# Comparison of a Computer-Based to Hands-On Lesson in Experimental Design*

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**Abstract.** In this study, we compared our computer tutor ("TED" for Training in Experimental Design) to a teacher-guided control lesson also targeting experimental design but incorporating hands-on learning. Students in both groups showed significant gains in ability to design unconfounded experiments. TED instruction was significantly more efficient than the control lesson. When the teacher's ratings of student ability were co-varied, students in the TED condition significantly out-performed control students on both immediate and delayed far transfer assessments taken three weeks after instruction. Students in both groups also reported a preference for physical over virtual materials.

**Keywords:** computer-based tutor; experimental design; middle-school students.

## 1 Introduction

An essential component to scientific literacy is an individual's ability to design and evaluate experiments. Students may struggle to apply this fundamental skill in various contexts, falling into "cookbook" recipes of how to conduct scientific investigations, focusing more on materials than conceptual content. Some have claimed this problem is even worse with computerized instruction: "The conceptual or research goals of the laboratory get lost in the attention for equipment and there is no conceptual learning, nor learning of research or inquiry skills. Computers can glue students' minds and hands even more strongly to the world of equipment…[1]". To test such indictments of computer-supported instruction as well as to answer the practical question of how our computer tutor ("TED" for Training in Experimental Design) compares to what we considered to be a "good" lesson on experimental design, we compared TED to

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ateacher-guided lesson incorporating more commonly used hands-on lab equipment. We were interested in comparing both learning/transfer and motivational outcomes.

## 2 Comparison of TED to Control Lesson

### 2.1 Participants, Design, and Procedure

Participants were 29 8th-graders in two classes at a local magnet school who did not show initial mastery of experimental design skills. Students in the 4th period class were assigned to the Control lesson and all students in the 5th period class to TED instruction. Both groups completed a 6-item computerized story pretest in which they designed and evaluated experiments in three contexts (drinks, cookies, and rockets). Then students participated in the 2-period lesson on consecutive days in their respective condition. Both groups then completed the computerized story posttest[1]. They were reassessed three weeks later. Between the posttest and follow-up, all students completed a motivation survey assessing their enjoyment of different parts of the lessons and interest in science.

**TED lesson.** TED is a computerized tutor that administers instruction to help 4th-8th-graders learn the Control of Variables Strategy (CVS), the strategy of 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. The instruction delivered in TED is based on the "explicit" CVS instruction developed by Klahr and colleagues [3], and involves evaluating experiments and receiving "explicit" feedback and explanations of the rationale for applying CVS.

**Control lesson.** The Cambridge Physics Outlet (CPO) Science Company offers their Foundations of Physical Science curriculum [2] to schools to support students' understanding of science through hands-on investigations and basic concept lessons. Investigation 1.2 targets experimental design using ramps. In this lesson, students designed and ran experiments to test a predicted relationship between ramp steepness and car speed. Discrepant results led to a discussion, then conclusion this was due to experimental confounds. Thus, this lesson also addressed the rationale for using CVS.

### 2.2 Results

**Pretest and posttest outcomes.** There was no difference in the mean number of unconfounded experiments students designed or corrected on the pretest (Table 1). Though students in the TED condition tended to score higher on the posttest, this difference was not significant, $F(1, 26) = 1.95$, $p = .17$. On the delayed posttest, though TED students again tended to set up more unconfounded experiments, this difference was also not significant, $F(1, 25) = 1.68$, $p = .21$. Because standardized reading scores—typically correlated with CVS outcome measures—were not available, the teacher rated each student's general ability on a 5-point scale. Co-varying these ratings, TED students scored significantly higher on immediate, $F(1, 25) = 7.48$, $p = .01$, and delayed posttest, $F(1, 24) = 5.34$, $p = .03$.

[1] Due to space limitations, we will not discuss the results of standardized posttests also taken other than to note there were no significant effects of condition.

**Table 1.** Mean story test score and efficiency (and standard deviations) by condition and time

| | Mean score (maximum of 6) | | | Efficiency | |
|---|---|---|---|---|---|
| Condition | Pretest | Posttest | Delayed | Pre-to-Post | Pre-to-Delayed |
| Control | 1.33 (1.18) | 2.53 (2.23) | 3.07(2.12) | 0.08 (0.13) | 0.12 (0.12) |
| TED | 1.15 (1.21) | 3.50 (2.10) | 3.85 (2.44) | 0.21 (0.19) | 0.26 (0.20) |

**Instructional efficiency.** On the final day of the intervention, to finish the lesson and posttests, the Control class ran 20 minutes late, causing the TED class to be shortened by 20 minutes. Thus, Control students had an extra 40 minutes to complete instruction and posttests. Students in the Control condition also took significantly longer on the posttest ($p < .01$). Because instructional times were significantly different, we compared instructional efficiency (i.e., pre-to-posttest gain divided by instructional time). As shown in Table 1, TED instruction was significantly more efficient with respect to both pre-to-immediate gains, $F(1, 27) = 4.43$, $p < .05$, and pre-to-delayed gains, $F(1, 26) = 4.67$, $p = .04$.

**Survey results.** On the motivational survey, the primary difference for both groups was a reported preference for working with real over simulated ramps.

## 3 Conclusions

Students in the TED condition had significantly higher immediate and delayed posttest scores when teacher ratings of student ability were factored out. Furthermore, TED instruction was significantly more efficient, as measured using either immediate or delayed story posttest gains. We believe these results are due to the more focused and repeated *conceptual* CVS instruction given in TED. Regarding students' reported preference for physical over virtual ramps, student enjoyment of virtual ramps may be increased by, for example, allowing them to run experiments, once correctly designed. However, adding such functionality risks diverting attention from instructional aspects more closely tied to meaningful learning.

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