Cognitive Task Analysis 1

Announcements

- Change of plan for next Tuesday
  - Go to PSLC Poster Session
  - Outside of 6115 in the new Gates building
  - Return to class by 5:30 to discuss
- Are the posted slides complete? On a PC?
- Today's plan
  - Review assignment 1
  - Questions on assignment 2?
  - Intro to Cognitive Task Analysis
  - Example of Aptitude-Treatment Interaction?

Cognitive Task Analysis

- Techniques to specify *cognitive structures & processes* associated with task performance
  - Structured interviews of experts
  - Think alouds of experts & novices performing tasks
  - Computer simulations of human reasoning

Definitions of Cognitive Task Analysis

- Clark reading
  - Clark's or Chipman's?
  - We will use Chipman's broader definition
- Others
  - The general term used to describe a set of methods and techniques that specify the cognitive structures and processes associated with task performance. The focal point is the underlying cognitive processes, rather than observable behaviors. (Clark & Estes, 1996)
  - Another defining characteristic of CTA is an attempt to describe the differences between novices and experts in the development of knowledge about tasks

Kinds of Cognitive Task Analysis

- 2 Kinds of Approaches
  - Empirical: Based on observation, data, exp.
  - Analytical: Based on theory, modeling.
- 2 Kinds of Goals
  - Descriptive: How students actually solve problems. What Ss need to learn.
  - Prescriptive: How students should solve problems. What Ss need to know.
- 4 Combinations ...

Kinds of Cognitive Task Analysis

Where does Clark fit?

	Empirical	Theoretical
Descriptive	Think-aloud of novice. Difficulty Factors Assessment.	Cognitive modeling of errors, informal strategies.
Prescriptive	Think-aloud of expert. DFA	Cognitive modeling of success, normative strategies.

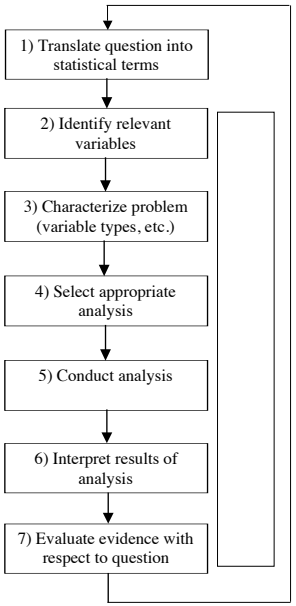
Example: Think Alouds in Statistics Tutor Development

- Task: Exploratory Data Analysis
  - Given problem description and data set
  - Inspect data to generate summaries & conclusions
  - Evaluate the level of support for conclusions
- Example Problem

  In men's golf, professional players compete in either the regular tour (if they're under 51 years old) or in the senior tour (if they are 51 or older). Your friend wants to know if there is a difference in the amount of prize money won by the players in the 2 tours. This friend has recorded the prize money of the top 30 players in each tour. The variable *money* contains the money won by each of the players last year. The variable *tour* indicates which tour the player competed in, 1=regular, 2=senior. The variable *rank* indicates player rank, 1=top in the tour.

Task Analysis of Major Goals in Statistical Analysis

- This is an "analytic prescriptive" form of CTA
- Break down task:
  - 7 major goals
  - Each goal has involves multiple steps or subgoals to perform
  - Write if-then rules (productions) that describe how each subgoals is achieved



Sample Transcript

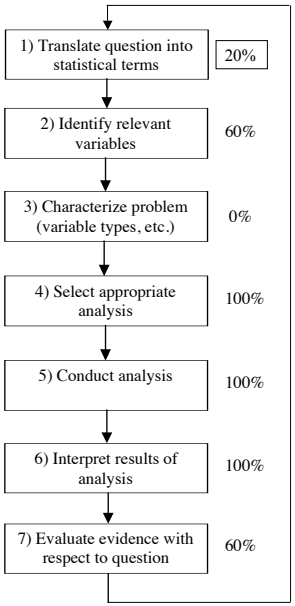
L#	Participants words & actions	Annotation
1	Oh, okay.	
2	So we need to, he wants to know whether there is a	Goal 1
3	difference in the amount of prize money, the amount of	
4	money won by players in the two tours.	
5	So, I think this is the prize money, uh, money contains the	Goal 2
6	prize money won by each of these players.	
7	Tour indicates which tour the player competes in.	
8	Well, you don't really need rank, in order to solve this, right?	
9	Cause like, well, I don't know.	
10	Um... I'm gonna do a boxplot... ...	Goal 4
11	[Subject uses statistics package to make a boxplot]	Goal 5
12	oh, cool (laugh)- I did it.	
13	All right, uh, so just looking at the average.	Goal 6
14	It looks like the people in the senior tour get less money.	
15	Um, and there's a lot less variation in the amount of money	
16	that, like all the prizes.	
17	A couple little outliers in each which means like, I don't	
18	know, like some people won, like a lot of money at a time…	

