Access, Action, Agency: Inclusive Design for the Non-visual Use of a Highly Interactive Simulation

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Importance of Accessible Science: quotes from participants

P1: *"I wanted to study Chemistry, but when I started losing my sight in high school, my teachers could not figure out a way for me to do it."*

P6: *"Interesting, I hear you talk about the negative charges and everything, and I feel kind of stupid because I don't even remember if like the little static shocks we get are negative or positive."*

PhET Sims: Effective Learning Tools

- PhET Interactive Simulations (or "sims") utilize a design approach called *implicit scaffolding* (Podolefsky, Moore & Perkins, 2013)
- Visual design & layout cue students towards interacting with the Balloon by grabbing & dragging it with the mouse
- Tool-mediated learning: learner, tool & learning objectives work together dynamically (Vygotsky & Cole, 1978)

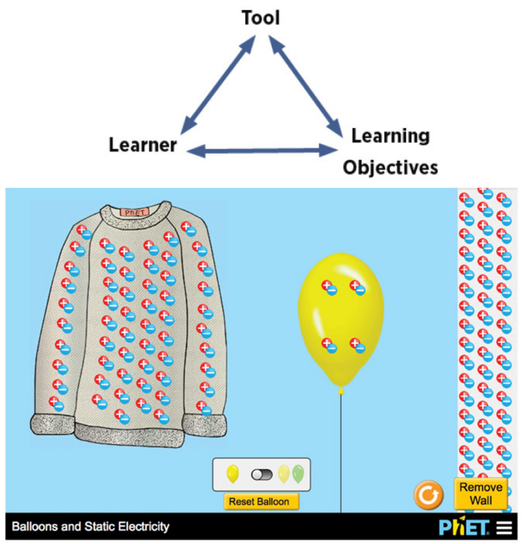

Figure 1: *Tool-mediated learning Triad & the PhET Sim, Balloons and Static Electricity.*

Design Challenge Original PhET sim design was a virtual *black box* to screen readers.

- **Access:** Describe the visual representations of the objects & controls (e.g., buttons), so there is **perceivable access** for a screen reader user
- **Action:** Design interactive features to be **operable via the keyboard**, so students can take action
- **Agency:** Make **descriptions & interactions understandable**, so students can engage in exploration of the scientific concepts around static electricity in their own way - asking questions; testing hypotheses.

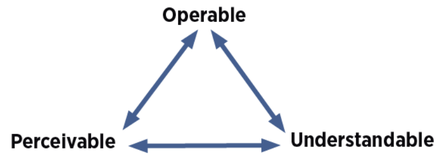

Figure 2: *Accessible design features focus on perceivability, operability & understandability*

Accessible Design Features

1. **Robust Parallel DOM:** (PhET, 2015) a content & interaction layer that is fully **perceivable** & **operable** while using a screen reader & a keyboard. The sim is no longer a "black box" to screen reader users
2. **Learnable Custom Keyboard Interactions:** accessible drag & release mechanism for the Balloon (WASD keys & Arrow keys); a set of hotkey combinations (Maximova, 2013) for jumping the Balloon to important locations
3. **Descriptions** for all static content, & a plan for many of the more complex dynamic descriptions including:
   - Charge for Balloon, & Sweater & Wall
   - Balloon position while dragging,
   - Balloon sticking states upon release, &
   - Induced charge descriptions for Wall.

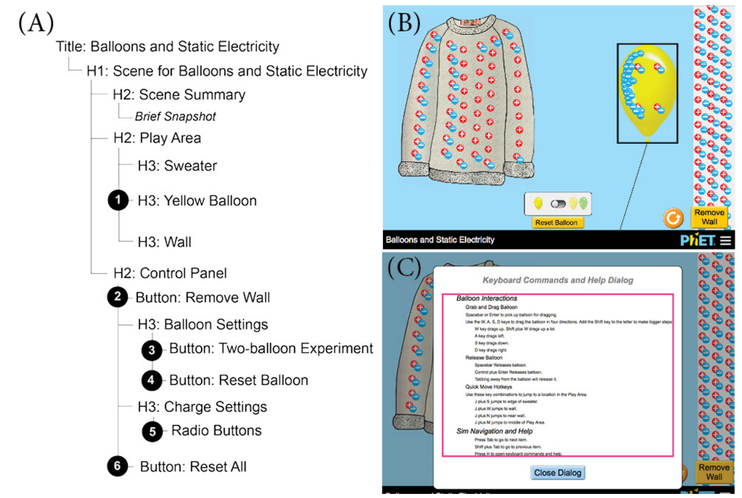

Figure 3: *(A) Simplified Parallel DOM structure with Tab navigation (numbered in black circles). (B) Keyboard accessibility: Balloon in grabbed state near Wall. (C) Descriptions for custom keyboard interactions accessed by pressing H key.*

Iterative Inclusive Design Approach: To test our design & progress, we interviewed 12 screen reader users.

