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Description Strategies to Make an Interactive Science Simulation Accessible

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Abstract

Interactive simulations are increasingly important in science education, yet most are inaccessible to blind learners. In developing an accessible prototype of a PhET interactive science simulation, we encountered significant challenges in providing screen reader access, including the need to: 1) describe unpredictable event sequences, 2) cue productive interactions, and 3) to simultaneously convey multiple changes. To address these challenges, we extended existing practices for verbal description of visual interactive content, and we created new strategies for developing rich description for accessible interactive science simulations.

Keywords

Blind/Low Vision, Research & Development, Web, Interactives; Science Simulation; Natural Language Description; Non-visual Access

Introduction

Science simulations range in complexity from simple to highly complex. A broad range of description strategies are needed to effectively increase non-visual access to all interactive simulations. Recent guidelines (Keane and Laverent) for the description of interactive scientific graphics are particularly relevant for simple interactives, but more complex interactives, like simulations, present significant challenges. In this work, we share strategies for designing descriptions for a complex interactive simulation. We developed our strategies through an iterative design process, including extensive user interaction analysis and feedback, for a PhET interactive science simulation (Smith, et al.).

The PhET Interactive Simulations project at the University of Colorado Boulder creates science and mathematics simulations (or "sims") for teaching and learning from elementary school to college. The PhET project reaches students around the world with over 150 interactive sims. Each sim is visually rich, highly interactive, and supports exploratory learning. In 2014 the PhET project began an initiative to increase the accessibility of PhET sims. This work focuses on the development of descriptions intended for screen reader access for the sim *Balloons and Static Electricity*.

The *Balloons and Static Electricity* sim (Fig.1) addresses topics related to charge and static electricity for students of age 10 to adult. The sim includes a Balloon, a Sweater, and a Wall, and allows students to explore the transfer of charges between these three objects, and the resulting effect of a negative or neutral net charge on the Balloon.

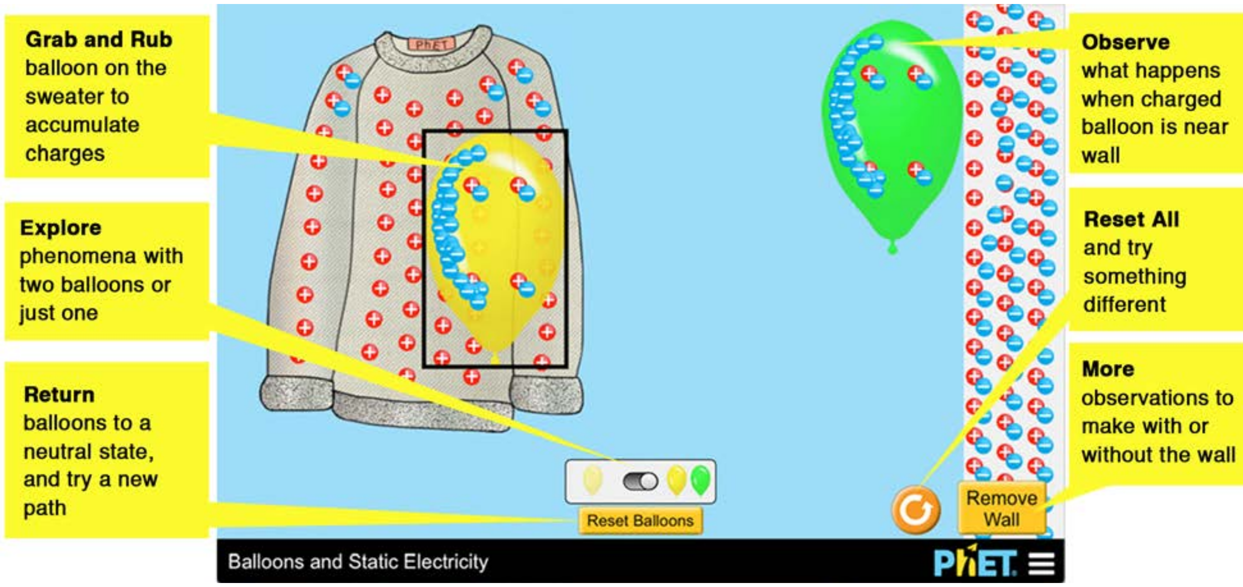

Fig. 1. In the *Balloons and Static Electricity* Sim, Students Can Try Several Possible Explorations (yellow callouts) with the Interactive Objects to Learn About Static Electricity.