Observations about this verbal report

- No evidence for goal 3, characterize the problem
  - Line 10: student simply jumps to selecting a data representation (goal 4) without thinking about why.
- No evidence for goal 7, evaluate evidence
- Minor interpretation error
  - Line 13: student mentions the "average" when in fact boxplots display the median not the mean
- *Note: These observations may be indicated in the annotation column of the transcript*

Comparing Think Aloud Results with Task Analysis

- Percentages to the right of each step represent the percentage of students in the think-aloud study who showed explicit evidence of engaging in that step.
- Step 3 is totally absent!
  - A tutor can help students to do & remember to do step 3



Using if-then rules to model differences between novices & experts

- Novices make errors either because
  - Lack of knowledge -- modeled as a missing rule
  - Incorrect knowledge -- modeled as a "buggy" rule
- Missing rule (to set goal 3):
  Characterize problem
  If goal is to do an exploratory data analysis
  & relevant variables have been identified
  then
  set a subgoal to identify variable types
- Buggy rule (skipping from goal 2 to 4):
  Select any data representation
  If goal is to do an exploratory data analysis
  & relevant variables have been identified
  then
  set a subgoal to conduct an analysis by picking any data representation

Clark's CTA Families

- Differ strategies for knowledge elicitation (empirical)
  - Observation and interviews
    - Informal
  - Process tracing
    - More structured
  - Conceptual techniques
    - Formal, with fixed protocols for interaction with participants
- Formal models (theoretical)
  - Simulations of task performance or "cognitive models"

Clark's steps

- Collect preliminary knowledge
- Identify knowledge representations
- Apply focused knowledge elicitation methods
- Analyze and verify data acquired
- Format results for intended application

Knowledge representations schemes

- Clark's
  - Concept maps
  - Flow charts
  - Semantic nets
- Other's
  - Goal trees
  - If-then rules written in English
  - Cognitive modeling, like ACT-R

My Steps In Task Analysis

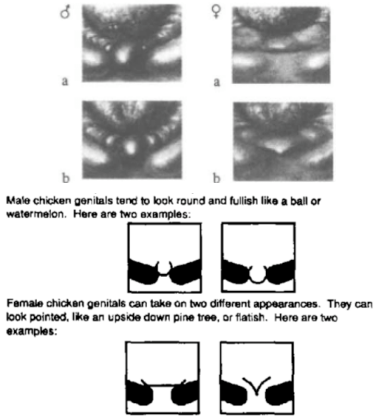
- What are instructional objectives?
  - Standards, existing tests, signature tasks
- Has someone done the work for you? Don't reinvent the wheel. Do a literature review!
  - "8 weeks of analysis saves an hour in the library"
- Specify space of tasks
- Do either or both:
  - Theoretical task analysis: Create a model that is sufficient to deal with space of tasks
  - Empirical task analysis: Do think aloud, difficulty factors assessment, expert interviews...

