Using Log Data Analysis to Identify Common Misconceptions Across Games

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Advances in the Analysis of Process Data from Game-Based Assessments

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Games As A Black Box

- Students don’t know much here.
  - Pretest
  - Game
  - Posttest

- Students know a lot more here.

What happened here?
Elements of Game-Based Assessment

• Specification of constructs of interest
  ✓ game design

• Selection of indicators
  ✓ logging

• Evidence identification
  ✓ cluster analysis

• Evidence accumulation
  ✓ repeat findings
Specification of Constructs of Interest

• What do you want players to know?
  ✓ Knowledge Specifications

• Does game design reflect the construct?

• Do you log indicators of the construct?

• Are you recoding what you need for analysis?
What Should They Know?

Knowledge Specifications

1.0 Does the student understand the meaning and importance of the whole unit?
   1.1 The size of a rational number is relative to how the whole unit is defined.
   1.2 In mathematics, a whole unit is understood to be of some quantity.
   1.3 The whole unit can be represented as an interval on the number line.

2.0 Does the student understand the meaning of addition as applied to fractions?
   2.1 To add quantities, the units or parts of units must be identical.
   2.2 Identical units can be added to create a single numerical sum.
   2.3 Dissimilar quantities cannot be represented as a single sum.

3.0 Does the student understand the meaning of the denominator in a fraction?
   3.1 The denominator of a fraction represents the number of identical parts in a whole unit.
   3.2 As the denominator gets larger, the size of each fractional part gets smaller.
   3.3 As the fractional part size gets smaller, the number of pieces in the whole gets larger.
Game Design

Game mechanics reflect content

• Individual actions have meaning
• Students can see consequences
Example: Save Patch
Example: Wiki Jones

Divide each unit into 3 equal pieces.
• Create an algorithm (or many algorithms) that calculate the probability that the student understands each concept
• Update the probability as they play
• Print out the final probability and use it to make inferences about the student
Selection of Indicators

- Actions not answers or inferences
- Only “important” actions
- Context information
- General and specific information
- In a structured format
# Example: Logging

<table>
<thead>
<tr>
<th>ID</th>
<th>Game Time</th>
<th>Data Code</th>
<th>Data Description</th>
<th>Data 01</th>
<th>Data 02</th>
<th>Data 03</th>
</tr>
</thead>
<tbody>
<tr>
<td>1115</td>
<td>3044.927</td>
<td>2050</td>
<td>Scrolled rope from [initial value] to [resulting value]</td>
<td>1/1</td>
<td>3/3</td>
<td></td>
</tr>
<tr>
<td>1115</td>
<td>3051.117</td>
<td>3000</td>
<td>selected coil of [coil value]</td>
<td>1/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1115</td>
<td>3054.667</td>
<td>3010</td>
<td>added fraction at [position]: added [value] to yield [resulting value]</td>
<td>1/0</td>
<td>1/3</td>
<td>1/3</td>
</tr>
<tr>
<td>1115</td>
<td>3058.443</td>
<td>3000</td>
<td>selected coil of [coil value]</td>
<td>1/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1115</td>
<td>3054.667</td>
<td>3010</td>
<td>added fraction at [position]: added [value] to yield [resulting value]</td>
<td>1/0</td>
<td>1/3</td>
<td>2/3</td>
</tr>
<tr>
<td>1115</td>
<td>3088.886</td>
<td>3020</td>
<td>Submitted answer: clicked Go on [stage] – [level]</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1115</td>
<td>3097.562</td>
<td>3021</td>
<td>Moved: [direction] from [position] length [value]</td>
<td>Right</td>
<td>1/0</td>
<td>2/3</td>
</tr>
<tr>
<td>1115</td>
<td>3106.224</td>
<td>4020</td>
<td>Received feedback: [type] consisting of [text]</td>
<td>Success</td>
<td>Congra-</td>
<td></td>
</tr>
<tr>
<td>1115</td>
<td>3108.491</td>
<td>5000</td>
<td>Advanced to next level: [stage] – [level]</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

