Comparison of a Computer-based to a Hands-on Lesson in Experimental Design

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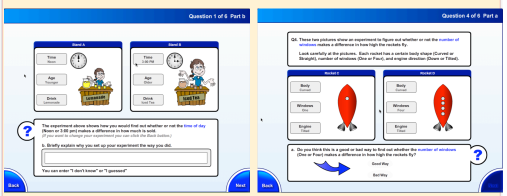
Background

An essential component of scientific literacy is an individual's ability to design and evaluate experiments. However, students may struggle to apply this fundamental skill in various contexts, instead falling into "cookbook" recipes of how to conduct scientific investigations, focusing more on materials than conceptual content. In this study, the effectiveness of a computer-based program teaching the Control of Variables Strategy (CVS) of experimental design was compared to a lesson covering similar content--the procedural and conceptual aspects of experimental design--but using hands-on lab equipment. Specifically, we wanted to see which form of instruction would yield better learning, time efficiency, and motivational outcomes, a computer based tutor, TED ("Training in Experimental Design") or what we considered a "good" teacher-guided lesson.

Figure 1. Story pre/posttest design (left) and evaluate (right) items.



Methods

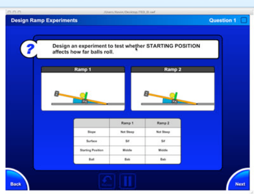
Participants. Twenty-nine 8th-grade students from a local school served as participants (15 in CPO and 14 in the TED condition).

Design. The design was two-condition (TED vs. Control) between-subjects quasi-experimental. All students in the 4th period science class were assigned to the Control lesson and all students in the 5th period class to TED (lesson details shown below).

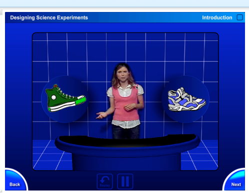
Procedure.

- Day 1: Both groups were given computerized story pretest (Figure 1 to left).
  - For each of 3 different problem scenarios (selling drinks, designing rockets; baking cookies), students design and evaluate an experiment.
- Days 2 & 3: TED/CPO lesson, given during students' regular science class period on two consecutive days (details below).
- Day 3: Immediate posttest (taken immediately after lesson):
  - Computerized story posttest, identical to story pretest, assessing "far" transfer to items in different domains than but having similar task demands as training items.
  - Standardized item paper posttest assessing "distant" transfer to different domains *and* task demands.
- One week later: Motivation survey: what did (not) like about different parts of the lesson, its overall effect on interest in science, etc.
- Three weeks later: paper story and standardized delayed posttests.

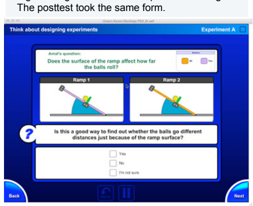
TED lesson. TED is a computerized tutor that administers instruction on the Control of Variables Strategy (CVS), setting up an unconfounded experiment by changing only the variable of interest. The interface for TED includes virtual ramps whose four variables (e.g., slope) can be manipulated by the user. Instruction is based on that developed by Klahr and colleagues (e.g., Chen & Klahr, 1999), which involves evaluating experiments and receiving feedback and conceptual explanations of CVS. The version of the TED tutor used in this evaluation was not adaptive.



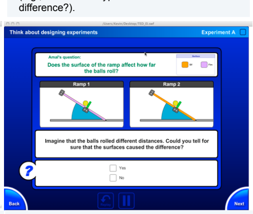
- (1) Students were introduced to the ramps, (variables and levels), then completed a pretest where they were asked to design experiments for a given target variable and explain their designs. The posttest took the same form.



- (2) Students viewed a brief video introducing the lesson, the learning goal of the lesson, and several examples of experimental comparison questions (e.g., Do different types of shoes make a difference?).



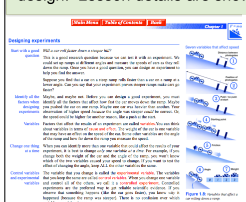
- (3) In the Explicit Instruction portion, students evaluated a series of 3 experiments as either a good or bad way to find out about the focal variable and then typed explanations for their responses.

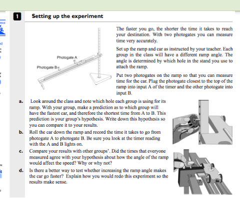


- (4) For each experiment, students were then asked whether they could "tell for sure" that the focal variable caused any differences in how far the balls rolled and typed explanations for their responses.

- (5) The tutor fixed any confounded experiments. Students were prompted to explain why the corrected experiment is a good way to find out about the focal variable and questions shown in (3). After the 3 evaluated experiments, students completed a posttest identical to the pretest (1).

CPO lesson. The Cambridge Physics Outlet, or CPO Science Company's Foundations of Physical Science curriculum (Hsu, 2002) supports students' understanding of science through teacher-guided hands-on investigations and basic concept lessons. The CPO science curriculum is approved in the Pittsburgh Public schools. In Investigation 1.2, students designed experiments to test a predicted relationship. When results did not support their prediction, a classroom discussion led to identification of experimental confounds, corrected in the design. Lesson details are shown below.





- (1) As a class, students read and discussed a portion of their textbooks introducing fundamentals of good experimental design, projected on an overhead (shown above). This included brief explanations of the "logic" of CVS: that if factors other than the focal variable differ, one of those factors could be responsible for a difference in outcomes.

- The class predicted that carts on steeper slopes would take less time to roll down the ramps.