Some examples …

- … and how CTA translates into better instruction

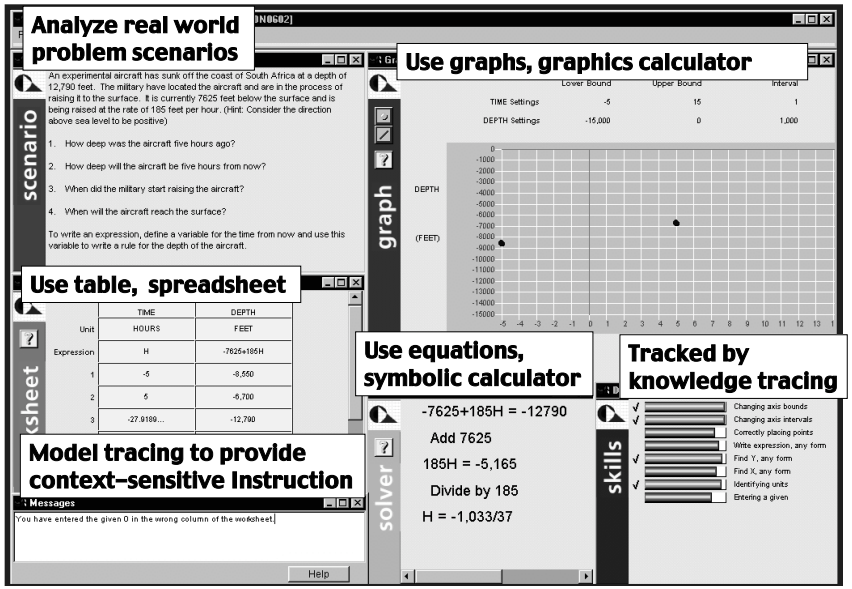
Unpacking & repacking expertise: Chick sexing

- Experts don't know, what they know
  - 98% accurate after years of on-the-job training
- Interviews led to design of "pictures in which *critical features* of various types were indicated"
- After just minutes of instruction, novices brought to 84% accuracy!

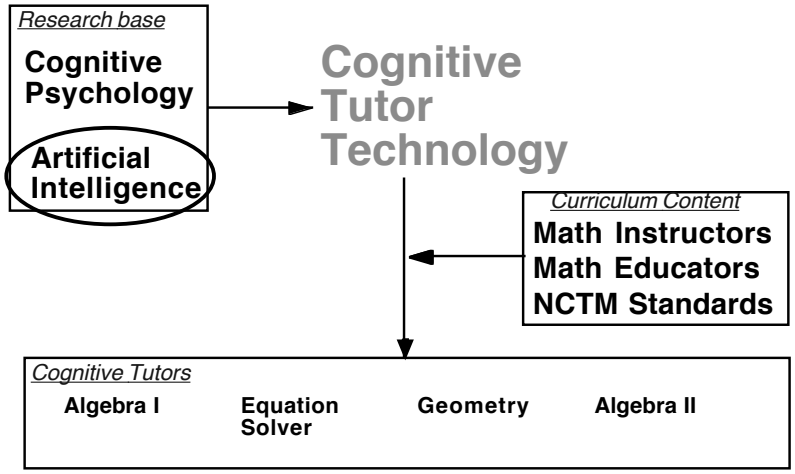


Biederman & Shiffrar (1987). Sexing Day-Old Chicks: A Case Study and Expert Systems Analysis of a Difficult Perceptual-Learning Task. JEP: Learning, Memory, & Cognition.

Algebra Cognitive Tutor: Example Activity



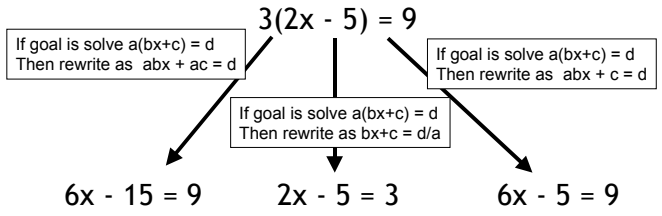
Cognitive Tutors: Combining Cognitive Psychology & Intelligent tutoring systems



Cognitive Tutor Technology

Use cognitive model to individualize instruction

- Cognitive Model: A system that can solve problems in the various ways students can



- Model Tracing: Follows student through their individual approach to a problem -> context-sensitive instruction

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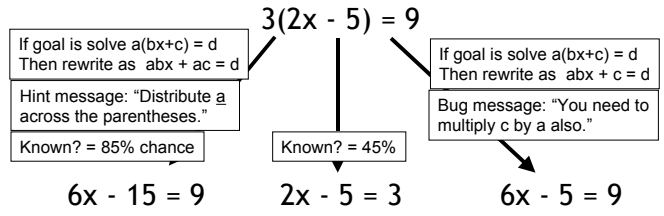

- Model Tracing: Follows student through their individual approach to a problem -> context-sensitive instruction
- Knowledge Tracing: Assesses student's knowledge growth -> individualized activity selection and pacing