Prior Work

Prior work in the development of *verbalized natural language descriptions* (or simply 'descriptions') is addressing significant access challenges in scientific images (DIAGRAM Center), graphs (Moskovitch and Walker), molecular chemical diagrams (Sorge, et al.), and math games (Gerino, et al.). The Keane and Laverent report provides guidance on creating effective descriptions for visually impaired students using interactive scientific graphics. Interactive scientific graphics are defined as "images that will change their appearance in response to actions taken by an external agent" (p.9). These resources provide useful guidance on aspects of developing effective descriptions (e.g., guidelines regarding brevity, context, and timeliness). In our work with a complex interactive sim we discovered new challenges in providing description during interaction, requiring development of additional strategies.

Method

Design Approach

Prior to this project, the *Balloons and Static Electricity* sim was inaccessible to screen reader software. Our goals in developing descriptions, was to support access through technology (computers and software) commonly available in classrooms and to incorporate descriptions into the same sim used by students without disabilities – resulting in a single, more inclusive, sim.

Our accessible design approach embraces the principles of the Web Content Accessibility Guidelines, and leverages the semantics of HTML5 and WAI-ARIA. It rests on three pillars:

1. **Infrastructure:** A robust webpage-like structure, our parallel Document Object Model (PDOM), that provides a hierarchical representation of the sim's objects, and that supports communication between sim, browser, and screen reader software.
2. **Multiple access points:** Keyboard navigation and operation that provide users familiar ways to navigate and interact with the sim, including screen reader commands.
3. **Descriptions:** Text-based descriptions read out by screen reader software that provide cues for interaction, dynamic state information, and real-time feedback as students explore and engage with the sim.

About the Participants & Procedures

As part of an iterative design process, we recruited 14 screen reader users for interviews - 12 on early prototypes (see also Smith, et al.), and 2 on more recent prototypes for a total of 14 interviews. The participants spanned a broad age range (19 years to 61 years). Participants demonstrated differing levels of expertise with their preferred screen reader. All participants had at least some post-secondary education.

Early prototypes were keyboard accessible, and contained descriptions for all static representations – names and descriptions of objects that do not change (blue sections in Fig.2), and two dynamic descriptions representing the changing amount of charge on the Balloon and the Sweater. The remaining dynamic representations were provided through live description by the interviewer, in what is sometimes called a Wizard of Oz procedure. This method allowed us to learn how participants explored an interactive sim, to test the wording of our static and dynamic descriptions, and to identify gaps in our description plan. Between interviews, we revised the design of the descriptions and the keyboard interactions. The last two interviews have been conducted on more complete prototypes without any live description provided.

Discussion

In this work, we summarize three description challenges found in our interviews, and the strategies we developed during our iterative design process to address these challenges. A side-by-side demonstration of the latest visual prototype and its description hierarchy can be found online at bit.ly/phetdemos-balloons-and-static-electricity.

Challenge 1: How to support multiple pathways of interaction and exploration?

PhET sims are designed to provide open-ended, exploratory experiences. In *Balloons and Static Electricity*, students may explore what happens when the Balloon is released near the Sweater or near the Wall. Students may explore what happens when the Balloon has a small or large amount of negative charges and is released. Students may explore both learning pathways, and more, in any order.

Additionally, students using a screen reader can utilize multiple ways to interact with an online resource. They may use any (or all) of the following approaches: the *arrow (or cursor) keys* to listen to descriptions line by line, screen reader *shortcut keys* to listen for structural features (e.g., headings), or the *Tab key* to navigate through interactive objects (e.g., buttons). Descriptions designed for *Balloons and Static Electricity* needed to support screen reader users in exploring multiple learning pathways in the sim while using diverse interaction approaches.

Our strategy to support multiple pathways of interaction and exploration is to provide a rich hierarchical system of modular descriptions. The hierarchical structure provides navigational support, uniquely identifies the objects in the sim with unchanging (or static) descriptions, and reflects any state changes to these objects with updated (or dynamic) descriptions. It also provides a summarized up-to-date description of the entire sim (the Scene Summary). All descriptions are modular, and make sense in context when heard in any order.

