Cognitive Tutors

NAPLeS Webinar, Feb 2014

Vincent Aleven

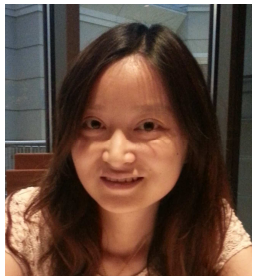
Associate Professor

Human-Computer Interaction Institute

Pittsburgh Science of Learning Center (LearnLab)

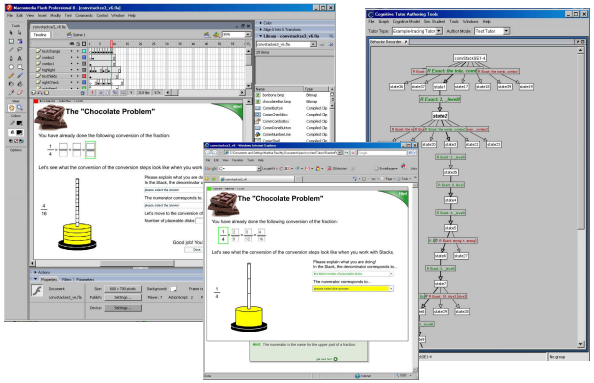
Carnegie Mellon University

Based on work by many, many people, including Kenneth Koedinger (CMU) and Yanjin Long (CMU)

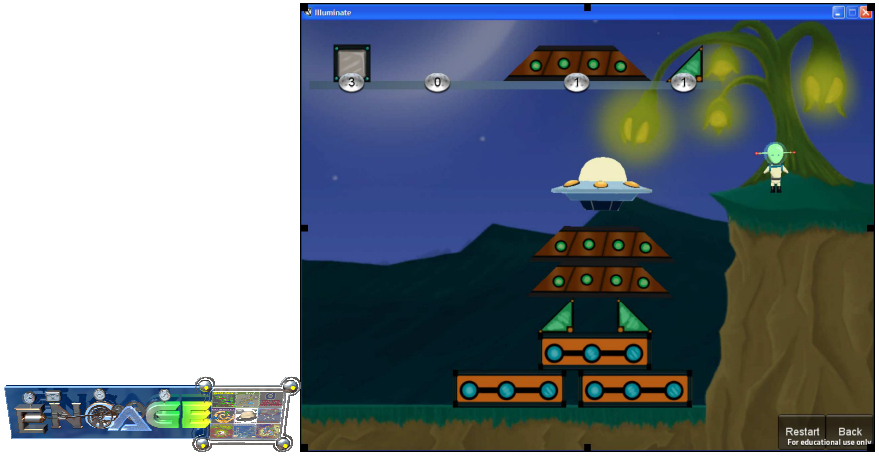


. . . . . .

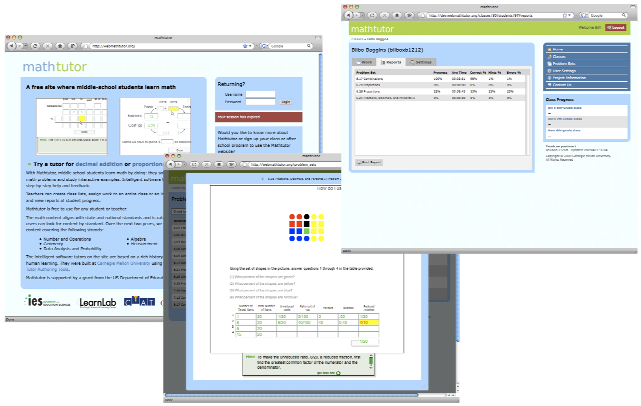
My Other Research in Adaptive Learning Technologies



CTAT: Authoring tools for rapid development of Intelligent Tutoring Systems with Ken Koedinger



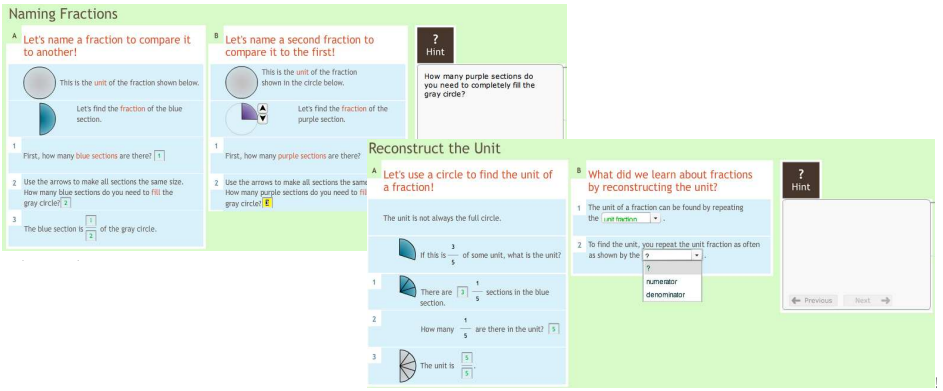
ENGAGE: game for grades 1-3 science learning
Collaboration between HCII, ETC, and Psych; with Steven Dow, Ken Koedinger, and Carolyn Rosé



***Mathtutor:* free web-based tutors for middle-school math**

with Bruce McLaren

http://mathtutor.web.cmu.edu



Individual and collaborative learning with tutors for 4th and 5th grade fractions

With Nikol Rummel, Martina Rau, Jenny Olsen, and Dan Belenky

Overview

- Cognitive Tutors
- Supporting metacognition with Cognitive Tutors
  - Self-Assessment
  - Self-Explanation
- Non-Programmer Authoring Tools for creating tutor

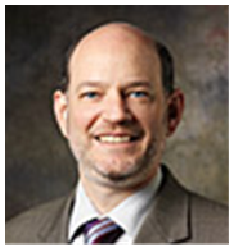
Take-Home Messages

- Cognitive Tutors
  - Practical application of cognitive science that demonstrably improves student learning in schools and has been commercially successful
  - Combination of cognitive theory, cognitive task analysis, cognitive modeling, AI technology, and math education expertise
  - Provides individualized, detailed guidance during complex problem solving
- Cognitive Tutors can support self-assessment and self-explanation effectively
  - Good to include metacognition and self-regulated learning in the theoretical perspective
- Non-programmer tools reduce authoring time and cost
  - Used widely for research purposes

Overview

- Cognitive Tutors
- Supporting metacognition with Cognitive Tutors
  - Self-Assessment
  - Self-Explanation
- Non-Programmer Authoring Tools for creating tutor



John Anderson, Ken Koedinger, Albert Corbett, Steve Ritter, and others

What is an "Intelligent Tutoring System" (ITS)?

- A kind of educational software
  - Supports "learning by doing" with personalized, step-by-step guidance
- Uses cognitive modeling and artificial intelligence techniques to
  - Provide human tutor-like behavior
  - Be flexible, diagnostic & adaptive
  - Provide personalized instruction (e.g., select problems on an individual basis)

President Obama on Intelligent Tutoring Systems

"[W]e will devote more than three percent of our GDP to research and development. …. Just think what this will allow us to accomplish: solar cells as cheap as paint, and green buildings that produce all of the energy they consume; *learning software as effective as a personal tutor;* prosthetics so advanced that you could play the piano again; an expansion of the frontiers of human knowledge about ourselves and world the around us. We can do this."

