Assessing Systems Thinking Using a Design Improvement Task and CAD Logs

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Function-Behavior-Structure Framework
(Gero, 1990; Gero & Kannengiesser, 2004)

**Functions**
- provide_daylighting
- control_heat_loss

**Behaviors**
- light_transmission
- thermal_conduction

**Behavior Variables**
- window_area
- window_length
- window_height
- window_transparency
- window_U_value
- window_material

**Systems Thinking**
1. Understanding each FBS chain and interconnections of multiple chains
2. Make trade-offs and optimizations

**Assessment Tasks**
Simulated Environment for Engineering Design

Energy3D

Architectural Engineering
Solar Engineering
Urban Planning

Solar Analysis
Thermal Analysis
Energy Analysis
Collecting Fine-Grained Design Process Data

- Construction event: Capture a construction event (add, remove, etc.)
- Simulation event: Capture a simulation event and record its results
- Changes in artifact properties: Track changes of an artifact property (size, etc.)
- Changes in design note: Track changes in a design note
- Snapshot of designs: Generate snapshot states of design
Building Energy System:
A Designed System Embedded in Natural Systems

Environmental Temperatures

Solar Insolation

Energy Consumption & Production

Cost Breakdown
Design Improvement Task

- Assessment Design Strategies
  - Use bad design features to systematically elicit knowledge of the system
  - Use quantitative measure to elicit trade-off and optimization behaviors
  - Limit the range of possible changes to facilitate interpretation

This colonial house looks nice. It meets all the geometric requirements (style, area, and height). However, its estimated annual energy consumption is more than 60,000 kWh. Please revise the model to **reduce its net annual energy consumption** without compromising its aesthetic value.
Specifically, **do not change** the style, shape, and dimension of the house and the number and size of the windows and doors. The maximum number of solar panels you can put on the roof is 40. **Budget: $60,000**
Design Performance Measure 1:
System Performance Score
(Net Energy Consumption)
Design Performance Measure 2: Design Quality Score
(Number of Desirable Design Features – Number of Constraint Violations)

Initial State

- Improved insulation for roof, walls, windows, and doors
- Lower Solar Heat Gain Coefficient for Windows
- Optimize south-facing window surface area
- Use deciduous trees
- Use light colors for roof and walls
- Place solar panels on the south-facing roof
- Add more solar panels
- Increase solar cell efficiency
- Plant trees in front of windows

Final State

- Extended roof overhang
- Maintain curb appeal
- Within the given budget
- Optimize south-facing window surface area
- Lower Solar Heat Gain Coefficient for Windows
Design Process Measures

- **# of Energy Analysis**

- **# of Visualization Usage**

- **# of Model Manipulation**
Research Questions

• To what extent does students’ performance on the design improvement task reflect their knowledge of the system?

• How is the knowledge elicited by the design improvement task different from the knowledge elicited by traditional knowledge assessment?
**TREE_TYPE**

9. A two-story south-facing house is about 30 feet high and located in Massachusetts. The house owner wants to plant trees to improve energy efficiency of the house. Which of the following trees would you choose, assuming the total costs of these options are the same?

A. Ten boxwood trees, 5 feet tall and 4 feet wide, Evergreen (doesn’t shed leaves annually)

B. Ten Japanese barberry trees, 5 feet tall and 4 feet wide, Deciduous (sheds leaves annually)

C. Two Weeping Alaskan Cedar trees, 25 feet tall and 20 feet wide, Evergreen (doesn’t shed leaves annually)

D. Two White Dogwood trees, 25 feet tall and 20 feet wide, Deciduous (sheds leaves annually)

E. I am not sure

Please explain your choice:
_____________________________________________________________________________
_____________________________________________________________________________
_____________________________________________________________________________

<table>
<thead>
<tr>
<th>Levels</th>
<th>Response Description</th>
<th>Example Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 4</td>
<td>Connecting 3 or more normative ideas</td>
<td>Two dogwood trees would be the best trees to plant in this situation because the tree sheds leaves, so the trees will block sun going into the windows in the summer (1). And in the winter the leaves will shed so more light will be able to come through the windows (2) and heat the house. Also the trees are tall enough to cover many windows (3), but not tall enough to block the solar panels from getting sun energy, either in the summer or in the winter (4).</td>
</tr>
<tr>
<td>Level 3</td>
<td>Connecting 2 normative ideas</td>
<td>They will provide shade during the summer (1), and not block the sun in the winter (2).</td>
</tr>
<tr>
<td>Level 2</td>
<td>Using 1 normative idea</td>
<td>The deciduous trees would shade the windows in the summer (1) lowering AC cost.</td>
</tr>
<tr>
<td>Level 1</td>
<td>Using relevant but alternative ideas</td>
<td>Because the tree this height could collect energy more easily (X) and if they shed their leaves, they could survive a New England winter (X).</td>
</tr>
<tr>
<td>Level 0</td>
<td>Irrelevant ideas or no answer</td>
<td>Seems most logical.</td>
</tr>
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Constructs & Measurements

**Design Improvement Task**
- Design process measures
  - # of Energy Analysis
  - # of Visualization Usage
  - # of Model Manipulation
- Design performance measures
  - System Performance (Net Energy Consumption)
  - Design Quality (# of Desirable Design Features - # of Constraint Violation)

**Knowledge Test**
- Knowledge assessment measure
  - Knowledge Test Score (Design Choice & Explanations)
Data Collection

• Participants & Context
  • School: Northeastern, ethnic minority (20%), low income (12%)
  • Students: N=43, 9th graders, physical science, 2 class sections

• Procedure
### Results

#### Design Improvement Task

<table>
<thead>
<tr>
<th># of Energy Analysis</th>
<th># of Visualization Usage</th>
<th># of Model Manipulation</th>
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#### Knowledge Test

- Design Performance Measures
  - System Performance (Net Energy Consumption)
  - Design Quality (# of Desirable Design Features)

#### Knowledge Test Score

- Design Choice & Explanations

#### Correlations

- **System Performance (Net Energy Consumption)**
  - # of Energy Analysis: 0.375*
  - # of Visualization Usage: -0.182
  - # of Model Manipulation: -0.210

- **Design Quality (# of Desirable Design Features)**
  - # of Energy Analysis: 0.073
  - # of Visualization Usage: 0.019
  - # of Model Manipulation: 0.192

- **Knowledge Test Score (Design Choice & Explanations)**
  - System Performance (Net Energy Consumption): 0.254
  - Design Quality (# of Desirable Design Features): 0.379*

* * p < 0.05
Discussion

• Design improvement task
  – Effectively elicit procedural knowledge (e.g., applying, trade-offs, optimizations)
  – Elicit knowledge of the entire system

• Simulated environment for engineering design
  – Fully automated data collection and scoring
  – Feasible to implement at scale
Limitations & Future Work

• Limitations
  – Small sample size (N = 43), weak correlations could not be detected
  – Context: near-transfer, order of administration
  – System performance score: weighting issue

• Future Work
  – Larger sample size
  – Replication in various contexts
  – Calibrate system performance score
Thank you very much!

Questions?

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The Concord Consortium

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