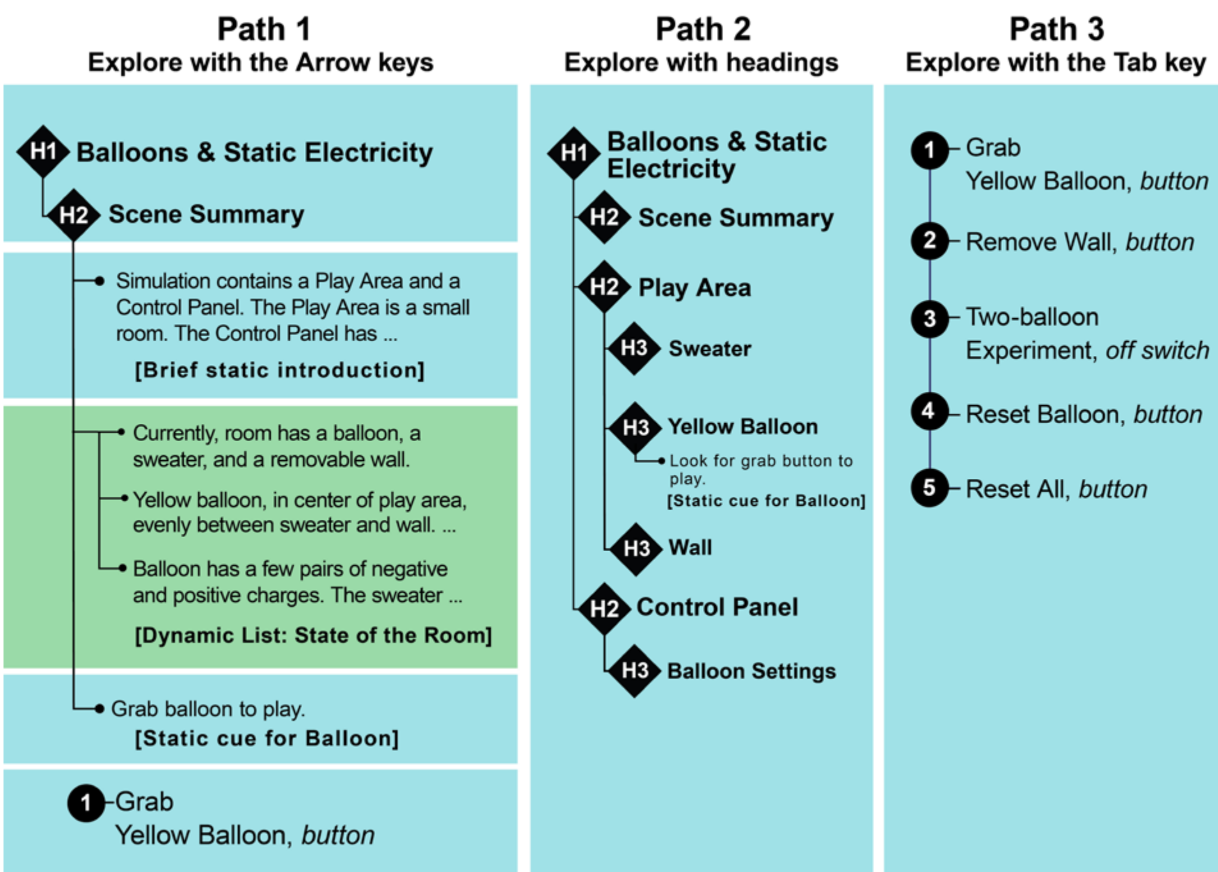

Fig. 2. Three Possible Interactive Learning Pathways Through the Sim's Hierarchical Description Structure: Arrow keys (left), headings (center), and Tab key (right).

The result is a rich set of descriptions that can be navigated by screen reader users in multiple ways (Fig.2), and remain understandable regardless of the learning pathway explored. A student choosing to navigate the sim line-by-line with the arrows keys (Fig.2, Path 1) will first encounter the Scene Summary (a big-picture view of the sim) and a cue for interaction. The student may choose to immediately interact by following the interaction cue, or continue exploring with the arrow keys to assess all possible interactions before choosing their learning path. A student choosing to navigate the sim by using shortcut keys to browse headings (Fig.2, Path 2) will find seven meaningful headings including those for the “Scene Summary” and “Play Area” sections. Exploring any section more deeply will provide the opportunity to interact with objects in the sim. A student choosing to navigate the interactive objects in the sim using the Tab key (Fig.2, Path 3) will find action-oriented static descriptions, like the “Grab Yellow Balloon” button or “Remove Wall” button, each understandable independent of other descriptions.

Challenge 2: How to support productive exploration without over-directing?

