The Effect of Causal-identification Prompts on Far-transfer Performance in Comparisons of Two Lessons on Experimental Design

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Background

The ability to design and evaluate experiments is critical in both science classes and in the real world. Although elementary and middle school students often do not possess these skills, they can be taught with relatively brief direct instruction (e.g., Chen & Klahr, 1999). However, in schools with more challenging student populations, such instruction is less successful (Klahr & Li, 2005). This was the impetus for building the TED ("Training in Experimental Design") computer tutor.

Instructional goals:
- Increase elementary and middle school children's understanding of scientific experimentation, including procedural (*how* to design good experiments) and conceptual (i.e., *why* experiments are/are not informative) understandings.
- Close the achievement gap between high- and low-SES students.

Design goal: Develop an intelligent tutor that will provide enjoyable and effective adaptive instruction based on individual reading level, knowledge state and mastery in real time across a variety of tasks and domains.

Research goal: Identify means of instruction that promote far-transfer performance. We hypothesize that feature-focusing on the underlying rationale of the Control of Variables Strategy (CVS), causal determinacy, will lead to a better integrated understanding of CVS and improved far-transfer performance.

Overview

To address these goals, we compared results within and across two studies comparing TED instruction to what we considered a "good" teacher-guided lesson from a public school curriculum. Based on results from the Fall 2009 study, modifications were implemented in TED for the Fall 2010 study.

Fall 2009 and Fall 2010 studies

Design. Two-condition quasi-experimental; all students in one science class were assigned to the Control (CPO) lesson and all students in the other class to TED. Feature-focus manipulation: Within the TED conditions, students were randomly assigned to either the "baseline" (BL) or "added questions" (AQ) condition. "Added questions" (AQ) students were required to identify all possible causes of experimental outcomes (refer to Fig. 1g) for each exemplar set-up under consideration.

Participants. Fall 2009: 29 8th-grade students from a local science and technology magnet school serving primarily low-SES students who did not show incoming CVS mastery (i.e., set up at least 67% non-confounded experiments on the pretest) served as participants (15 in CPO and 14 in the TED condition). Fall 2010: 24 non-mastery 6th-grade students from the same magnet school (10 CPO and 14 TED).

Procedure. The studies' procedures are described in the table below.

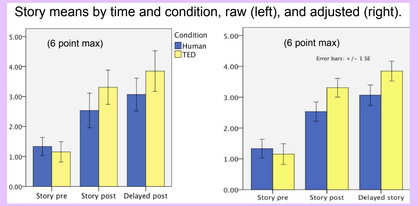
	Fall 2009 (8th-graders)		Fall 2010 (6th-graders)	
	CPO (4th period)	TED (5th period)	TED (4th period)	CPO (5th period)
Day 1	Intro to lesson (pp. 7-10 textbook: Read aloud and discuss)		Intro to lesson (pp. 7-10 textbook: Ss answer questions on worksheet based on text material; discuss answers)	
	Story pretest (on-line)		Story pretest (on-line)	
			Part 1 of TED lesson (ramps intro, ramps pre, remedial, evaluate Exp A)	Review textbook (ID carts variables, review of "controlled experiment," etc.)
Day 2	Review textbook (ID carts variables, review of "controlled experiment," etc.)	Part 1 of TED lesson (ramps intro, ramps pre, intro video, evaluate Exp A)	Part 2 of TED lesson (evaluate Exp's B & C, ramps posttest)	CPO ramps lesson (Ss IDed confounds; discuss controlling variables; re-run experiment)
Day 3	CPO ramps lesson (Ss IDed confounds; discuss controlling variables; re-run experiment) **(Lesson ran 20 min late.)**	Part 2 of TED lesson (evaluate Exp's B & C, ramps posttest) **(Lesson shortened 20 min.)**	Story posttest (on-line)	
	Story posttest (on-line)		User survey (paper/pencil)	
1 week later	User survey (pencil/paper)			
	Delayed Story test (paper)		Revised/harder Delayed Story test (paper)	
3 weeks later	Standardized items (paper): Four items		Standardized items (paper) Two items	

CPO lesson. The same teacher in 2009 and 2010 presented a lesson on experimental design using materials and a lesson from The Cambridge Physics Outlet, or CPO Science Company's Foundations of Physical Science curriculum (Hsu, 2002), approved in the Pittsburgh Public schools.