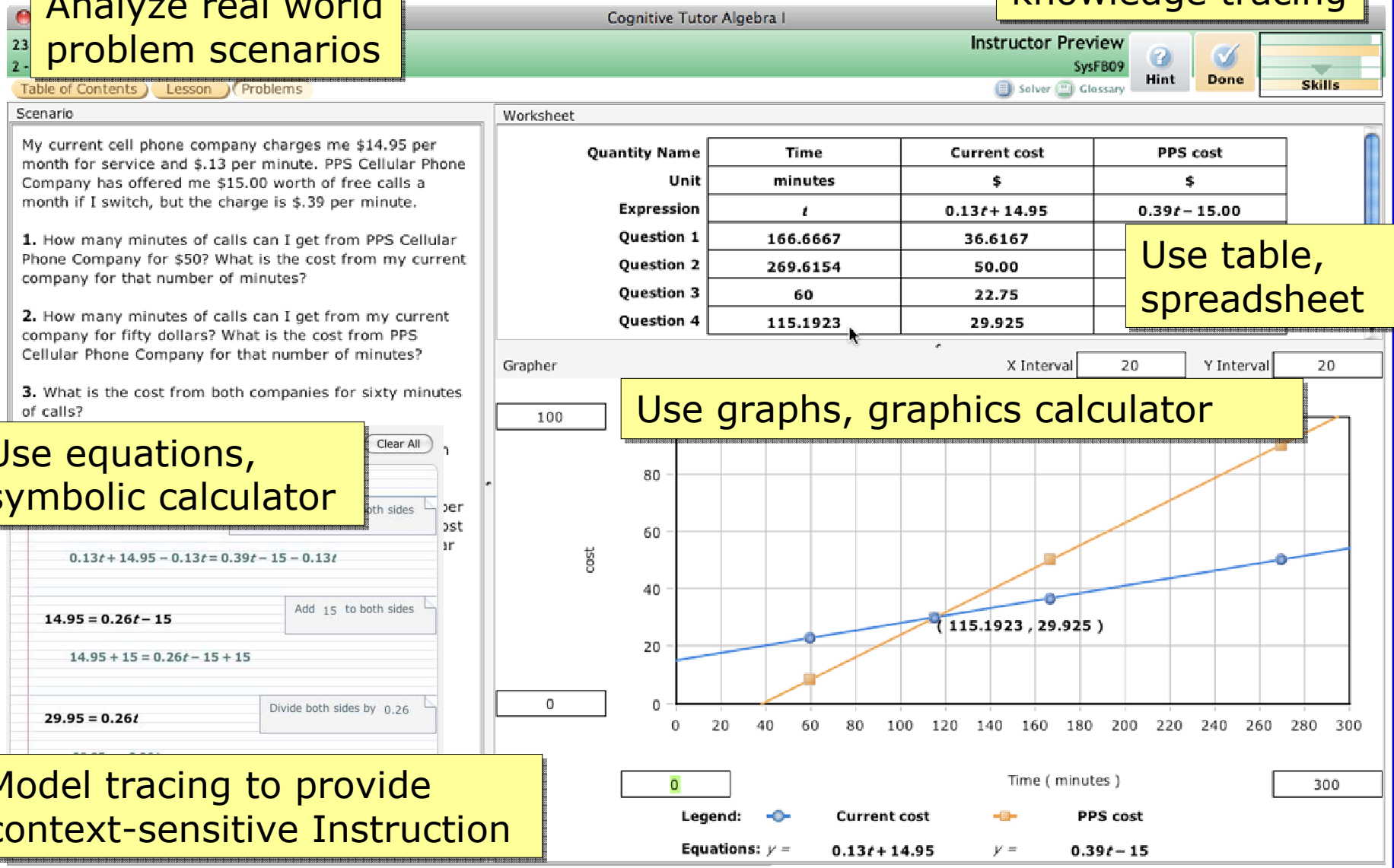
http://my.barackobama.com/page/community/post/amyhamblin/gGxW3n

Algebra Cognitive Tutor

LearnLab
Pittsburgh Science of Learning Center

Analyze real world problem scenarios

Tracked by knowledge tracing



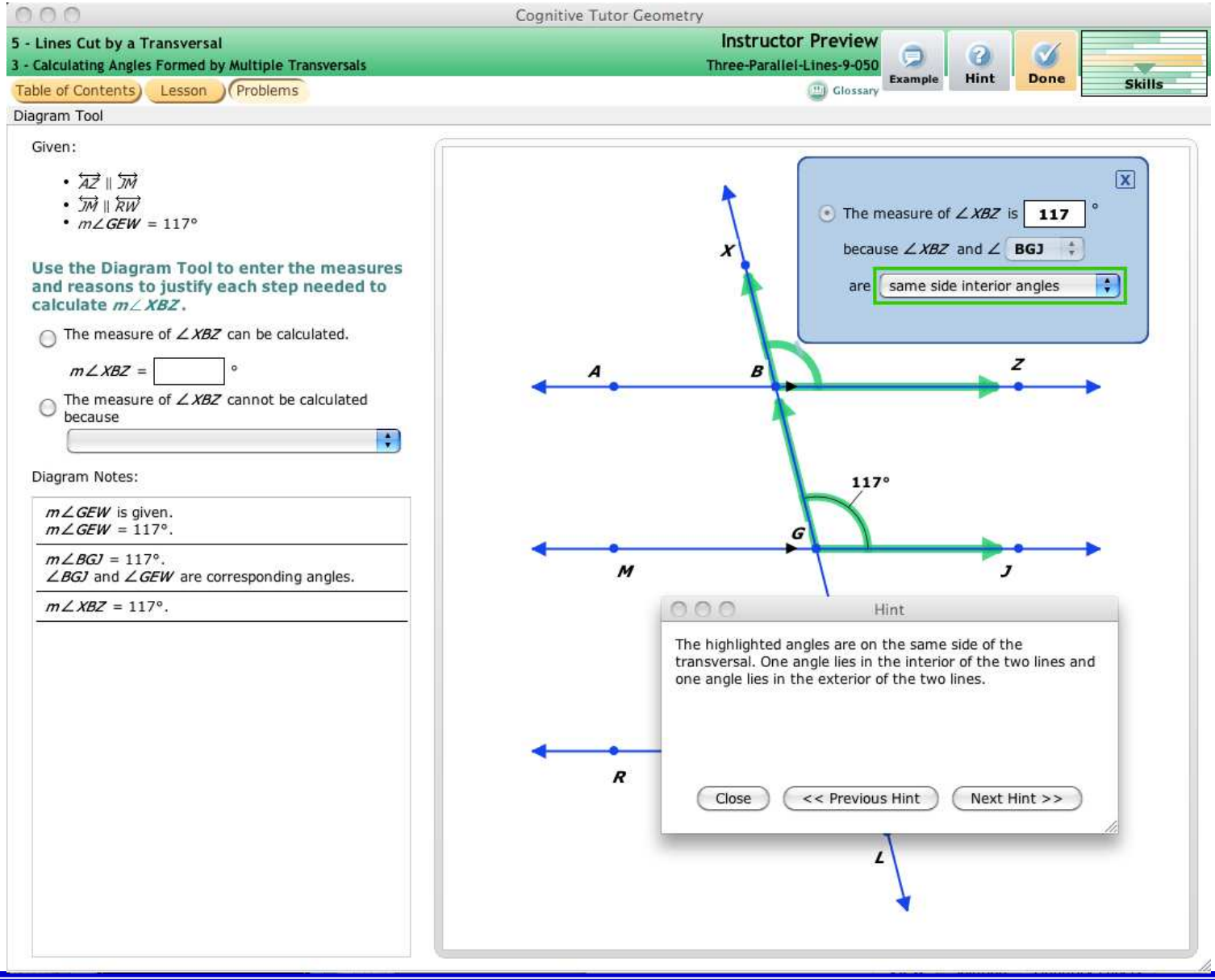
Use table, spreadsheet

Use graphs, graphics calculator

Use equations, symbolic calculator

Model tracing to provide context-sensitive Instruction

Cognitive Tutor Geometry



The nested loop of conventional teaching

For each chapter in curriculum

- Read chapter
- For each exercise, solve it
- Teacher gives feedback on all solutions at once
- Take a test on chapter

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

The nested loops of Computer-Assisted Instruction (CAI)

For each chapter in curriculum

- Read chapter
- For each exercise
  - Attempt answer
  - Get feedback & hints on answer; try again
  - If mastery is reached, exit loop
- Take a test on chapter