The design of the descriptions need to support students not only in exploring the sim, but also in choosing productive explorations for learning. With the *Balloons and Static Electricity* sim, learning from the sim requires interaction with the Balloon. The Balloon’s large size, its bright color, and its central location between the Sweater and Wall provide implicit visual cues. These cues indicate to sighted students that interacting with the Balloon and exploring relationships between the Balloon, Sweater, and Wall will be productive (Podolefsky, et al.), and students typically begin interacting with the Balloon within seconds of sim use. In our early accessible prototypes, screen reader users did not initially interact with the Balloon, choosing less informative interactions first. In these initial designs, neither the cues for interaction nor the Balloon descriptions effectively communicated the significance of the Balloon.

Our strategy to support productive exploration is to cue productive interactions through both navigation order and description. We designed the hierarchical navigation order to align with the visual scaffolding of the sim. Unchanging (or static) descriptions identify objects within the sim, indicate their hierarchical relationships to each other, and simultaneously provide a pedagogically relevant navigation order for the interactive items in the sim. For example, the Sweater, the Balloon, and the Wall are found within the hierarchy in the "Play Area" section (Fig.2, column 2). Though structurally at the same level of importance, when listening in order (first to last), the Balloon description comes after the description of the Sweater and before the description of the Wall. This order situates the Balloon semantically between the Sweater and the Wall, just as it is situated between these two objects in the visual layout, and cues the user that there are likely relationships to explore between these objects.

To highlight the significance of the Balloon, we embedded three playful interaction cues to suggest that grabbing the Balloon might be a productive way to begin exploration. The sim's Scene Summary ends with a non-specific cue, "Grab balloon to play," (Fig.2, column 1). A second cue, "Look for grab button to play" (Fig.2, column 2), is found at the end of the Balloon's description, and provides specific structural information about the "Grab" interaction (i.e., it is a button). The final cue, the button's label, is simple and action-oriented, "Grab Yellow Balloon".

The static descriptions and navigation ordering provide information to the student about the objects and the relationships between them, while the interaction cues provide hints at what might be a productive opportunity for exploration. The navigation ordering neither prohibits nor enforces any specific interaction pathway, and nothing in the descriptions indicate to students specifically what explorations to engage with. Each description only provides cues to the student to support exploration.

To illustrate, here is an example user scenario. A student arrives at the sim, and the screen reader automatically begins reading the Scene Summary from the top of the description hierarchy, which ends with "Grab balloon to play." The screen reader continues, reading through the Play Area, Sweater and Balloon descriptions. In the Balloon's description, they hear the cue, "Look for Grab button to play". The student presses the *Tab key* and hears, "Grab Yellow Balloon, button". They press the Spacebar to begin an interactive exploration with the Balloon.

Challenge 3: How to support awareness of multiple simultaneous changes?

As students explore and interact with the sim, they make changes to objects and these changes can affect other objects. A single interaction often results in multiple simultaneous changes that students need to know about. For example, pressing the Reset All button (Table 1) results in state changes to at least two objects, the Balloon and the Sweater. A more complex example is the interaction of dragging the Balloon and rubbing it on the Sweater (Fig.3). This interaction results in multiple changes to the Balloon (position and net charge), and to the Sweater (location of remaining pairs of charges and net charge). Descriptions repeat as rubbing continues.

Table 1. Improved Description for the Reset All Button

Early prototypes released state changes for all objects upon pressing the Reset All button	**Redesigned description releases an alert to summarize what happened**
• Yellow balloon in center of Play Area. • Has no more negative charges than positive charges. • Sweater has no more positive charges than negative charges.	• Sim screen restarted. • Everything reset.