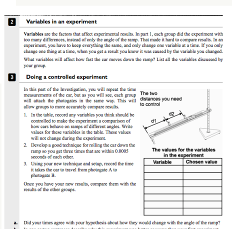
- (2) Groups assigned to ramps of different slopes designed experiments to test their prediction.

- Students followed the instructions shown above, which did not outline how to set up non-focal variables.

- (3) The class reconvened to discuss their results, revealing failure to control variables as the cause of the non-linear relationship between ramp slope and cart speed.

- (4) Students returned to their lab groups to re-run the experiment, controlling all non-focal variables. Instructions given are shown to the right.

- (5) The class reconvened and found their predicted negative relationship between steepness and time.



Results: TED vs. Teacher-delivered CPO lesson

- *Pretest.* Of students who did not show CVS pretest mastery, there was no difference in mean number of unconfounded experiments students designed or corrected on the story pretest, out of 6 (Table 1).

- *Far transfer.* Though students in the TED condition tended to score higher on the story posttest (Table 1), this difference was not significant, $F(1, 26) = 1.95$, $p = .17$. On the delayed story posttest, though students in the TED condition again tended to perform better (Table 1), this was also not significant, $F(1, 25) = 1.68$, $p = .21$.

Table 1. Story means (SDs) by time.

Condition	Story Pretest	Story Posttest	Delayed
CPO	1.33 (1.18)	2.53 (2.23)	3.07 (2.12)
TED	1.15 (1.21)	3.50 (2.10)	3.85 (2.44)

- Standardized measures of ability are frequently related to CVS transfer performance, but were not available. Teacher's ratings of students' "general ability" on a 5-point Likert scale were used as covariates. Now TED students significantly out-performed CPO students on both the immediate and delayed story posttests, $F(1, 25) = 7.48$, $p = .01$; $F(1, 24) = 5.34$, $p = .03$, respectively.

- *Lesson duration.* On the final day of the intervention, the CPO class required an extra 20 minutes to complete the instruction and posttest, resulting in the TED class being shortened by 20 minutes. Thus, CPO students had an extra 40 minutes to complete instruction and posttests. Students in the CPO condition took significantly longer to complete the immediate story posttest ($p < .01$).

Table 2. Mean story post efficiency scores (SDs).

Condition	Immediate	Delayed
CPO	0.08 (0.13)	0.12 (0.12)
TED	0.21 (0.19)	0.26 (0.20)

- *Lesson efficiency.* Since instructional times were significantly different, instructional efficiencies (i.e., pre-to-posttest gain divided by instructional time) were compared (Table 2). The story pre-to-immediate posttest and pre-to-delayed posttest efficiencies were both greater for the TED lesson, $F(1, 27) = 4.43$, $p < .05$; $F(1, 26) = 4.67$, $p = .04$, respectively.

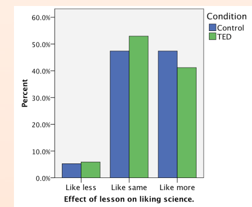
- *Standardized test items.* All students were given a paper-and-pencil assessment consisting of four experimental design questions from standardized science tests (out of 5). There were no differences on either the immediate (Table 3), $F(1, 25) = 2.72$, $p = .11$, or delayed posttest, $F(1, 25) = 0.07$, $p = .80$. There were no differences when student ability estimates were covaried.

Table 3. Mean standardized item scores (SDs).

Condition	Immediate	Delayed
CPO	2.73 (1.33)	2.80 (1.01)
TED	2.00 (0.85)	2.92 (1.31)

- *Survey results.* The primary finding favoring aspects of one lesson over another was an overwhelming reported preference for working with real over virtual ramps for *both* TED and CPO groups.

- There was no difference in reported effect of the lesson on how much they liked science: in each group about half of the students reported they liked science the same and almost half reported liking science more than before the lesson (shown below).



- Students in the TED condition reported enjoying the video introduction significantly *less* than other portions of the program (ramps pre/posttest, explicit instruction, story posttest). Unlike these other portions, the video introduction is not interactive.

- Finally, students in the CPO condition reported enjoying the hand-on activity, using the carts and ramps, more than any other aspect of the lesson (i.e., the initial class discussion ((1) in CPO lesson details), the post-experimental discussion (3), and completing the story pre- or posttests). There were no other differences.

Conclusions

Students given TED instruction scored significantly higher on the immediate and delayed story posttests when teacher's ratings of their general abilities were co-varied. TED instruction was also significantly more efficient, measured by pre-to-immediate or pre-to-delayed posttest gains, even without controlling for student ability. We believe the more intensive focus on the conceptual aspects of experimental design (i.e., why it is necessary to control variables) contributed to the far transfer advantage of TED instruction.

Regarding the reported preference for physical over virtual ramps, student enjoyment using the virtual ramps may be increased by adding such functionality as allowing them to run experiments, once correctly designed. However, adding such functionality risks diverting attention from instructional features more closely tied to meaningful learning. Alternatively, it is possible that students may benefit more from combining aspects of both lessons. We will continue to investigate ways to improve the learning, efficiency and motivational outcomes of lessons on experimental design, in an effort to design instruction that is both fun and promotes maximal cognitive gains, including distant transfer.

References

Chen, Z. & Klahr, D. (1999). All other things being equal: Children's acquisition of the control of variables strategy, *Child Development, 70*, 1098 -1120.
Hsu, T. (2002). "Foundations of Physical Science." *Cambridge Physics Outlet*, 2002.

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