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

The nested loops of ITS

For each chapter in curriculum

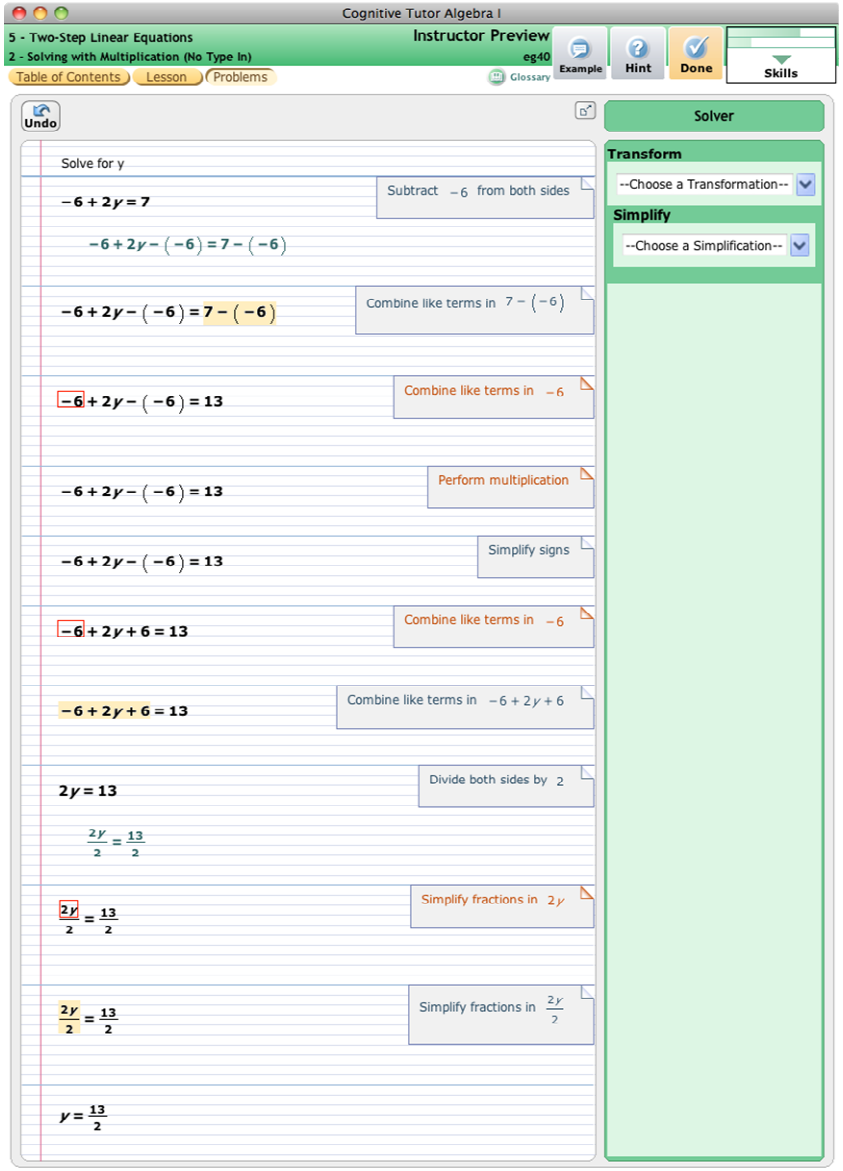
- Read chapter
- For each exercise
  - For each step in solution
    - Student attempts step
    - Get feedback & hints on step; try again
  - If mastery is reached, exit loop
- Take a test on chapter

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education, 16*(3), 227-265.

Inner loop

Step-by-step guidance

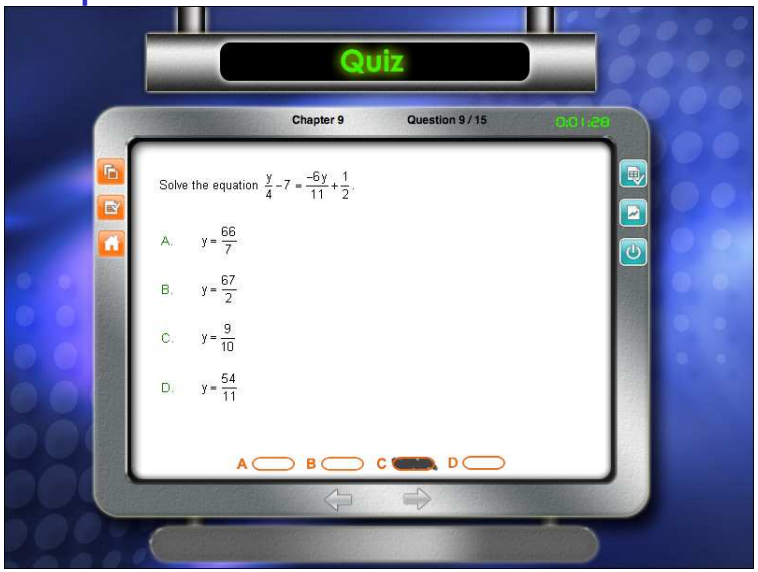
Cognitive Tutor Algebra

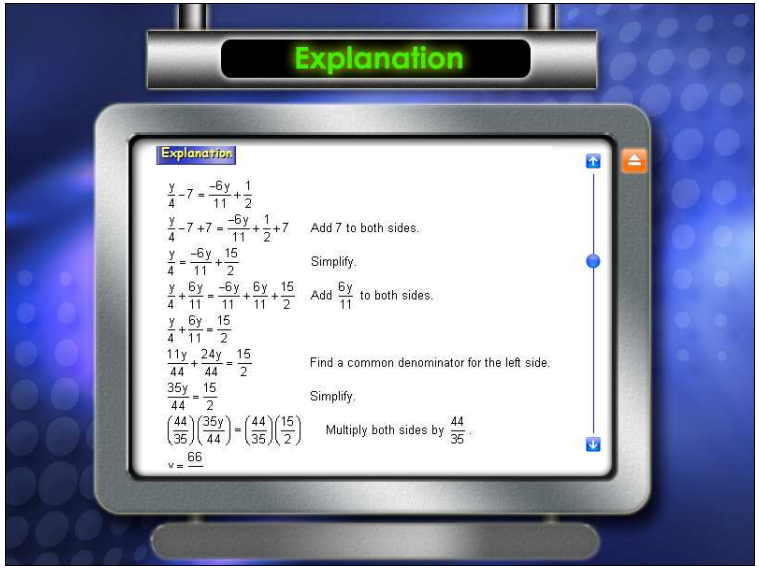


No inner loop

Multiple choice, end-of-quizz explanation

Math Success 2010





Real-world Impact of Cognitive Tutor Courses

The New York Times **Technology**

Software Tutors Offer Help and Customized Hints

Chris Maynard for The New York Times

MATH COACH - Rochelle Brown, left, and Iesha Antonetti, students at Middle School 103 in the Bronx, use Cognitive Tutor software to reinforce math skills. The software is designed to give students individualized instruction when personal attention is scarce.

