Designing Math Games for Learning: CATS Project

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Warp Speed, Mr. Sulu: Integrating Games, Technology, and Assessment to Accelerate Learning in the 21st Century

Redondo Beach, CA– April 29, 2014
Talk Overview

• Project studies overview and studies

• Design process #1: Review log data during game design process to identify common successes and errors

• Design Process #2: Modify game based on log data findings

• Design Process #3: Involve teachers in studies with professional development
Center for Advanced Technology in Schools (CATS)

- 5-year research and development Center funded by the US Department of Education (IES)
  - National Center for Instructional Technology
- Led by CRESST, multiple partners nationally
- How can games and other technology tools be designed and implemented to optimally improve student learning?
  - Initial focus: middle school math/algebra readiness
Overall Project Research Questions

• To what extent do different game design features affect student outcomes?

• To what extent do environments that vary in structure and degree of supervision (e.g., classrooms, after school, homework) affect student outcomes?

• To what extent do student background characteristics interact with effects of the game on student outcomes?
CATS Games
Save Patch
# Instructional Design Studies

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<thead>
<tr>
<th>Study</th>
<th>Study Number</th>
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<td>Pilot test of the effects of in-game instruction and feedback on math and game performance</td>
<td>119</td>
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<td>Effect of type of tutorial on math and game performance</td>
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<td>Effect of feedback on math and game performance</td>
<td>184</td>
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<td>Effect of format of tutorial and feedback on math and game performance</td>
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<td>Effect of self-assessment on math and game performance</td>
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<td>Effect of narrative on math and game performance</td>
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<td>Exploratory study of the effect of collaboration on math and game outcome</td>
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<td>Effect of scoring information as feedback, for motivation, and as rewards on math and game performance</td>
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<td>Pilot test of in-game checkpoint problems</td>
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<td>Aligning instruction and assessment with game and simulation design</td>
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<td>Efficacy Study</td>
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Important Design Process #1: Reviewing Log Data During Game Design
Log Data

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Error Identification in *Save Patch*

- Errors were identified through cluster analysis
  - *Cluster analysis is a type of data mining*
  - *Cluster analysis groups actions into action sets*
  - *One set of actions is done by one group of people, another set of actions is done by another group of people*

- Cluster analysis identified a majority of action sets performed in the game

- Cluster analysis identified two major mathematical errors: partitioning & unitizing
Log Data Study Example

• 244 students (115 males, 115 females, 14 not reported) played *Save Patch* for 40 minutes

• Computed average number of unitizing and partitioning errors made per level

• Multinomial logistic regression
  
  ✓ *Dependent variables: learning and confusion*

  ✓ *Independent variables: pretest score, low self-belief in math, positive game experience*

  ✓ *Independent variables broken out into Algebra and Pre-algebra students*
Study Conclusion

• For Algebra students:
  ✓ *Positive game experience, Partitioning errors = opportunity*
  ✓ *Low self-belief in math, Unitizing errors = obstacle*

• For Pre-algebra students:
  ✓ *Unitizing errors = obstacle*

• Students who can’t identify the unit, can’t learn from the game

• Students with sufficient math knowledge broaden their schema through partitioning errors
Important Design Process #2: Modify Game Based on Log Data Findings
Identifying Misconceptions

- Logged every action each student took
- Cluster analysis identified actions that occurred together
- Groups of co-occurring actions were examined by content experts
- Student strategies were identified
Partitioning Misconception

- Students believe the denominator is the number of dividing lines rather than the spaces between.
Partitioning Misconception

- Students believe the denominator is the number of dividing lines rather than the spaces between.

\[ \frac{1}{3} \quad \frac{1}{3} \quad \frac{1}{3} \quad \frac{1}{3} \quad = \frac{4}{3} \]
Partitioning Misconception

- True when the representation is a circle

\[
\frac{1}{3} \cdot \frac{1}{3} = \frac{3}{3}
\]
Partitioning Misconception

• True when the representation is a circle
Incorporation of Misconception in Game
Unitizing Misconceptions

- Students believe there is always one unit in the representation

\[ = \frac{4}{2} \]
Unitizing Misconceptions

• Students believe there is always one unit in the representation

\[ \frac{1}{4} \quad \frac{1}{4} \quad \frac{1}{4} \quad \frac{1}{4} = \frac{4}{4} \]
Incorporation of Misconception in Game
Other Misconceptions

- Students think a whole always has to start at zero and end at one
Other Misconceptions

- Students think a whole always has to start at zero and end at one
Incorporation of Misconception in Game
Other Misconceptions

• Students think a fraction must be a mixed number instead of an improper fraction.

\[ 1 \frac{1}{2} \]

\[ \frac{3}{2} \]
Incorporation of Misconception in Game
Save Patch

• Identifying Fractions Stages:
  ✓ Identifying Whole Numbers
  ✓ Identifying Unit Fractions
  ✓ Identifying Unit Fractions and Whole Numbers
  ✓ Identifying Whole Numbers That Cross the Unit Marker
  ✓ Identifying Proper Fractions
  ✓ Identifying Improper Fractions
Important Design Process #3: Involve Teachers in Studies Through Professional Development
Professional Development in Efficacy Study 1

- 62 teachers
  - 32 rational numbers
  - 30 control (solving equations)
- 25 schools in 9 districts
- California and Nevada
Professional Development Design

• Teachers pre-assigned to condition
• Evenings and weekends
• One four-hour session
  ✓ Teachers given binder with PD content
  ✓ Facilitators demonstrated how to introduce games to students
  ✓ Teachers played all games/discussion
  ✓ Administered survey
Professional Development Survey: Self-report

- Over 90% of teachers claimed to be prepared or very prepared to:
  - give students instruction on the games
  - help students who have trouble with the games
  - explain math in the games
  - connect the games to classroom instruction
  - manage the classroom during game play
  - fill out teacher logs
Post-Efficacy Study
Teacher Survey: Self-report

- Playing games was essential part of PD: 96-100% agree or strongly agree

<table>
<thead>
<tr>
<th>The PD helped me understand...</th>
<th>Rational Numbers Teachers</th>
<th>Control (SE) Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>the key math ideas</td>
<td>89%</td>
<td>80%</td>
</tr>
<tr>
<td>student misconceptions that might show up in games</td>
<td>78%</td>
<td>72%</td>
</tr>
<tr>
<td>link of games to math instruction</td>
<td>66%</td>
<td>52%</td>
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</table>
How helpful were the games in helping students learn math concepts?

**Rational Numbers Teachers**
- Very Helpful: 46%
- Helpful: 27%
- A little: 27%
- Not at all: 0%

**Control Teachers**
- Very Helpful: 38%
- Helpful: 45%
- A little: 13%
- Not at all: 4%
Design Process Overview

- Review log data during game design process to identify common successes and errors
- Modify game based on log data findings
- Involve teachers in studies through professional development