859 students
1,208,133 rows
### Example: Logging

17,685 unique mnemonics

<table>
<thead>
<tr>
<th>ID</th>
<th>Game Time</th>
<th>Data Code</th>
<th>Mnemonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1115</td>
<td>3044.927</td>
<td>2050</td>
<td>SCROLL_1o1_TO_3o3</td>
</tr>
<tr>
<td>1115</td>
<td>3051.117</td>
<td>3000</td>
<td>SELECT_1o3</td>
</tr>
<tr>
<td>1115</td>
<td>3054.667</td>
<td>3010</td>
<td>ADD_1o3_AT_1o0_GET_1o3</td>
</tr>
<tr>
<td>1115</td>
<td>3058.443</td>
<td>3000</td>
<td>SELECT_1o3</td>
</tr>
<tr>
<td>1115</td>
<td>3054.667</td>
<td>3010</td>
<td>ADD_1o3_AT_1o0_GET_2o3</td>
</tr>
<tr>
<td>1115</td>
<td>3088.886</td>
<td>3020</td>
<td>GO_WITH_2o3_AT_1o0</td>
</tr>
<tr>
<td>1115</td>
<td>3097.562</td>
<td>3021</td>
<td>MOVED_Right_2o3_FROM_1o0</td>
</tr>
<tr>
<td>1115</td>
<td>3106.224</td>
<td>4020</td>
<td>FB_Success_WITH_2o3_ON_1o0</td>
</tr>
<tr>
<td>1115</td>
<td>3108.491</td>
<td>5000</td>
<td>ADVANCED_TO_S2_L4</td>
</tr>
</tbody>
</table>
Logging

- Allows for summary statistics
- Allows differentiation between the same actions in different contexts
- Allows differentiation between user actions and programmed game actions
- Allows for knowledge discovery through various forms of data mining
Evidence Identification

- What do you do with 17,000 actions?
- Reduce them
  - Not all are meaningful
  - Not all are common
  - Many of them co-occur
- Create groups of common, meaningful actions
Cluster Analysis

• Identifies groups of actions
  ✓ Based on differences in behavior

• Uses a distance matrix
  ✓ Groups actions if both performed by same people
  ✓ Separates actions if both performed by different people

• Resulting clusters represent different strategies
Fuzzy Feature Cluster Analysis

• Feature clustering clusters actions, not people
• Fuzzy clustering is probabilistic
• Fuzzy clustering allows a given action to belong to more than one cluster
• We clustered actions by attempt, not by level
Example: Cluster Analysis

fanny(data, 4, TRUE, 2, cluster.only = FALSE, 550, 1e-15, 0)
Example: Cluster Analysis

Students who make a **Partitioning Error** count dividing marks instead of spaces to determine the denominator.

\[
\frac{3}{3} \div 1 \div 2 \div 3 \div \frac{1}{3} \div \frac{1}{3} = \text{Correct Solution}
\]

\[
\frac{3}{2} \div 1 \div 2 \div \frac{1}{2} \div \frac{1}{2} = \text{Partitioning Error}
\]
Evidence Accumulation

- Same errors in same contexts
  - Within an environment
  - Across environments
  - On paper-and-pencil tests
- Same errors across populations
- Errors predictive of performance
Students who make a Partitioning Error count dividing marks instead of spaces to determine the denominator.

= Correct Solution

= Partitioning Error
Same Errors Across Populations

• Across 8 districts, students make partitioning errors 21% to 55% of the time (mean = 35%)
  ✓ *Districts with lower API had higher partitioning percentages (p < .001)*

• Of 889 students, only 55 did not make partitioning errors in the game
  ✓ *On average, students made partitioning errors 22% of the time (sd = 15)*
Errors Predictive of Performance

• Errors predict performance
  ✓ Students who make partitioning errors have lower posttest scores \((p < .001)\)

• Errors predict errors
  ✓ Students who make partitioning errors in Wiki Jones are more likely to make partitioning errors in Save Patch \((p = .045)\)

• Reducing errors increases performance
  ✓ Students who make errors in Wiki Jones but don’t make partitioning errors in Save Patch have higher posttest scores \((p < .001)\)
Into the Black Box

Game Design
Logging
Data Mining

Analysis