- Spin-off company Carnegie Learning, Inc.
- Over 500,000 students per year

Carnegie Learning™
THE COGNITIVE TUTOR® COMPANY

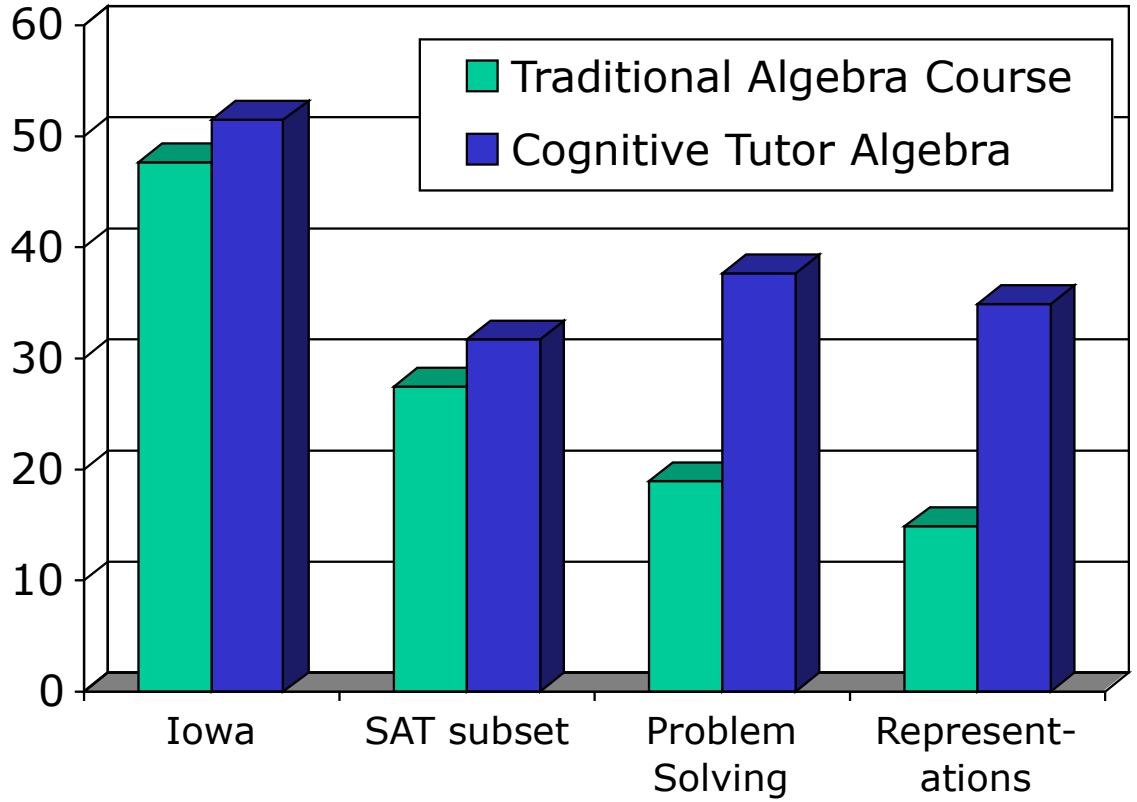
Replicated Field Studies

- Controlled, full year classroom experiments
- Replicated over 3 years in urban schools
- In Pittsburgh & Milwaukee

- Results:

  50-100% better on problem solving & representation use.

  15-25% better on standardized tests.

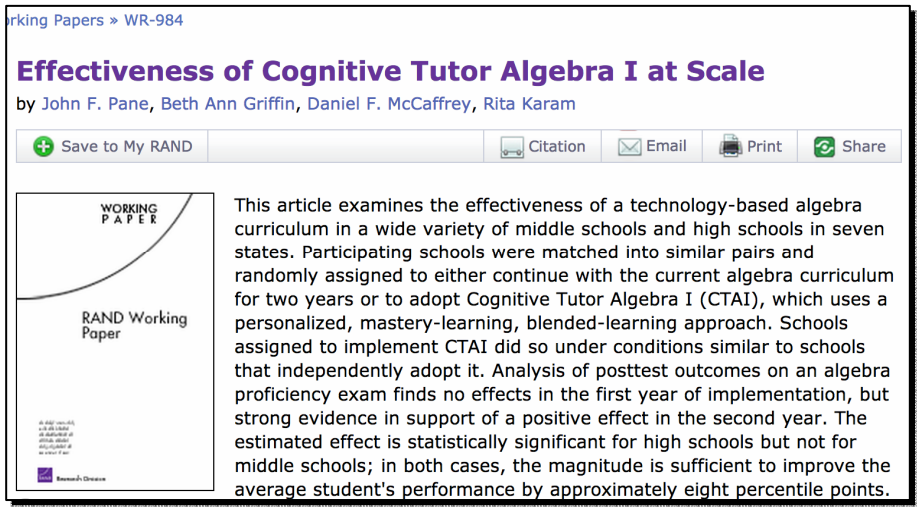


Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. A. (1997). Intelligent tutoring goes to school in the big city. *International Journal of Artificial Intelligence in Education, 8*(1), 30-43.

Effectiveness of Cognitive Tutor Algebra at Scale

- Funded by US Dept. of Ed ($6M); conducted by RAND
- 147 schools, 7 geographic areas, over 19,000 students
- Random assignment by school

- No special implementation support
  - Intent-to-treat study
- Standardized test outcome (McGraw Hill Acuity)


rking Papers » WR-984

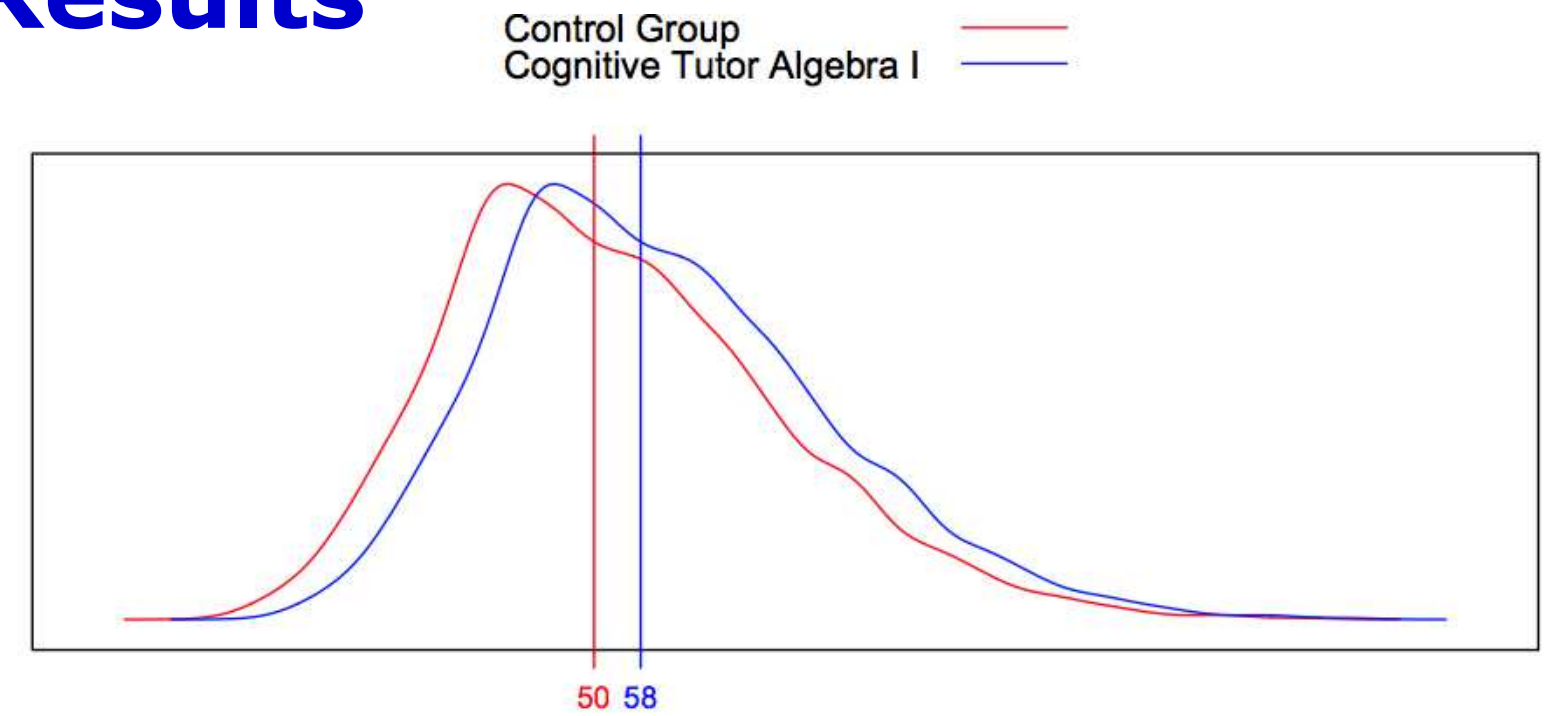
Effectiveness of Cognitive Tutor Algebra I at Scale

by John F. Pane, Beth Ann Griffin, Daniel F. McCaffrey, Rita Karam

Save to My RAND | Citation | Email | Print | Share

This article examines the effectiveness of a technology-based algebra curriculum in a wide variety of middle schools and high schools in seven states. Participating schools were matched into similar pairs and randomly assigned to either continue with the current algebra curriculum for two years or to adopt Cognitive Tutor Algebra I (CTAI), which uses a personalized, mastery-learning, blended-learning approach. Schools assigned to implement CTAI did so under conditions similar to schools that independently adopt it. Analysis of posttest outcomes on an algebra proficiency exam finds no effects in the first year of implementation, but strong evidence in support of a positive effect in the second year. The estimated effect is statistically significant for high schools but not for middle schools; in both cases, the magnitude is sufficient to improve the average student's performance by approximately eight percentile points.

