Comparing Students' Performance with Physical and Virtual Manipulatives in a Simple Machines Curriculum

Jacquelyn J. Chini, Adrian Carmichael, N. Sanjay Rebello and Elizabeth Gire: *Kansas State University*; Sadhana Puntambekar, *University of Wisconsin, Madison*

Abstract

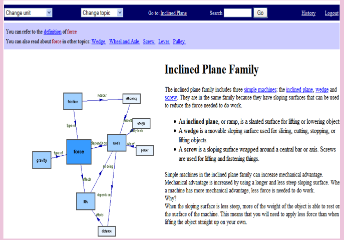
We compare the effects of physical versus virtual manipulatives in an inclined plane curriculum for students enrolled in a conceptual-based introductory physics laboratory. ANCOVA with pre-test score as a covariate showed that post-test scores for students who completed activities about length and height with virtual manipulatives (M=.775, SD=.026) were significantly higher than those of students who performed the same activities with physical manipulatives (M=.662, SD=.019), F(1,63)=13.5, p<.001, r=.43. Individual post-test questions that attributed to performance spread are identified and analyzed. We then analyze the manipulatives through the lens of dynamic transfer in an effort to explain the difference in students' performance.

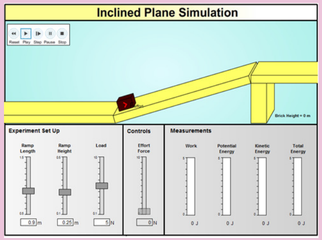
Research Motive

- Investigate how student learning is supported by interaction with physical and virtual manipulatives
- Previous studies in physics have shown mixed results
  - Virtual outperforms physical (see: Finkelstein *et al.*, 2005; Zacharia, 2007; Zacharia, Olympiou, & Papaevripidou, 2008)
  - No performance difference (see: Zacharia & Constantinou, 2008; Klahr, Triona & Williams, 2007)

Context of Study

- CoMPASS (Concept Map Project-based Activity Scaffolding System) inclined plane curriculum





Study Design & Test Results

- Participants: five sections of introductory conceptual-based physics students in laboratory
- Completed two of three experiments due to time constraints

Section	N	Pre-test Mean	Pre-test S.D.	Post-test Mean	Post-test S.D.
Length/Height Physical	29	59.9%	13.8%	66.2%	10.2%
Length/Height Virtual	37	60.0%	13.7%	77.5%	15.8%
Length/Friction Physical	23	59.2%	17.8%	66.0%	12.2%
Length/Friction Physical	31	60.1%	13.6%	65.9%	10.7%
Length/Friction Virtual	36	56.7%	15.5%	67.1%	13.6%

Analysis

- ANCOVA with pre-test score as a covariate was used to compare the post-test scores of students who had performed the same activities with different manipulatives

Experiment	Effect	F	p	r
Length/Height	Pre-test	F(1, 63)=15.2	<.001	.44
	Manipulative	F(1, 63)=13.5	<.001	.42
Length/Friction	Pre-test	F(1, 78)=17.5	<.001	.43
	Manipulative	F(1, 78)=.735	.394	--

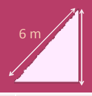
- Pearson's chi-square test was used to identify individual questions on which students who used the simulation to perform the Length & Height activities significantly outperformed students who used the physical equipment

Question	χ^2	p	Odds Ratio
6	$\chi^2(1)=21.1$	<.001	13.9
7	$\chi^2(1)=5.5$	.019	3.6
14	$\chi^2(1)=44.8$	<.001	177.8

Q6. You used a 5 m long ramp with no friction to move an object into a van. If you used a 10 m long ramp with no friction to move the object into the same van, the work needed would:

Answers to Q6	*LH Physical*	*LH Virtual*
A. Increase	55%	11%
B. Decrease	24%	11%
C. Stay the same	**21%**	**78%**
D. Not enough info	0%	0%

Q7. Jane is lifting a box straight up to a height of 2 meters. Mary is using the ramp shown below. If friction is not a factor, what can you tell about the *work done* by Jane and Mary?



Answers to Q7	*LH Physical*	*LH Virtual*
A. Jane is doing more work	38%	49%
B. Mary is doing more work	38%	3%
C. Jane and Mary are doing the same work	**21%**	**49%**
D. Not enough information	3%	0%

Q14. An object sits at the top of a frictionless ramp. How does the object's potential energy compare to the work required to move it to the top of the ramp?

Answers to Q14	*LH Physical*	*LH Virtual*
A. The object's potential energy is greater than the required work	28%	8%
B. The object's potential energy is less than the required work	69%	0%
C. The object's potential energy is the same as the required work	**3%**	**86%**
D. Not enough info	0%	5%

Theory: Dynamic Transfer and Properties of Successful Computer Use

- **Dynamic transfer** involves application of component competencies in an environment to yield new concepts. In contrast, **similarity transfer** involves application of well-formed concepts to a new situation (Schwartz, Varma, and Martin, 2008). Specific properties of the environment support dynamic transfer, as shown below.
- We have built a "master list" of the reasons computers can be potentially useful learning tools from the physics education research literature (Thornton and Sokoloff, 1990; Redish, Saul and Steinberg, 1997; Finkelstein *et al.*, 2005), shown below.
- We find significant overlap between these characteristics and the properties of an environment that supports dynamic transfer (Schwartz, Varma, and Martin, 2008).

Properties of Successful Computer Use	Characteristics of Environment for Dynamic Transfer
C1. Focus on the physical world.	DT1. Allows for distributed memory.
C2. Immediate feedback is available.	DT2. Offers alternative interpretations and feedback.
C3. Collaboration is encouraged.	DT3. Offers candidate structures by constraining and structuring actions.
C4. Powerful tools reduce drudgery.	DT4. Provides a focal point for coordination of different knowledge pockets.
C5. Understand the specific and familiar before moving to the more general and abstract.	
C6. Students are actively engaged in exploring and constructing their own understanding.	
C7. Useful models for forming concepts are made visible.	
C8. Students are constrained in productive ways.	

Discussion

- Students' performance on Q6 and Q14 can be linked to the type of manipulative used. Students who used the virtual manipulative saw only a frictionless environment, while students who used the physical manipulative typically chose answers based on the data from the physical experiment.
- Q7 appears to have been difficult for both groups. Students' responses are not explained by the presence or absence of friction.
- Using the lens of an environment supportive of dynamic transfer, the simulation seems to better meet these characteristics than the physical equipment.
  - Simulation calculates and displays work and potential energy, allowing for *distributed memory*.
  - Bar charts in simulation offer fast *feedback and alternative interpretations*.
  - Simulation *constrains and structures actions* by creating the inclined plane students chose and moving load at constant velocity to supply accurate force reading. Students using physical equipment had to construct and measure the inclined plane themselves and had fewer options.
  - Simulation provides a *focal point for coordination* by displaying relevant physics concepts all in one place.
- **Future Work:** Are there added benefits from performing physical and virtual experiments for the same activity?

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.