Comparing Students’ Performance and Reasoning with Physical and Virtual Manipulatives to Learn about Pulleys

JACQUELYN J. CHINI
ADRIAN CARMICHAEL & N. SANJAY REBELLO: KANSAS STATE UNIVERSITY
AMY ROUINFAR: FLORIDA STATE UNIVERSITY
SADHANA PUNTAMBEKAR: UNIVERSITY OF WISCONSIN, MADISON

This work is supported in part by U.S. National Science Foundation under the GK-12 Program (grant) (NSF DGE-0841414, P.I. Ferguson) and U.S. Department of Education, Institute of Education Sciences Award R305A080507.

Background

- Previous studies have shown mixed results:
  - Simulations outperform analogous physical experiments
    - Zacharia, Olympiou, & Papaevripidou, 2008
    - Finkelstein, et al., 2005
  - No difference in learning using physical or virtual manipulatives
    - Klahr, Triona, & Williams, 2007
    - Zacharia & Constantinou, 2008

- Zacharia and Constantinou (2008):
  - More research is needed to describe how physical and virtual manipulatives should be integrated in a physics curriculum.
Context

- CoMPASS\(^1\) pulley Curriculum
  - Hypertext system
  - Physical experiment
  - Simulation

CoMPASS: Concept Mapped Project-based Activity Scaffolding System

\(^1\)Puntambekar, Stylianou & Goldstein (2007)

Research Questions

- Is there a difference in understanding as measured by students’ **performance on a multiple choice test**?

- Is there a difference in understanding as measured by students’ **verbal explanations and reasoning**?
Theoretical Background

Context affects the ideas students use
- Hammer (2002) resources
  - Resources: potentially useful ideas students bring to learning situation
  - Context activates particular resources

Description of Studies

**In-Class Study (N=132)**
- Pre-test
- Physical or Virtual Activity
- Mid-test
- Virtual or Physical Activity
- Post-test

**Interview Study (N=13)**
- Pre-test
- Pre-test Interview (Half of Q’s)
- Physical or Virtual Activity
- Post-test
- Post-test Interview (Half of Q’s)
Analysis

Quantitative Data: Multiple Choice Pre-test & Mid-/Post-test
Statistical tests: • Overall score • Question-by-question

Qualitative Data: Interview transcripts of Pre-test & Post-test
Phenomenographic Analysis¹: Identified Q’s of interest

¹Marton, 1986

Quantitative Results: Overall Score

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pre-test</th>
<th>Mid-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Physical</td>
<td>71</td>
<td>37%</td>
</tr>
<tr>
<td>Virtual</td>
<td>61</td>
<td>33%</td>
</tr>
</tbody>
</table>

- ANCOVA results:
  - Covariate (pre-test score) significantly related to the mid-test score $F(1, 129)=26.5$, $p<.001$
  - Treatment (physical or virtual experiment) not significantly related to mid-test score $F(1, 129)=.946$, $p=.332$
Quantitative Results: By Concept

- Students in physical condition performed better on questions related to force, distance of rope pulled, and mechanical advantage.
- Students in virtual condition performed better on questions related to work.
- To be reported in Gire et al., 2010, *International Conference of the Learning Sciences*.

Specific Questions with Performance Difference

<table>
<thead>
<tr>
<th>Question</th>
<th>Physical Pre (%)</th>
<th>Virtual Pre (%)</th>
<th>p-value</th>
<th>Physical Mid/Post (%)</th>
<th>Virtual Mid/Post (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>11%</td>
<td>11%</td>
<td>.970</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Q1</td>
<td>83%</td>
<td>62%</td>
<td>.008</td>
<td>71%</td>
<td>17%</td>
</tr>
<tr>
<td>Q6.2</td>
<td>32%</td>
<td>42%</td>
<td>.230</td>
<td>29%</td>
<td>33%</td>
</tr>
<tr>
<td>Q6.2</td>
<td>28%</td>
<td>80%</td>
<td>&lt;.001</td>
<td>14%</td>
<td>67%</td>
</tr>
</tbody>
</table>

Which setup requires the least:
- Q1: force?
- Q6.2: work?
Physical Outperforms Virtual

<table>
<thead>
<tr>
<th>Less force?</th>
<th>Physical Pre</th>
<th>Virtual Pre</th>
<th>Physical Post</th>
<th>Virtual Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single fixed</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Single movable</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

- **Pre-instruction, mainly intuition-based resources**
  - Easier to pull down than to pull up
  - Easier to pull with gravity than against gravity

- **Post-instruction, no observed trend in reasoning**
  - One student (virtual) used common sense reasoning
    - Working against gravity to pull up
  - One student (physical) provided scientifically correct reasoning
    - Distance increases, so force decreases

Virtual Outperforms Physical

<table>
<thead>
<tr>
<th>More work?</th>
<th>Physical Pre</th>
<th>Virtual Pre</th>
<th>Physical Post</th>
<th>Virtual Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single fixed</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Single movable</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Same</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

- **Pre-instruction, difference in reasoning**
  - More force means more work: Used by all virtual and one physical

- **Post-instruction, difference in responses and reasoning**
  - Virtual provided scientifically correct reasoning
    - Eg: Object weighs the same and moves the same distance
  - Physical correctly identify factors but do not apply them correctly
    - Eg: Pulley requires more force; Pulley requires more distance pulled
Definitions of Force (Q1)

- Pre-instruction, no difference between physical and virtual
  - Effort or force physically exerted to lift object
  - Referred to work or included role for distance

- Post-instruction, observed difference
  - Physical: Effort or force physically exerted to lift object
  - Virtual: Referred to energy and/or included role for distance

Definitions of Work (Q 6.2)

- Pre-instruction, wide variety & varying scientific correctness
  - Change in kinetic energy (Virtual)
  - Spending energy (Physical)
  - Amount of effort and duration (Virtual)
  - What it takes to get the thing from point A to point B (Physical)

- Post-instruction, no difference between physical and virtual: mostly scientifically correct
  - How much object weighs and distance you have to move it (Physical & Virtual)
  - Amount of effort you put in over the distance pulled (Physical)
  - Work is equal to force times distance (Virtual)
  - Distance pulled divided by effort force (Virtual)
Discussion: Force

- “Common sense” reasoning
  - Observed more often before instruction than after instruction
  - Not observed after instruction for physical
  - Observed after instruction for virtual

- Possible explanation: Hammer’s\(^1\) model of conceptual resources
  - Context activates and deactivates resources students use to build understanding
  - Physical manipulatives may better support deactivation of resource related to “downward movement is easier”

\(^1\)Hammer, 2002

Discussion: Work

- Definitions of work
  - Students in physical and virtual provided equally useful definitions of work
  - Virtual more likely to use definition to arrive at correct answer
    - Physical having more difficulty applying definition in context

- Common sense resources: “more input means more output”
  - Used as “more force means more work” and “more distance pulled means more work”
  - Needs to be deactivated in favor of resource for proportional reasoning
    - “Force and distance change proportionally” (Virtual)
Conclusions

- While overall performance on the test was similar, specific concepts and questions exhibit a performance difference.
- Interviews allow us to probe these differences more deeply.
- Possible mechanism: physical and virtual activities may activate and deactivate different conceptual resources.
  - Force: Physical indicated suppression of “downward movement is easier”.
  - Work: Virtual indicated suppression of “more input means more output” possibly for a resource for proportional reasoning.

Gire et al., 2010

Thank you!

For more information,
Please contact:

Jackie Chini
haynicz@phys.ksu.edu

Or

Sanjay Rebello
srebello@phys.ksu.edu