Results



High School study

.21 standard deviation improvement relative to control group (in year 2)

Equivalent to year-over-year improvement on standardized test (CT students *doubled* normal improvement)

Chicago – HS Transformation Project

- HS students in CPS below median on ITBS assign to double-period math
  - 1 period Algebra, 1 Bridge to Algebra
- Either CT or Agile Mind (by school)
- Studied students just above or below median

- Study done by Chicago Consortium on School Research

Results

- Relative to other students, double-dose students had
  - Significantly higher grades in Algebra (esp for better-prepared students)
  - Significant increase in passing Trig (11th grade)
  - Significant increase in ACT Math scores
  - Significant increase in graduation rates (7.9 percentage points – 17% increase)
  - Significant increase in college enrollment (8.6 percentage points – 30% increase)

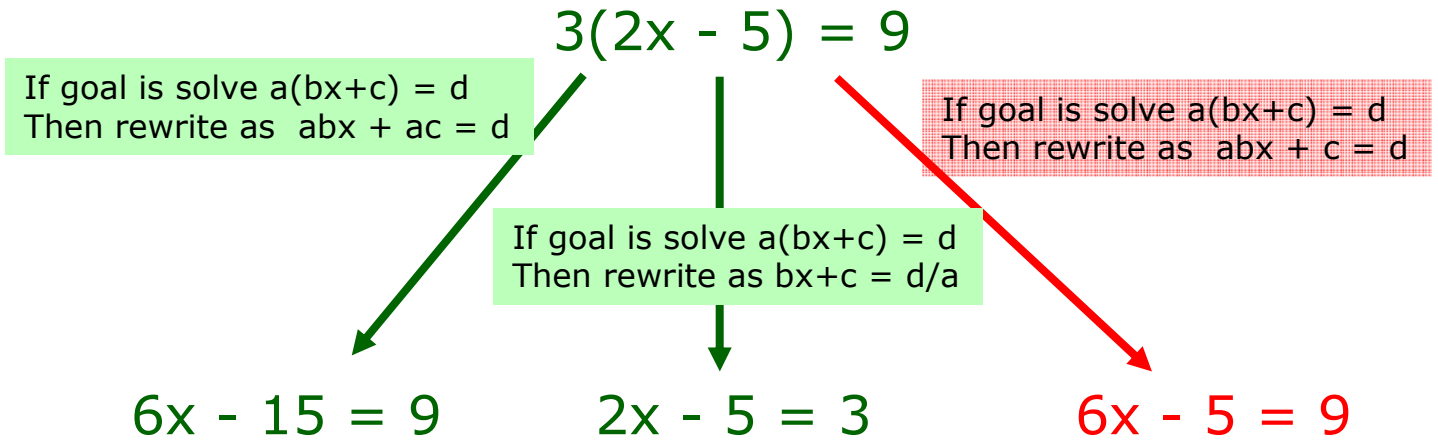
Cognitive Tutor Technology:
Use ACT-R theory to individualize instruction

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

Strategy 1:	IF the goal is to solve a(bx+c) = d THEN rewrite this as abx + ac = d
Strategy 2:	IF the goal is to solve a(bx+c) = d THEN rewrite this as bx + c = d/a
Misconception:	IF the goal is to solve a(bx+c) = d THEN rewrite this as abx + c = d

Cognitive Tutor Technology:
Use ACT-R theory 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

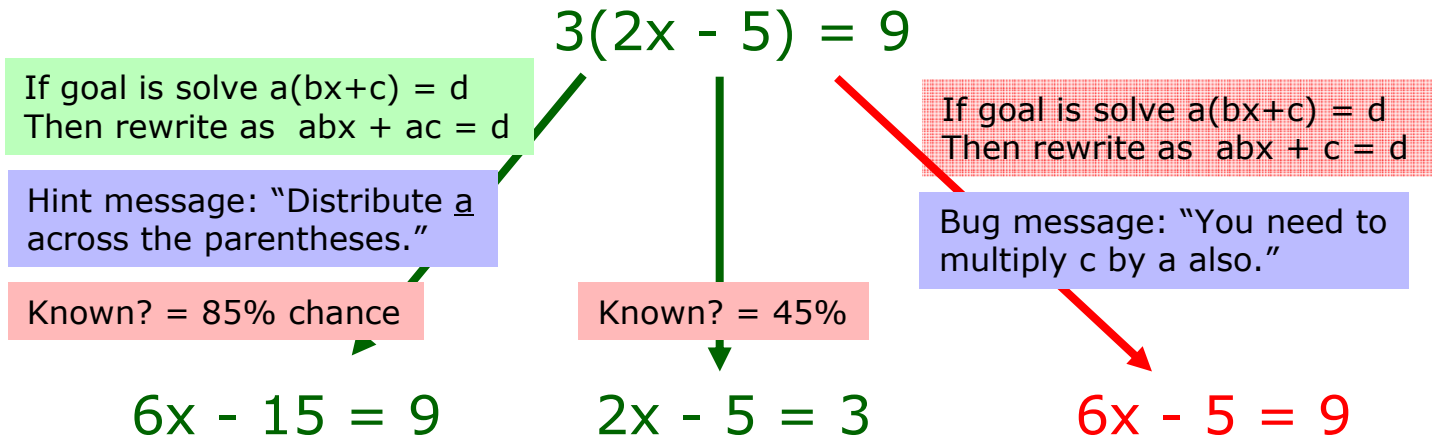
Folie 21

SoCS2 animate one by one?
Vincent Aleven; 17.12.2010

SoCS3 red for bug rule?
Vincent Aleven; 17.12.2010

Cognitive Tutor Technology:
Use ACT-R theory 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

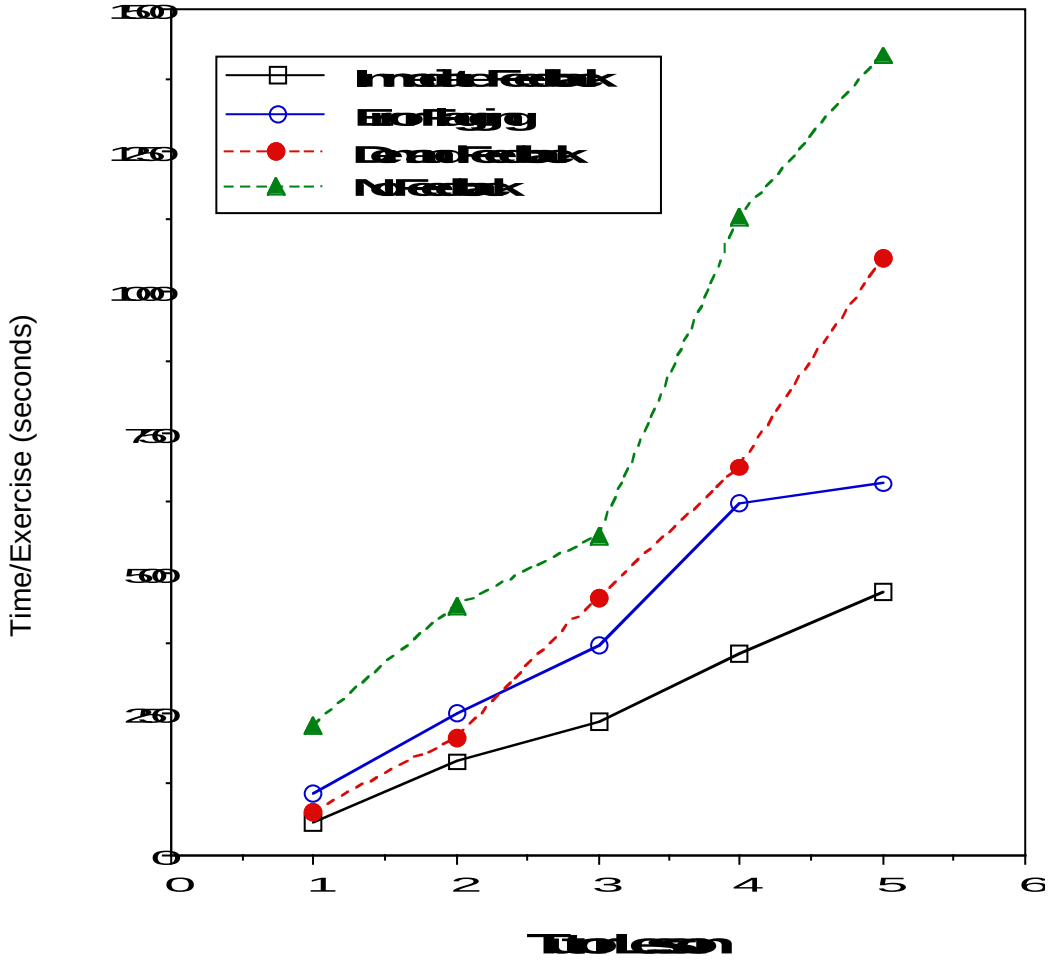
- Knowledge Tracing: Assesses student's knowledge growth -> individualized activity selection and pacing