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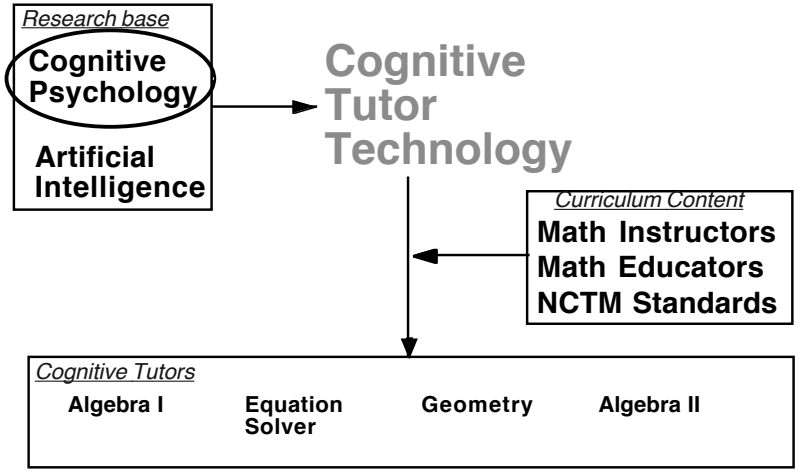


Cognitive Task Analysis Improves Instruction

Studies: Traditional instruction vs. CTA-based

- Med school catheter insertion (Velmahos et al., 2004)
  - Sig greater pre to post gain
  - Better with patients on all four measures used
  - Example: Sig fewer needle insertion attempts!
- Other examples
  - Radar system troubleshooting (Schaafstal et al., 2000)
  - Spreadsheet use (Merrill, 2002)
- Meta-analysis, 7 studies: 1.7 effect size! (Lee, 2004)

Isn’t knowledge analysis done for long-standing academic domains?

- Hasn't all this been worked out?
- Surely by now we understand the content of, say, Algebra?

Difficulty Factors Assessment:
Discovering What is Hard for Students to Learn

Which problem type is most difficult for Algebra students?

Story Problem

As a waiter, Ted gets $6 per hour. One night he made $66 in tips and earned a total of $81.90. How many hours did Ted work?

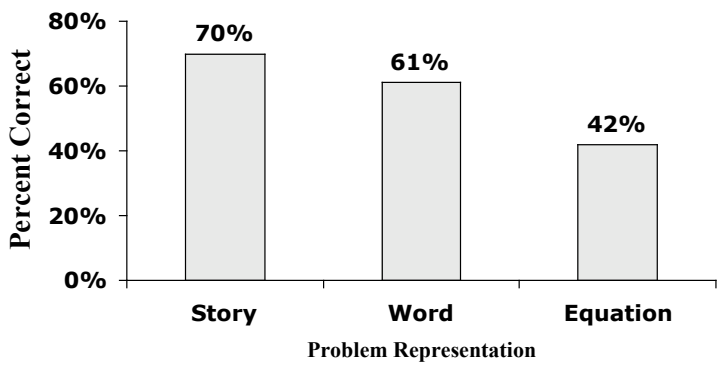
Word Problem

Starting with some number, if I multiply it by 6 and then add 66, I get 81.90. What number did I start with?

Equation

x * 6 + 66 = 81.90

Algebra Student Results: Story Problems are Easier!

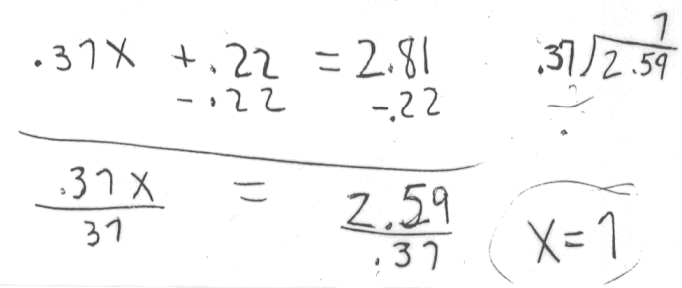


Koedinger, & Nathan (2004). The real story behind story problems: Effects of representations on quantitative reasoning. *The Journal of the Learning Sciences*.

