Developing an Intelligent Tutor for Training in Experimental Design (TED)

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**Project Goal**

Design, assess, and implement an intelligent, robust, flexible, and easy to use web-based tutor for teaching the Control of Variables Strategy (CVS) to elementary and middle school children. CVS mastery requires the acquisition of both procedural and conceptual knowledge elements that support the identification of causal factors. The current version of TED -- a computer-based tutor with limited intelligence (TED-1) -- will be transformed into an intelligent and adaptive cognitive tutor (TED-2) for CVS. TED-2 will provide real-time adaptive instruction based on a student’s reading level, knowledge state and mastery across a variety of tasks and science content domains.

**Background:** Our project is based on an extensive series of empirical studies with elementary- and middle-school children (e.g., Chen & Klahr, 1999; Toth, Klahr, & Chen, 2000; Klahr & Li, 2005) contrasting different instructional methods -- along a "direct" to "discovery" spectrum -- for teaching CVS.

**Target population:** Third through eighth grade students, diverse with respect to SES, reading ability, and experience in science inquiry. We believe that easy access to TED-2 will help science teachers in low-SES schools to substantially reduce the achievement gap in science. Potential LearnLab in Pittsburgh’s new Science & Technology School.

**TED Components**

- **Examples of instructional events and assessment events in existing TED-1**

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Story problems and Ramps problems used as pre/post-tests: evaluate and design experiments in three domains.</td>
<td>Story Pre</td>
</tr>
<tr>
<td>Pre-intervention</td>
<td>Pre</td>
</tr>
<tr>
<td>Introduction: Purpose of lesson, some term definitions, etc.</td>
<td>Pre</td>
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<td>Pre</td>
</tr>
<tr>
<td>Explicit CVS instruction (e.g., Klahr &amp; Nigan, 2004; Strand-Cary &amp; Klahr, 2008).</td>
<td>Pre</td>
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<tr>
<td>Remedial CVS instruction (e.g., “step-by-step” walk-through of setting up informative experiments) for students showing difficulty understanding explicit instruction (by Fall 2009).</td>
<td>Pre</td>
</tr>
<tr>
<td>Authentic problems (represented by circle) will be added in TED-2</td>
<td>Pre</td>
</tr>
</tbody>
</table>

**TED Instructional Flow:** Assessment events represented as squares; instructional events as hexagons; remedial instructional events as grayed ovals.

**A brief history of TED-1 Development**

- **Starting point:** "explicit instruction"; TED-1 was based on evidence that explicit instruction promotes high levels of CVS mastery and transfer. Key components of explicit instruction include presentation of "good" and "bad" experiments, probes for student explanations of why experiment is good or bad, feedback from instructor, modification of "bad" experiments to make them "good", final probe for student to explain the "good" experiment.

- **Teacher-delivered explicit instruction:** Evidence about common student misconceptions was extracted from discussion-based explicit instruction delivered in three 6th-grade classrooms (two low-SES and one middle-SES). The rates of CVS mastery gain were 80% in the middle-SES classroom, but only 33% and 36% in the two low-SES classrooms.

- **Students who did not achieve CVS mastery were individually tutored:** this (and subsequent) tutoring served as basis for informing remedial instruction in TED-1. Analysis of tutoring protocols revealed a range of student misconceptions, including those about the goal of the lesson. This information will inform model- and knowledge-tracing functions in TED-2.

- **Modified instruction:** in the next round of instruction, delivered in a third low-SES classroom, physical ramps were replaced with virtual ramps. CVS instruction was also modified such that the lesson included an introduction, then procedural rules of CVS were discussed prior to a brief discussion on conceptual underpinnings for CVS.

  - Near transfer: No difference between this and prior low-SES performance on ramps post-tests.
  - Far transfer: Initial explicit instruction better for all but low-reading and low-pretest students (whose performance did not differ).
  - These results suggest a sequential focus on procedural before conceptual knowledge was not beneficial to the students we are most hoping to help.

- **Back to basics:** Based on these findings, we focused instruction on conceptual understanding.

  - To simulate our final (TED-2) intelligent (model-tracing) tutor that tailors instruction to the individual student, we:
    - Used human tutors to diagnose students' initial knowledge state from their pretest response patterns and tutored students one-to-one or in small groups.
    - Used a fully navigable interface and a "database" of questions (practice and remedial) corresponding to CVS n(a)le(s). Tutors selected questions for individual students based on their assessments of students' knowledge states.
    - Tutoring sessions were analyzed to determine effective instructional "pathways" for students, given their current knowledge state; this information has informed TED-1 development and will continue to inform TED-2 development.

- **Common finding:** in all of these studies, we found significant relationships between reading achievement scores and gain in CVS, and also persistent student goal misconceptions (e.g., engineering goals, where students attempted to produce the largest experimental effects).

- **To address goal misconceptions:** we added an introduction stating the purpose of the instruction; to minimize elicitation of domain knowledge and in turn reduce goal misconceptions, two of the four variables used in the explicit instruction have "mystery" values (nonsense names).

- **To address the reading issue,** we added audio voice-over to the instruction and ramps tests.

- **Comparison of TED-1 to Human-delivered instruction:** Students' CVS learning from TED instruction (green horizontal pathway in flowchart to left) was compared to learning from the same instruction delivered by a human tutor in a middle-SES 5th-grade classroom.

  - Results: No difference between conditions in terms of near-transfer performance (Graph on left); however, boys in TED condition performed worse than other groups on far-transfer questions (Story post-test: Story pre-test after middle Graph).

- **Near Transfer Results:** Pre to post-test gains on ramps mastery (pre-post).

- **Far Transfer Results:** Pre to post-test scores on far-transfer questions (Story pre-test: Story post-test after middle Graph).

- **We identified a possible cause of this difference (placement of the experimental question below the set-up area on the Story post-test only),** and re-administered the Story post-test two weeks later. This time, there was no significant difference between conditions and no gender by condition interaction (Graph on right).

- **Near Transfer Results:** Pre to post-test gains on ramps mastery (pre-post).

**References**


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