Folie 22

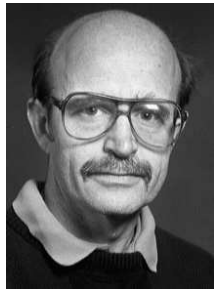
SoCS1 could leave out knowledge tracing part - even though it is kind of cool
Vincent Aleven; 17.12.2010

Step-by-step Feedback

(Corbett & Anderson, 1991)

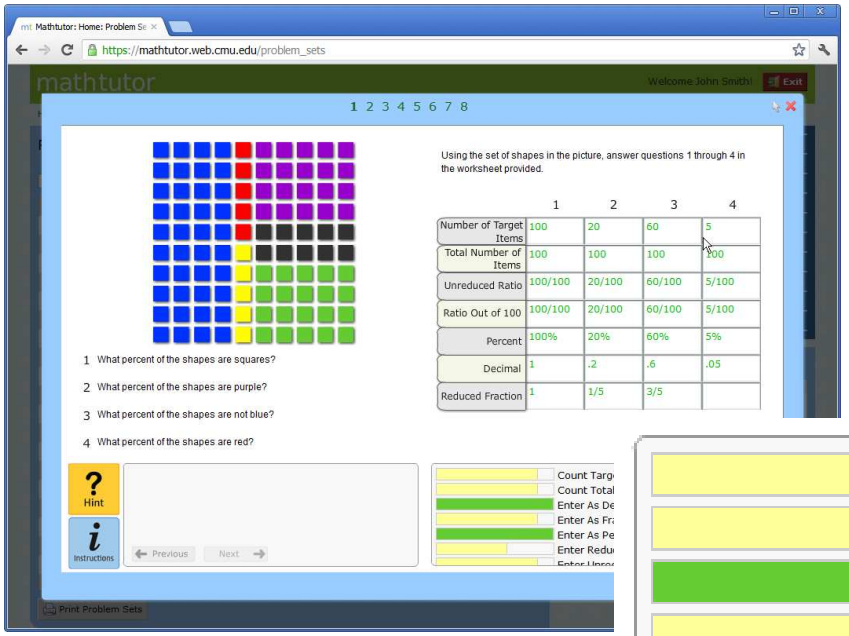


- Time to complete programming problems in LISP Tutor
- Immediate feedback vs. student-controlled feedback

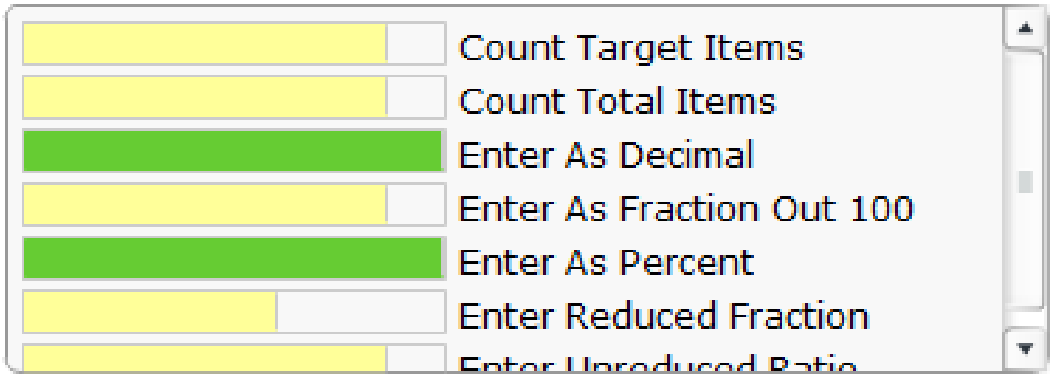


Cognitive Mastery Learning

Individualized Problem Selection



- Bayesian Knowledge-Tracing is used to keep track of student skill growth
  - Displayed in "Skill Meter"
- Used to implement "Cognitive Mastery" learning; tutor selects problems with un-mastered skills until students has research mastery for all targeted skills



Success factors in the Cognitive Tutor technology

- Technology: Rich problem-solving activities with step-by-step guidance; adaptivity (cognitive mastery)
- Research to investigate student thinking in the given domain
  - Cognitive task analysis
  - Cognitive modeling
- Collaboration with teachers
- Classroom research to improve the tutors

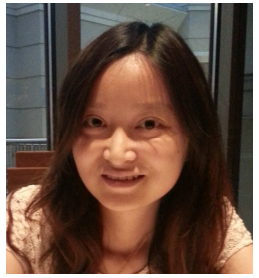
Further Reading

- Cognitive task analysis in tutor design
  - Koedinger, K. R., & Nathan, M. J. (2004). The real story behind story problems: Effects of representations on quantitative reasoning. *The Journal of the Learning Sciences, 13*(2), 129-164.
  - Baker, R. S. J. d., Corbett, A. T., & Koedinger, K. R. (2007). The difficulty factors approach to the design of lessons in intelligent tutor curricula. *International Journal of Artificial Intelligence and Education, 17*(4), 341-369.
- Feedback
  - Anderson, J. R., Conrad, F. G., & Corbett, A. T. (1989). Skill acquisition and the LISP tutor. *Cognitive Science*, *13*(4), 467 - 505. doi: 10.1016/0364-0213(89)90021-9
  - Mathan, S. A., & Koedinger, K. R. (2005). Fostering the intelligent novice: Learning from errors with metacognitive tutoring. *Educational Psychologist*, *40*(4), 257-265.
- Bayesian Knowledge Tracing and Cognitive Mastery
  - Corbett, A. T., & Anderson, J. R. (1995). Knowledge tracing: Modeling the acquisition of procedural knowledge. *User Modeling and User-Adapted Interaction*, *4*(4), 253-278.
  - Corbett, A., McLaughlin, M., & Scarpinatto, K. C. (2000). Modeling student knowledge: Cognitive tutors in high school and college. *User Modeling and User-Adapted Interaction*, *10*, 81-108.

Overview

- Cognitive Tutors
- Supporting metacognition with Cognitive Tutors
  - Self-Assessment
  - Self-Explanation
- Non-Programmer Authoring Tools for creating tutor

Long, Y., & Aleven, V. (2013). Skill diaries: Improve student learning in an intelligent tutoring system with periodic self-assessment. In H. C. Lane, K. Yacef, J. Mostow, & P. Pavlik (Eds.), *Proceedings of the 16th international conference on artificial intelligence in education AIED 2013* (pp. 249-258). Berlin Heidelberg: Springer. doi:10.1007/978-3-642-39112-5_2