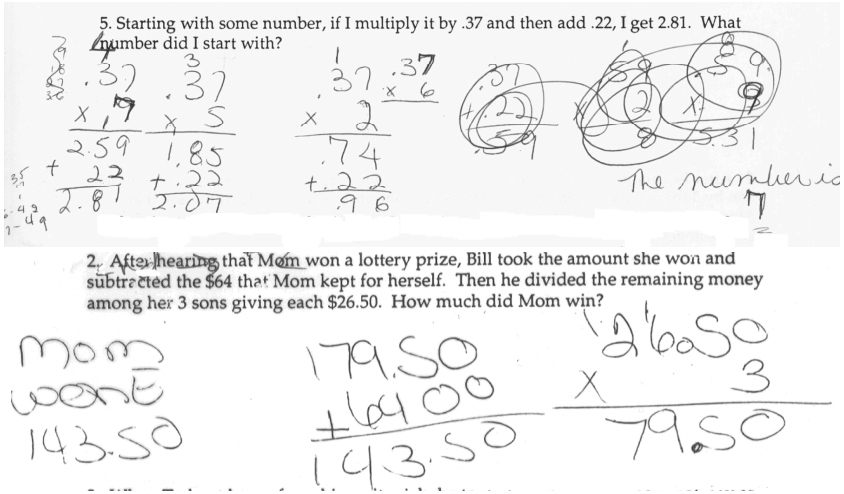
Koedinger, Alibali, & Nathan (2008). Trade-offs between grounded and abstract representations: Evidence from algebra problem solving. *Cognitive Science*.

Typical textbook strategy

8. After buying donuts at Wholey Donuts, Laura multiplies the number of donuts she bought by their price of $0.37 per donut. Then she adds the $0.22 charge for the box they came in and gets $2.81. How many donuts did she buy?

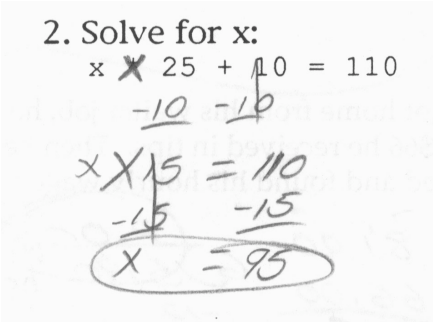


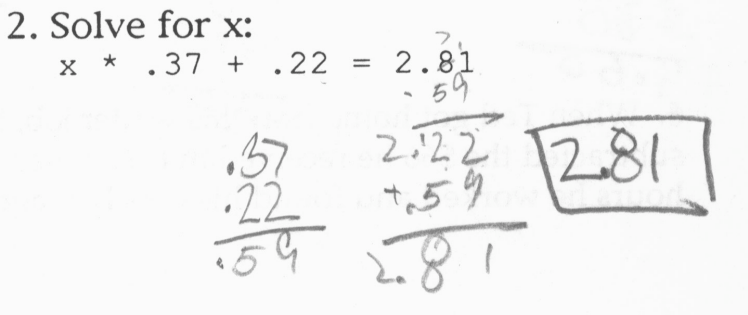
Informal Strategies



The foreign language of algebra:

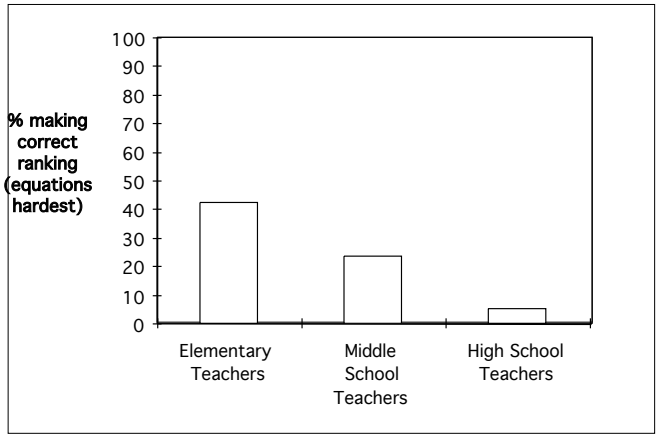
Difficulties with syntax & semantics





Expert Blind Spot:

Expertise can impair judgment of student difficulties



Nathan, M. J. & Koedinger, K. R. (2000). An investigation of teachers' beliefs of students' algebra development. *Cognition and Instruction*, *18*(2), 207-235