Figure 4: *Inclusive methods: Tactile marker for signing procedure; Camera set-up captured keyboard & screen.*

- **Methods:** inclusive protocols (Lazar et al, 2007; Graham, 2015) to recruit & interview 12 screen reader users, 5 women & 7 men, diverse in expertise & age (19 to 65 years)
- **Evaluation:** asked users to explore the prototype as if they were trying to learn with it & to think aloud (Lewis & Reiman, 1983; Chandrashekar et al, 2006) while exploring

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- **Design iterations:** made improvements to prototype between interviews (PhET Design Process)
- **Analysis:** analyzed recordings to identify design issues & to evaluate our approach

Findings: What Worked Well

- **Parallel DOM** supports non-visual exploration & interaction with the sim very effectively
  - familiar structure supports the "listen first-then interact" interaction pattern (Kurniawan et al, 2003; Fakrudeen et al, 2013)
  - supports multiple ways of listening & interacting: cursor keys; skimming & scanning by structure; navigate with the Tab key or by any screen reader navigation commands. Users interact once they find something of interest, or the item for which they were searching
- **Custom interactions** for moving & releasing the Balloon were learnable & easy to use & remember.
- Three **aspects of descriptions** worked well:
  - Scene Summary was useful for giving users an initial snapshot & big picture view
  - Timely dynamic descriptions for charge changes connected users actions with this important change (WAI-ARIA, 2014)
  - Timely system of interaction alerts created a meaningful interaction flow

Findings: Our Challenges

- Navigation cue in the Scene Summary is important & was too vague; needed to be clear, contextual & action-oriented
- Information on hotkey combinations was hard to find
- Not all descriptions were fully understood. There were different reasons for this:
  - Induced charge, for example is difficult to describe,
  - Charge information on the Sweater and Balloon were read out back-to-back obscuring updated details about changes in the amount of charge
- Balloon is a complex custom element:
  - Only 4 participants figured out how to move it completely on their own
  - Technical issues: no native HTML element for familiarity; ARIA role application adds verbosity; browser inconsistencies with live regions (WAI-ARIA, 2014)
  - Custom interactions (WASD letter keys) require explicit description which added verbosity
  - Balloon contains a lot of dynamic content, making it difficult to describe succinctly & complicating the sim's most important interaction

Findings: A Description Strategy Framework

- Because the Balloon was difficult to understand, we examined the descriptions carefully in the light of description guidelines for interactive scientific graphics (Keane & Laverent, 2014)
- Description strategy framework (see Figure 5) emerged containing 3 categories of descriptions
  - Static Descriptions
  - Dynamic Descriptions
  - Interaction Alerts
- Static & dynamic descriptions are the main ingredients of the sim content. Static descriptions form an outline & dynamic descriptions describe the changes in the scientific model - accessible to screen reader user in diverse ways.
- Interaction Alerts, only make sense at the time of interaction (e.g., "Left towards Sweater", "Wall removed from Play Area"). This category of description presents unique description challenges for highly interactive sims - different from simple interactive scientific graphics.
- Big idea: can interaction alerts be used strategically to improve understandability of descriptions during interaction?
  - 2nd rub: a few more charges picked up from Sweater
  - 3rd rub: a few more

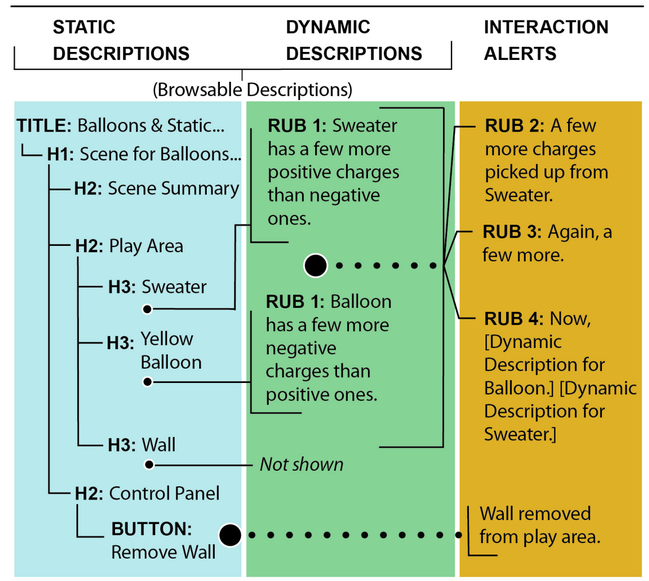


Figure 5: *Description Framework (simplified) shows Parallel DOM with Static & Dynamic Descriptions & Interaction Alerts.*

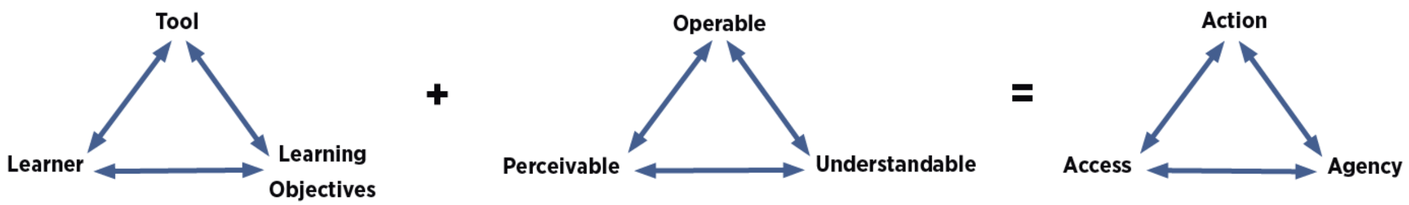
Quotes from Participants

P8: (paraphased for brevity) *"I'm new to this site, so I am first going to go through everything with the down arrow [...] I'm repeating stuff to make sure I didn't miss anything. [...] Now, I'm going to do a Tab through."*

P3: [with 2 negatively charged balloons on the Sweater] *"I want to see what happens if I put one balloon on top of the other."* [second Balloon repels and moves to the bottom of the sweater.] *"What will happen if I do the same thing on the Wall?"*

P5: [After first rubbing Balloon on Sweater] *"Hmmm...I got a lot more charges than I had before."*

Digital version with References visit http://terracoda.ca/research/



Conclusion & Future Work To PhET's Implicit Scaffolding framework, we added Web Accessibility best practices, in order to create Access, Action and Agency. The target users for our Interactive sim were screen reader users. Using inclusive processes, we created a design that also benefits students with dexterity impairments, and teachers who need accessible resources. Our next steps are to implement more descriptions & test our description framework with other sims.

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