on the overall sim experience [4]; and a demographics and technology use survey.

RESULTS

Experience: Description + Sound Effects/Sonifications

Five adult screen reader users with visual impairments, self-described: low-vision (2) or blind (3), used the sim with no visual display available. Participants rated the aesthetics of the sim as a 25.8 (SD=2.3) out of 28. They also rated the overall usability of the sim as 20.2 (SD=4.3) out of 24. Four of the participants specifically mentioned liking how the sounds and descriptions worked together to help them know what was happening. From open-ended questions, all reported the sounds and descriptions as being useful, and most (4/5) commented positively on description clarity.

Experience: Visual Display + Sound Effects/Sonification

Three children (7-9 years old) and three college students (all with no visual impairment) explored the sim without descriptions in think-aloud interviews. All learners explored the sim fully and described relationships between amount of charge and arm/hand location. Some sounds seemed to be attended to less by the children (e.g., charges on body), though no negative impact was observed in these cases. All students made relevant interpretations of the sound mappings, though not necessarily the intended mapping. For example, one student (9-year old) described the arm rotation/ratchet mapping as sounding “like a xylophone,” while another (college student) described the same sound as

“like a wind-up toy.” Both learners indicated the sound was present to provide feedback on arm location changes.

DISCUSSION

All eleven participants used the same sim, though they accessed different combinations of modalities during exploration. All were able to effectively use the sim and explored the key relationships in the sim. Some difficulties related to the relative volume of different sounds in the auditory display were found. When sound effects/sonifications were perceivable to learners, they indicated understanding of the sound/feature mappings. All learners indicated that, in general, they enjoyed the sim, and many indicated the auditory modality was helpful.

We encountered many challenging design decisions while creating the multimodal sim. Some challenges were specific to each modality (e.g., refining interaction, visuals, and descriptions to each scaffold learners to explore the key concepts; refining description to be concise and understandable across age groups; ensuring sound effects/sonifications were cohesive). Many challenges arose from the intersection of two or more modalities (e.g., designing sound effects/sonifications to layer with and complement both visuals and description – simultaneously).

Ensuring a coherent experience across all modality layers and their combinations required coordinated efforts across an interdisciplinary team and evaluation with diverse learners, overall a difficult but rewarding design process.

CONCLUSIONS

We present a multimodal science simulation, with visual display and robust auditory display (description, sound effects, and sonifications) capable of supporting learners with and without visual impairments. Building on our prior work in developing navigation and description for complex interactives, we introduced the design and evaluation of a simulation with new auditory display components, and its evaluation with learners utilizing different combinations of modalities (sound effects/sonifications with visual display or description). This work contributes to continued advancement of approaches and techniques to developing and evaluating accessible interactives for learning.

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