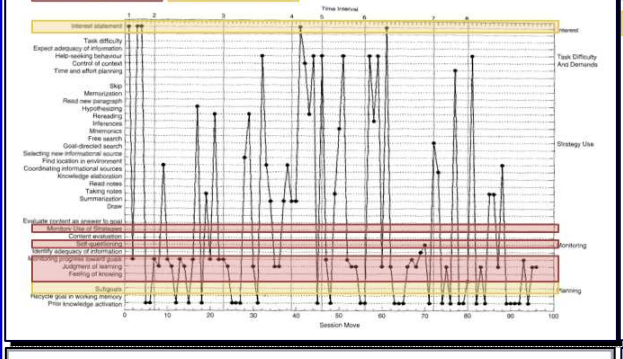


Self-Regulated Learning: Great Theoretical Diversity

LearnLab Pittsburgh Science of Learning Center

Azevedo's (2005) Model of SRL in HLEs

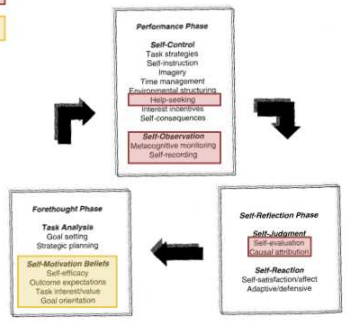
Metacognition | Motivation



Zimmerman's (2000) Model of SRL

Metacognition

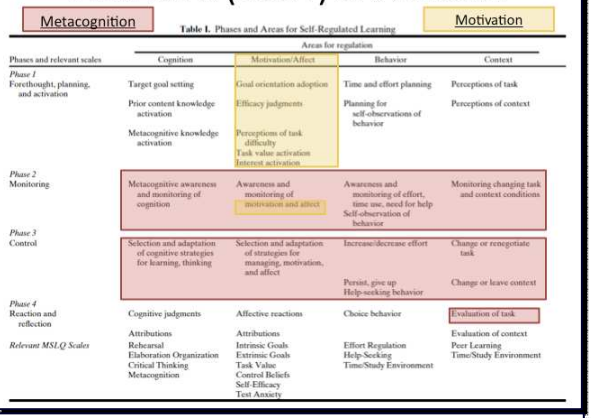
Motivation



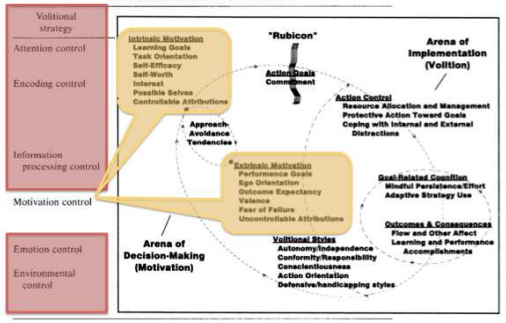
Pintrich's (2004) SRL Model

Metacognition

Motivation



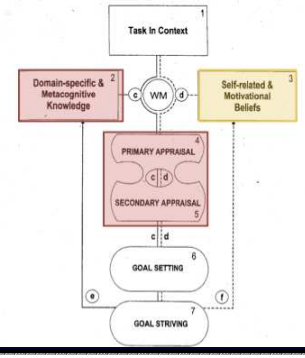
M&M in Corno's (1986; 1993) Theory of Volition in Self-Regulated Learning



Boekaerts' (2000) Model of Adaptable Learning

Metacognition

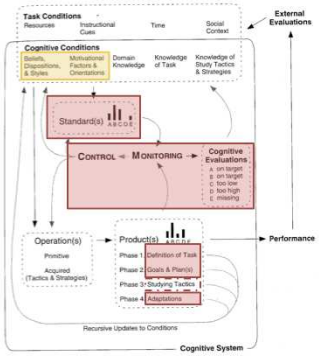
Motivation



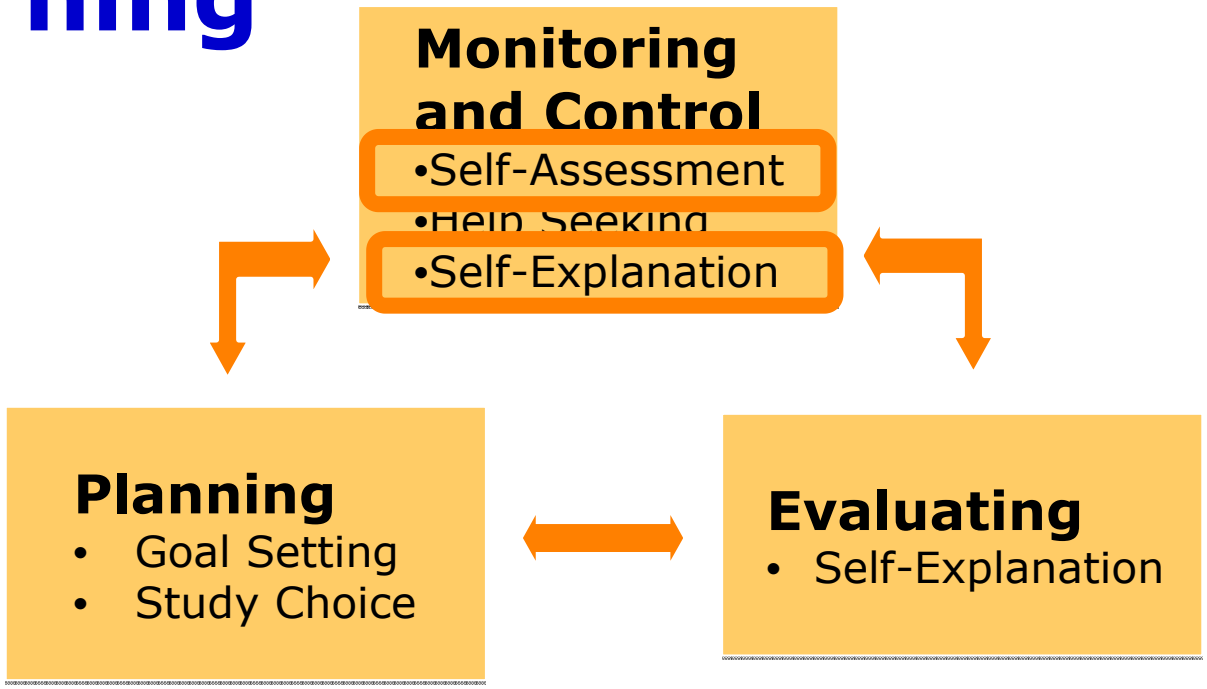
Winne & Hadwin's (1998) SRL Model

Metacognition

Motivation



Background: Self-Regulated Learning



- How do instructional intervention aimed at supporting these elements affect robust learning?

Why is Self-Assessment Important?

- The process of self-assessing can facilitate deep thinking and reflection
  (Boud, 2004; White & Frederiksen, 1998)

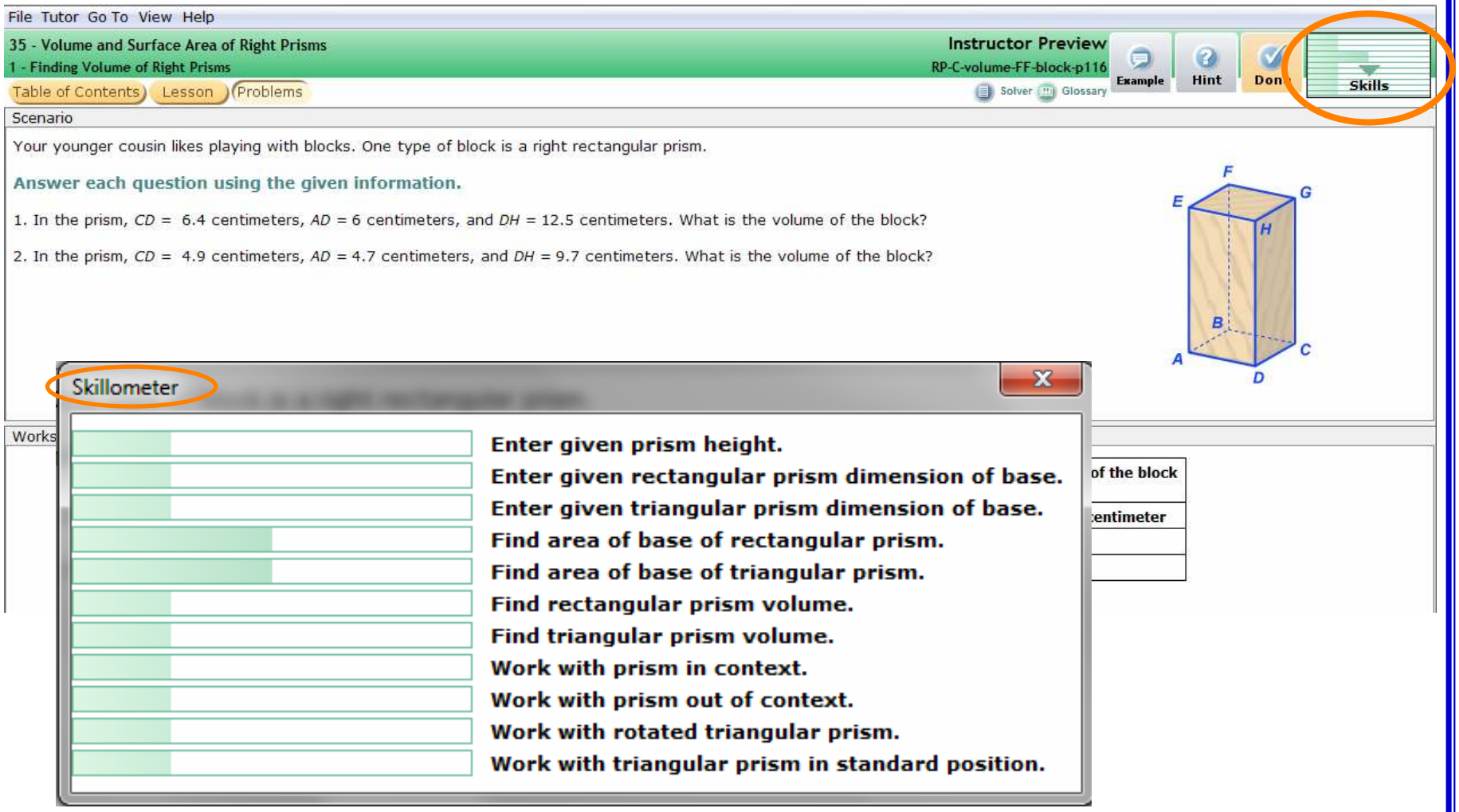
- The results of self-assessment can lead to better learning plans and study choices, as well as better learning outcomes
  (Thiede, Anderson & Therriault, 2003; Winne & Hadwin, 1998)