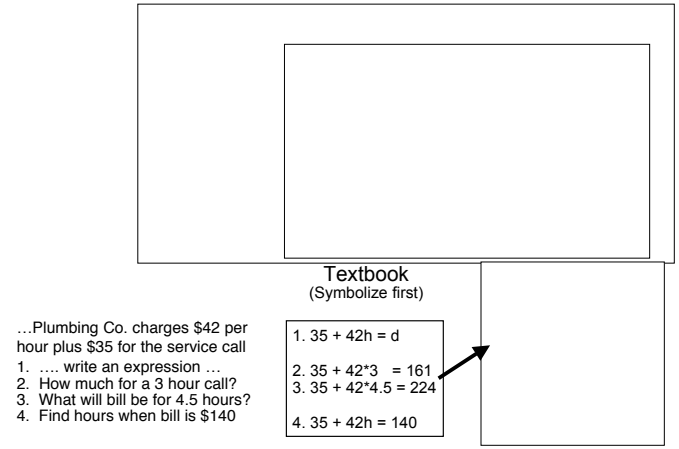
What's behind expert blind spot?

- Self-reflection on current cognition, biased memory of past learning
- Aware of verbally-mediated reasoning
  - False inference: More words => more thinking
- Not aware of implicit processing & learning
  - Fluent algebra language processing requires *extensive implicit learning*
  - Our minds are continually engaged in pattern induction, analogy, chunking, strengthening …

Example: Using Cognitive Task Analysis to design better algebra instruction

- Inductive support strategy
  - Help students generalize abstract math from their own intuitive concrete solutions
  - Similar to "progressive formalization" or "concreteness-fading" (Golstone & Son, 05)
- Test idea with an *in vivo experiment*
  - Experiment *within a real course* where we *test a single principle* (change one thing)

Parametric Study: Textbook vs. Cognitively-Based Design



Koedinger, K. R., & Anderson, J. R. (1998). Illustrating principled design: The early evolution of a cognitive tutor for algebra symbolization. *Interactive Learning Environments.*

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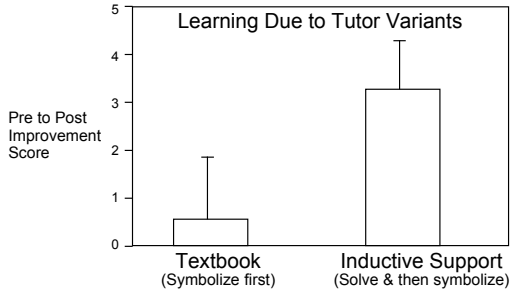

…Plumbing Co. charges $42 per hour plus $35 for the service call
1. …. write an expression …
2. How much for a 3 hour call?
3. What will bill be for 4.5 hours?
4. Find hours when bill is $140

1. 35 + 42h = d
2. 35 + 42*3 = 161
3. 35 + 42*4.5 = 224
4. 35 + 42h = 140

2. 35 + 42*3 = 161
3. 35 + 42*4.5 = 224
1. 35 + 42h = d
4. 35 + 42h = 140

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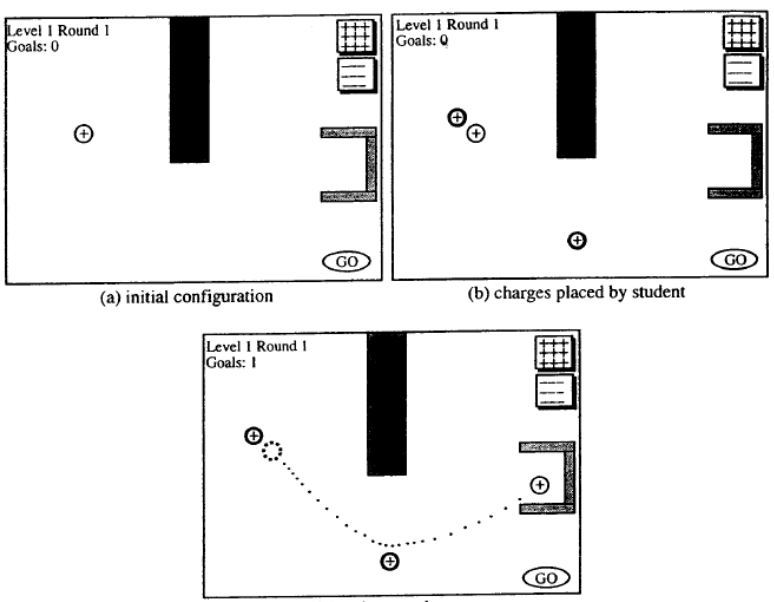
Extras

Example of Real Aptitude-Treatment Interaction

Following up discussion board
And illustrating some CTA!

