Evaluating the Embodiment Benefits of a Paper-Based TUI for Educational Simulations

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**Paper-to-Parameters**
Low-cost, paper-based strategy to provide spatial input to educational complex systems simulations

**Problem space:** learning about environmental science and the complex human-natural interactions

**Task:** incorporating green infrastructure into urban planning

**Step 1:** Students are provided stickers or paper cutouts bearing graphical symbols which represent elements in the simulation (e.g., particular species of plants or entire gardens, depending on level of scale).

**Step 2:** Students strategically arrange the symbols on a flat surface, like a sheet of paper or a classroom wall. A web camera is used to read the symbols and provide their coordinate information to the simulation.

**Step 3:** The simulation uses the provided coordinates to configure the spatial arrangement of simulation elements. The behavior of agents within the simulation is affected by the absolute and relative locations of these elements. Students can watch the simulation unfold via the classroom’s projector and collect information on outcomes.

**Step 4:** Students use collected information on outcomes to further their understanding of how agents are affected by the simulation elements, and to inform further testing of spatial configurations of simulation elements.

**Agent-Based Models (ABMs)**
ABMs are frequently used in Environmental Science and Urban Planning to model the interactions of human behaviour and natural systems.

- Part of the authentic science practice that children should learn
- Most ABMs designed for use by children lack convenient methods for specifying & manipulating spatial arrangement of simulation elements
- Graphical user interfaces typically rely on buttons and sliders
- Locations typically need to be programmed in

Prior work showed us that there is a large time savings using PtP (1m11s) over programming (1m18s).

**Tangible User Interfaces (TUIs)**
Embodied cognition theory and prior HCI work suggests that TUIs may be good for supporting:

- **Collaboration**
  - Ability to communicate with partner
  - Ability to monitor partner’s gaze
  - Simultaneous participation

- **Learning**
  - TUIs more directly link cognition and perception than the traditional input devices

- **Spatial tasks**
  - No need to translate “I want to place that thing next to that other thing” into abstract coordinate system

**Need for study:**
- Wish to build on prior work that makes claims about TUIs
  - Improving usability, problem solving, and collaboration
  - Many excellent qualitative studies, but not many controlled experiments

**Experiment**
Study design:
- Built a dual mouse drag-and-drop interface as a control; need equal access opportunity
- Within-subject, 2x2 with rotation experiment, as indicated in illustration below

<table>
<thead>
<tr>
<th>Interface Condition</th>
<th>Map</th>
<th>Paper-to-Parameters</th>
<th>Dual Mouse</th>
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**Data:**
- Video tape
- Score log
- Record of configurations
- Post-study Likert questionnaire on familiarity, usability & collaboration

**Collaboration**
Transcription and video analysis are forthcoming. For now, we have the user-reported Likert answers:

- **H1:** Faster Configuration Times with PtP
  - Average time spent per configuration:
    - Paper-to-Parameter: 1 minute 44 seconds
    - Dual Mouse: 1 minute 38 seconds
  - No significant difference

- **H2:** Higher Subjective Usability Ratings with PtP
  - Paper-to-Parameter: 4.7
  - Dual Mouse: 5.8
  - Probability explanation: computer vision read errors

- **H3:** Faster Convergence on Best Solutions with PtP
  - PtP resulted in a significantly faster convergence (t(17) = 2.58, p = 0.02, single-tailed)

- **H4:** More Exploration with PtP
  - Users explored more intermediate steps using the dual mouse
  - Dual Mouse: (M = 5.8)
  - PtP: (M = 4.7)
  - PtP resulted in a significantly faster convergence (t(17) = 2.81, p < 0.02, single-tailed)

- **H5:** Users will get higher scores with PtP
  - Average High Score: No significant difference
    - PtP: 1.525
    - Dual Mouse: 1.497

Lower ratings of PtP can be explained by glitches in the computer vision system, rather than by the nature of the tangible interaction.