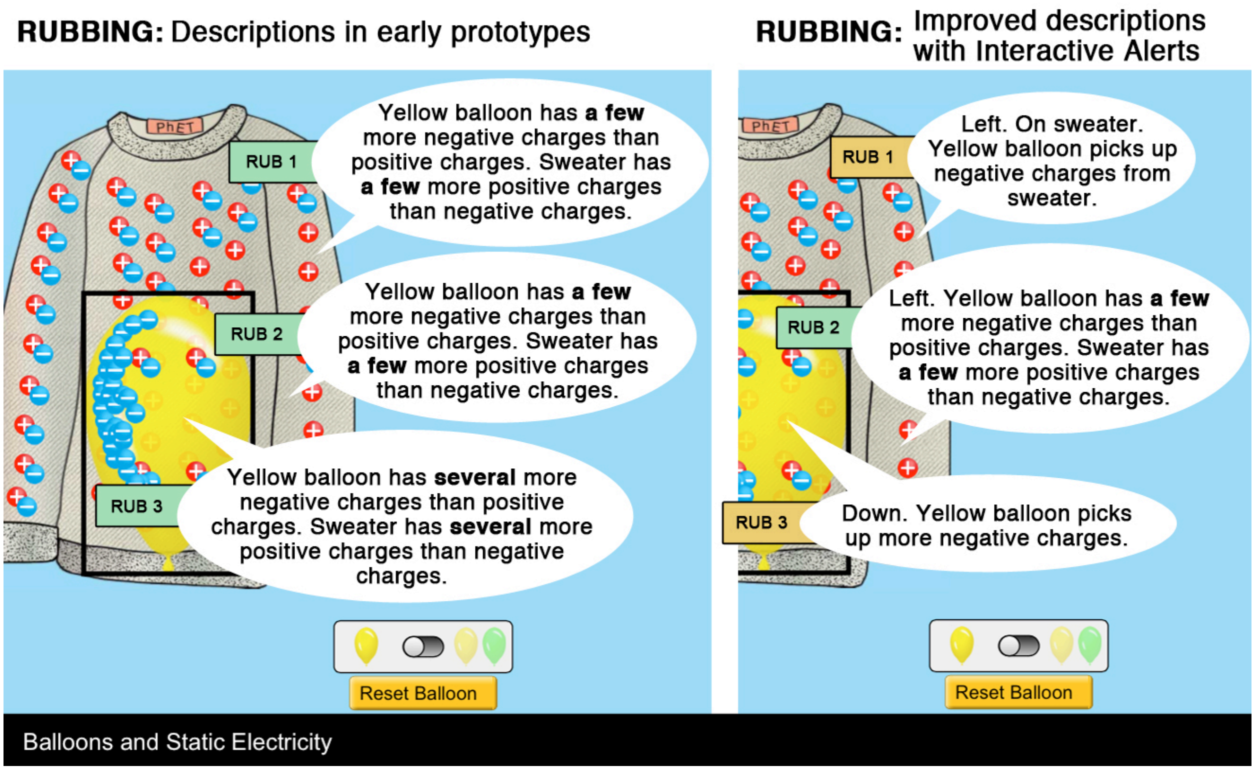

Fig. 3. Repetitive Dynamic Descriptions for the Balloon and Sweater (RUB 1, 2, and 3 on left), Layered with Interactive Alerts (RUB 1 and 3 on right) to Reduce Verbosity and Repetition.

In early prototypes, state changes were communicated through updated Dynamic Descriptions (Fig.5, column 2) for each sim object. Describing the state changes, alone, however; resulted in lengthy and repetitive descriptions when changes occurred simultaneously (Table 1, column 1 and Fig.3 speech bubbles on the left), and silence when no changes occurred. Users, in response, often ignored the verbose and repetitive descriptions, had to deduce on their own that the change in charges was due to a charge transfer, and were left unaware of the state of the sim when rubbing interactions resulted in no charges being transferred.

Our strategy for providing descriptions of multiple simultaneous changes is to design highly-contextualized description alerts (Interactive Alerts), to replace and/or strategically support state changes (Dynamic Descriptions). Dynamic Descriptions (Fig.4, column 2) reflect the state changes in the description hierarchy, can be accessed at any time for review, and are read aloud during interaction. Interactive Alerts (Fig.4, column 3), in comparison, are succinct descriptions of what is happening in the sim, are only announced in context at the instant they are relevant as the event occurs, and remain hidden from review in the sim's hierarchy.