Results: Fall 2009 TED vs. CPO lesson

- *Far transfer.* Because students in the CPO class had higher PSSA reading comprehension scores, they were covaried in ANCOVA. As shown to the right, TED students significantly out-performed CPO students on the immediate story post, $F(1, 26) = 5.76$, $p = .02$, and on the delayed story posttest, $F(1, 25) = 4.38$, $p = .047$, even though the CPO lesson was 40 minutes longer than the TED lesson.

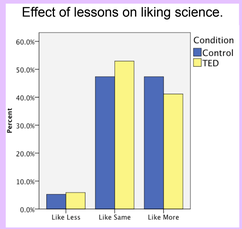
Story means by time and condition, raw (left), and adjusted (right).



Primary survey findings:
- A reported preference for working with real over virtual ramps in future lessons for both TED and CPO groups.
- Perhaps most importantly, there was no difference in the effect of the lessons on how much students liked science (shown to right).

Within-condition survey findings.
- TED students reported enjoying the video introduction less than other, interactive, portions of the program.
- CPO students reported enjoying the carts and ramps hands-on activity more than any other aspect of the lesson (i.e., the initial class discussion, the post-experimental discussion, and completing the story pre- or posttests); there were no other differences.

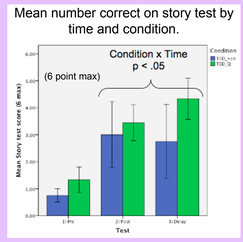
Effect of lessons on liking science.



Results: TED Baseline (BL) vs. Added-questions (AQ)

- *Far transfer*. There was a marginally significant condition by ability level interaction on the immediate story post ($p = .06$); lower-ability student performed better in the AQ condition and higher-ability students performed better in the BL condition.
- There was no significant difference between AQ and BL conditions on the delayed posttest.
- However, students in the AQ condition gained significantly from the immediate to delayed story posttest (shown to right), significantly more than BL students, who did not gain.

Mean number correct on story test by time and condition.



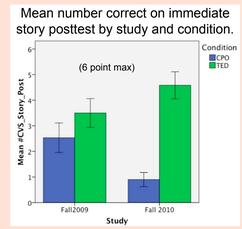
Thus, the non-adaptive, straight-line TED instruction compared favorably with a "good" control lesson. Would modified and adaptive instruction fare even better?

TED modifications for Fall 2010 study:
- Based on our previous analyses of students' misconceptions about the goal of the lesson that interfered with learning (Siler & Klahr, in press), instructional wordings that may have contributed to these misinterpretations were modified.
- Open-ended response boxes on the ramps pretest were replaced with drop-down menus.
- Knowledge-tracing capabilities (Corbett & Anderson, 1995) were integrated with these drop-down menus.
- The introductory video (Fig 1d) was removed and replaced with an interactive remedial phase, described next.
- Interactive remediation (e.g., Fig. 2) is given to students who do not show above-threshold understanding of basic aspects of CVS on the ramps pretest (e.g., identifying and varying the target variable across conditions) and prior to entering the instructional phase.

Results: Fall 2010 TED vs. CPO lesson

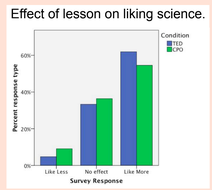
- *Far transfer (immediate story post).* There was a significant study by condition interaction, $F(1, 46) = 5.91$, $p = .02$, where there was a greater advantage for TED over CPO students in the Fall 2010 than in the Fall 2009 study (shown to right).
- TED 2010 (6th-grade) students scored marginally higher than the TED 2009 (8th-grade) students ($p = .08$).
  - These results suggest TED modifications positively impacted immediate far transfer performance.
- *Far transfer (delayed story post).* TED students also out-performed CPO students on the more difficult delayed story posttest, $F(1, 21) = 4.48$, $p < .05$.

Mean number correct on immediate story posttest by study and condition.



Primary survey findings:
- As in the Fall 2009 study, both TED and CPO students reported a preference for using physical over virtual ramps in future lessons (75% and 67%, respectively).
- There were no differences between TED and CPO conditions in mean enjoyment ratings for different parts of the respective lessons (M = 3.83; 3.77, respectively, out of 5),
- As in the previous study, there was no difference in reported effect of the lesson on liking science (shown to right).