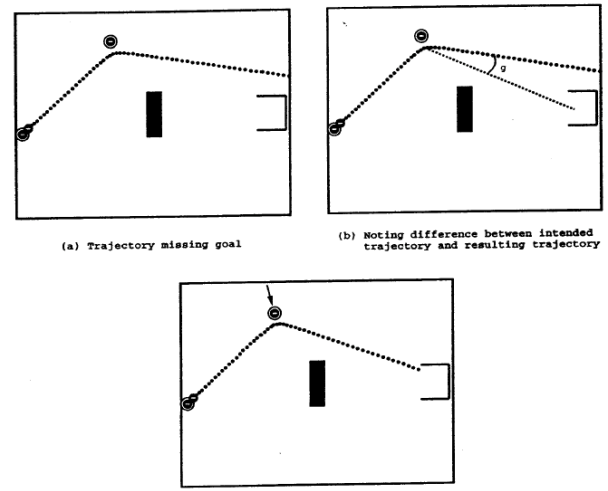


(a) initial configuration (b) charges placed by student

(c) trajectory shown

Figure 1. An example of simple interactions with Electric Field Hockey.

Think alouds of students …



(a) Trajectory missing goal

(b) Noting difference between intended trajectory and resulting trajectory

(c) Moving charge closer for more bend

Figure 4. Game success through charge adjustment.

Miller, C. S., Lehman, J. F., & Koedinger, K. R. (1999). Goals and learning in microworlds. *Cognitive Science, 23*, (3), 305-336.

Example rule from cognitive model

```
IF charge is 5 units away from path vertex

   AND puck trajectory did not bend enough (wrt Angle g)

THEN move charge 1 unit closer to path
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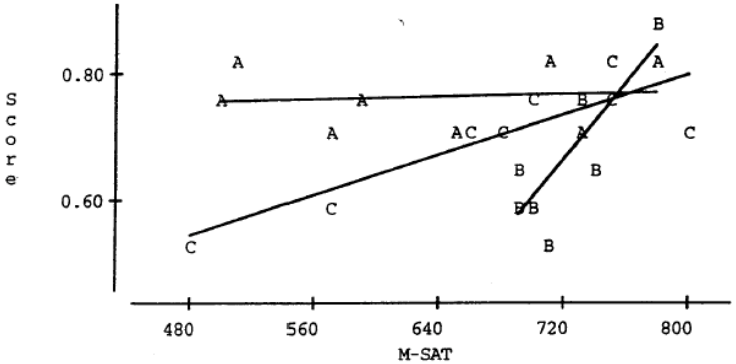
Figure 5. A chunk created from charge adjustment.

Aptitude-Treatment Interaction



A: no goal; B: standard goal; C: specific goal

Figure 10. Score versus mSAT by goal condition.

2nd "ATI" example

Wylie, R., Koedinger, K. R., Mitamura, T. (2009). Is self-explanation always better? The effects of adding self-explanation prompts to an English grammar tutor. In *Proceedings of the 31st Annual Conference of the Cognitive Science Society*. Amsterdam, The Netherlands. July 29-August 1, 2009.

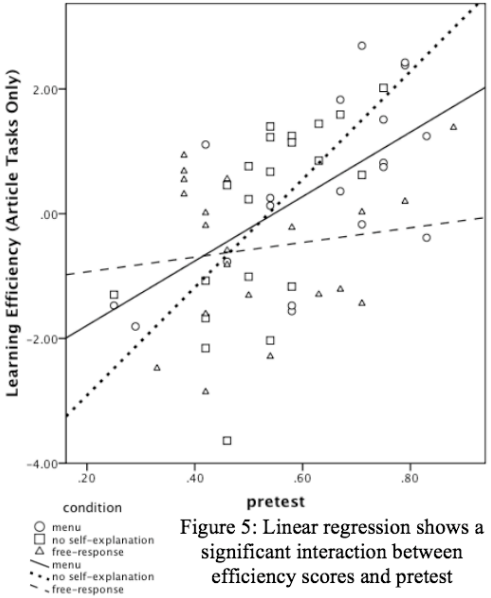


Figure 5: Linear regression shows a significant interaction between efficiency scores and pretest