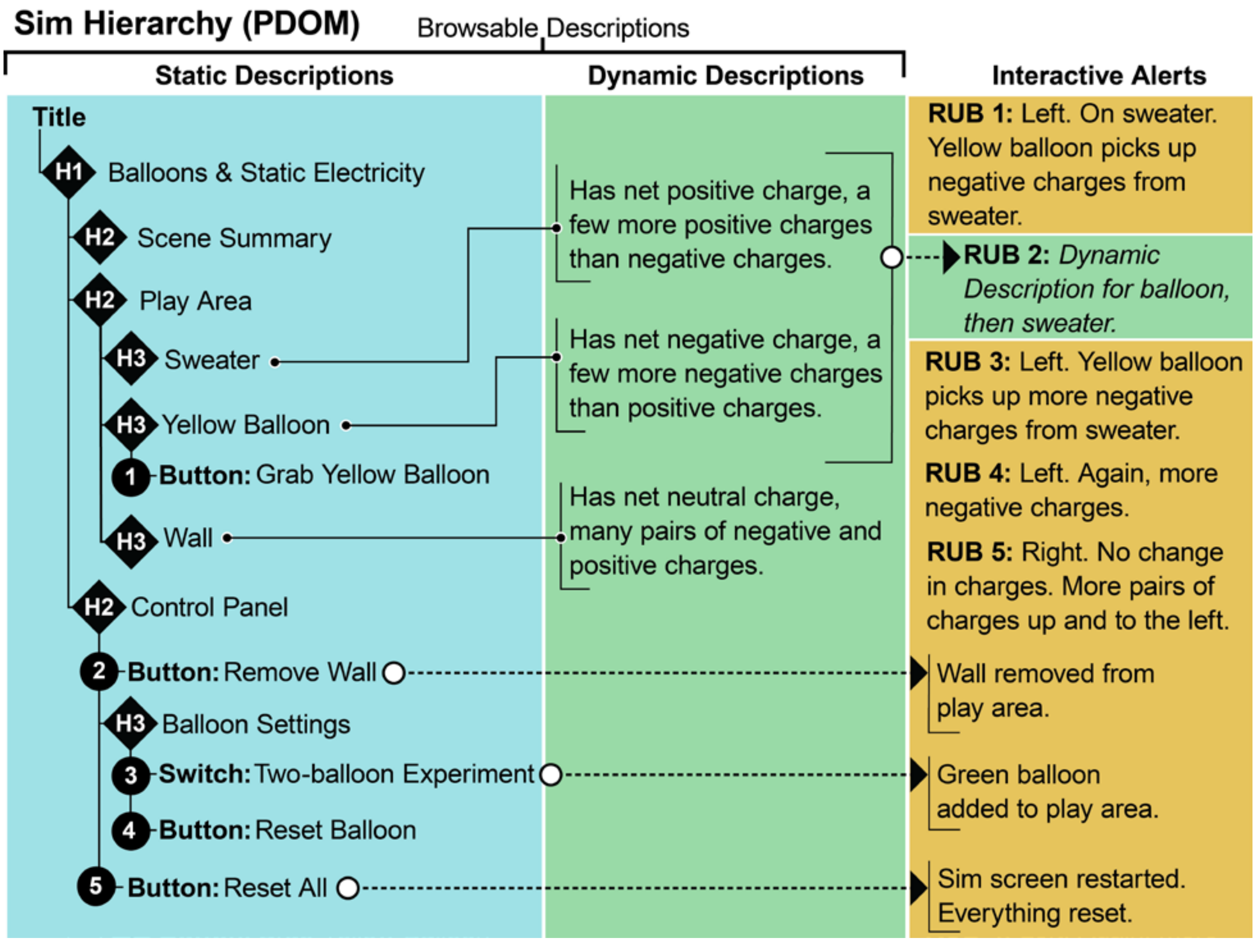

Fig. 4. Description Strategy Includes Three Types of Descriptions Embedded Within a Parallel DOM. Static Descriptions (column 1) form a Browsable Outline, Dynamic Descriptions (column 2) describe reviewable state changes, and Interactive Alerts (column 3) support interaction.

For interactions, like the Reset All example in Table 1, a summarized Interactive Alert, "Sim screen restarted. Everything reset", is read out instead of the two lengthier Dynamic Descriptions. For the more complex rubbing interaction (Fig.3), succinct real-time Interactive Alerts that describe what is happening support the lengthier and repetitive Dynamic Descriptions about the amount of charges on the sim's objects. The experience overall, in both scenarios, becomes more engaging while still effectively conveying the complexity of changes that the student's interaction caused.

Conclusion

Throughout our work we sought to maintain brevity, ensure timeliness of description delivery, and create descriptions that always make sense in context, consistent with previous work on descriptions for interactive scientific graphics (Keane and Laverent). To do this within a complex interactive simulation required that we utilize new strategies for the design and delivery of the descriptions. These strategies included providing a robust hierarchical structure to support multiple pathways of exploration and interaction, providing cues to support pedagogical use of the sim, and layering of three different types of description to support the conveyance of complexity. User testing with our sim prototypes indicate that these strategies can be used to effectively address the challenges we have highlighted for complex interactive simulations. The set of strategies presented may also be a useful companion to existing guidelines for describing other types of interactive graphics.

Acknowledgements

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