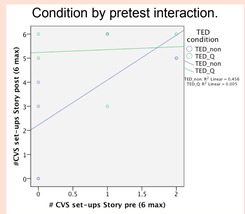
Effect of lesson on liking science.



Results: TED Baseline vs. Added-questions

- *Far transfer (immediate story post).* There was a marginally significant condition x story pretest interaction, $F(1, 8) = 7.59$, $p < .10$, where the "added questions" condition benefited lower-knowledge students (shown right). With or without this interaction in the model, AQ students scored significantly higher than baseline students.
- *Far transfer (delayed story post).* Likewise, added-questions students scored marginally higher on the delayed story posttest, $F(1, 9) = 15.63$, $p = .05$.

Condition by pretest interaction.



Conclusions

The modifications made to TED for the 2010 study-which tended to make instruction more explicit and involve more student/computer interaction–appears to have improved far-transfer performance. The addition of feature-focusing question prompts requiring students to identify all possible causal variables in given set-ups did not lead to significant gains in the Fall 2009 study, though there was an interaction trend in which lower-ability students tended to benefit more from the added-questions (AQ) condition. Also, AQ students-but not baseline students-showed significant gains from the immediate and delayed story posttest. These feature-focusing prompts were significantly related to gains in the Fall 2010 study, particularly for initially low-knowledge students. These results suggest that "active" feature-focusing is particularly beneficial for lower-knowledge and lower-ability students.

References

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Hsu, T. (2002). "Foundations of Physical Science." *Cambridge Physics Outlet*, 2002.
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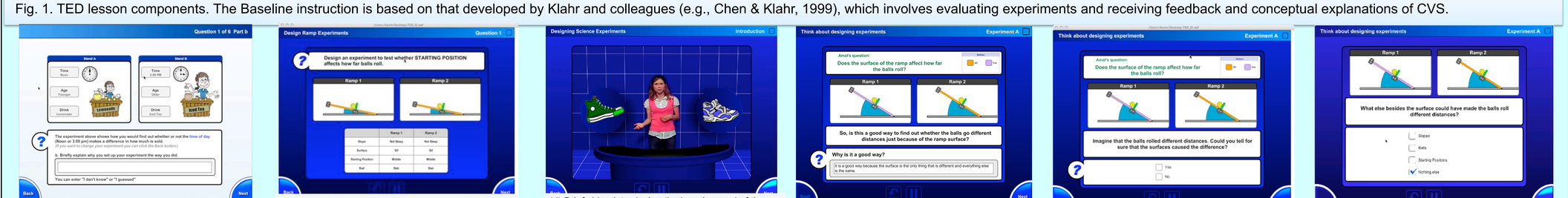
Fig. 1. TED lesson components. The Baseline instruction is based on that developed by Klahr and colleagues (e.g., Chen & Klahr, 1999), which involves evaluating experiments and receiving feedback and conceptual explanations of CVS.



(a) Story pre/posttest in which students evaluate and design experiments in 3 different domains.

(b) Intro to the ramps, then (c) ramps pre/posttest (above) where students design experiments then explain their designs using free-response (Fall 2009) or drop-down (Fall 2010) selections.

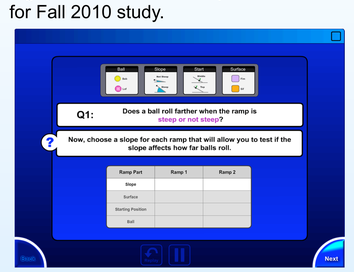
(d) Brief video introducing the learning goal of the lesson, and several examples of experimental comparison questions (e.g., Does shoe type matter?) (In Fall 2009 TED instruction only.)

(e) Instruction portion: students evaluate 3 experiments as either a good or bad way to find out about the focal variable and provide explanations.

(f) For each experiment, students are asked whether they could "tell for sure" that the focal variable caused any differences and provide an explanation.

(g) In the "Added-Questions" condition only, students were then prompted to identify all possible causal factors of different outcomes in the design.

Fig. 2. TED remedial components added for Fall 2010 study.



Remedial instruction for varying the given focal variable, which includes the rationale for varying.