- However, students' self-assessment is often inaccurate
  (Dunlosky & Lipko, 2007; Nelson, 1996)

Research Question

- Can self-assessment be supported effectively by means of (paper) skill diaries?
- Does such support for self-assessment lead to enhanced learning?

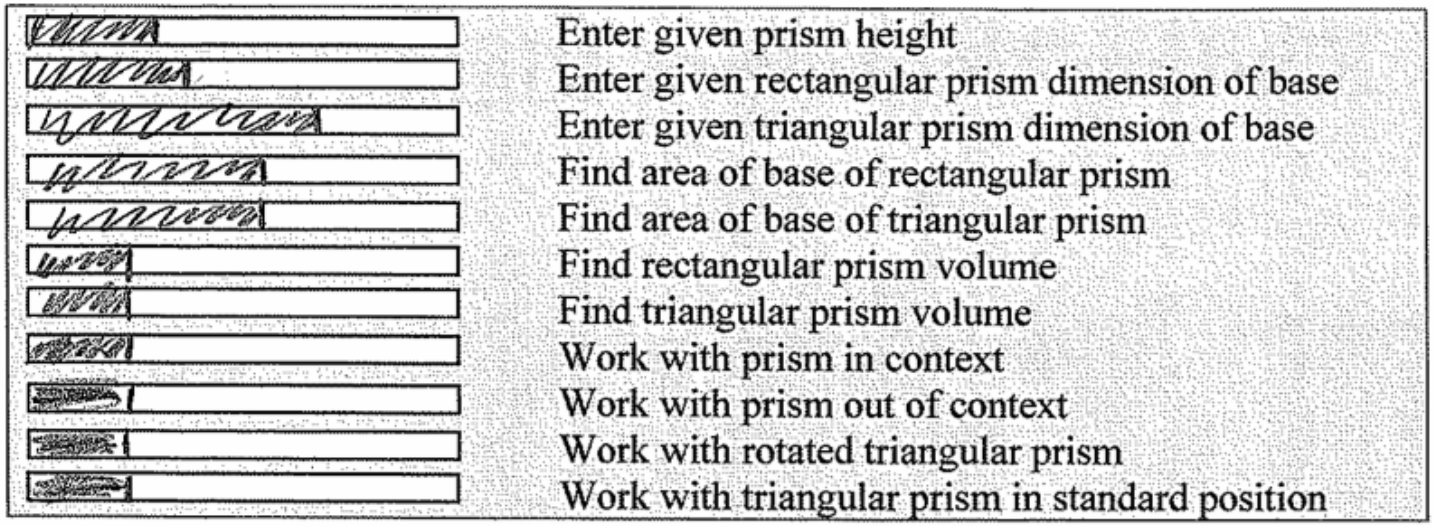
Geometry Cognitive Tutor
with Skill Meter



Skill Diary, Part 1

1. Please write down the current time on your computer: 10:21 am

2. Please complete the following blank skillbar (draw the bars) to make it the same as your current skillbar in the Tutor. The bars that you draw do not need to be perfect—do your best to make it look like your real bars in the Tutor.



Skill Diary, Part 2

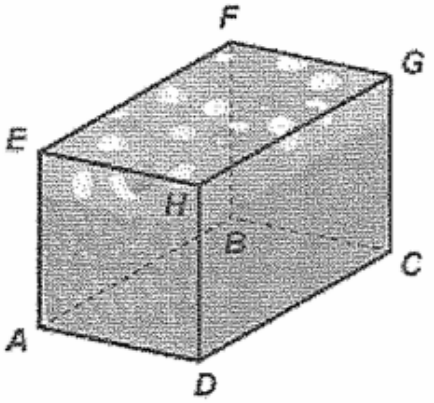
3. Please fill out the table below based on your current learning status in the Tutor:

Skill	Since the last tutor problem, this skill has become.... (check one)	Have you had any practice on this skill yet in this unit? (check one)	In your own opinion, rate your mastery of this skill from 1-7. 1 = poor to 7 = very good	In your own opinion, do you need more practice on this skill? (check one)
Enter given prism height	☒ Better ☐ Same ☐ Worse	☐ Yes ☐ No ☒ Not sure	☐ ☐ ☐ ☐ ☐ ☒ ☐ 1 2 3 4 5 6 7	☐ Yes ☒ No ☐ Not sure
Enter given rectangular prism dimension of base	☒ Better ☐ Same ☐ Worse	☐ Yes ☐ No ☒ Not sure	☐ ☐ ☐ ☐ ☐ ☒ ☐ 1 2 3 4 5 6 7	☐ Yes ☒ No ☐ Not sure
Enter given triangular prism dimension of base	☒ Better ☐ Same ☐ Worse	☐ Yes ☐ No ☒ Not sure	☐ ☐ ☐ ☐ ☐ ☒ ☐ 1 2 3 4 5 6 7	☐ Yes ☒ No ☐ Not sure
Find area of base of rectangular prism	☐ Better ☒ Same ☐ Worse	☐ Yes ☒ No ☐ Not sure	☐ ☐ ☐ ☐ ☒ ☐ ☐ 1 2 3 4 5 6 7	☐ Yes ☒ No ☐ Not sure
Find area of base of triangular prism	☐ Better ☐ Same ☒ Worse	☐ Yes ☐ No ☒ Not sure	☐ ☐ ☐ ☐ ☒ ☐ ☐ 1 2 3 4 5 6 7	☐ Yes ☒ No ☐ Not sure
Find rectangular prism volume	☐ Better ☐ Same ☒ Worse	☐ Yes ☐ No ☒ Not sure	☐ ☐ ☐ ☒ ☐ ☐ ☐ 1 2 3 4 5 6 7	☐ Yes ☒ No ☐ Not sure

Skill Diary, Part 3

4. Look at problems A, B, C, D, E and F below (do NOT solve them!). Rate how confident you are that you can solve each of them from 1 – 7. (**Circle one number**: 1= Not Confident, 7=Very Confident.)

A. Your aunt makes a fruit cake for a family reunion. The pan she uses is a right rectangular prism. In the prism, CD = 4 centimeters, AD = 2 centimeters, and DH = 3 centimeters, what is the volume of this block?



Not Confident						Very Confident
1	2	3	4	5	6	7

Skill Diary Study

- Hypothesis: Periodically filling out structured Skill Diaries helps students self-assess and learn better
- Participants:
  - 122 students from 2 teachers' 6 classes in a local high school
  - Complete data for 95 students
- Procedure: Students worked on tutor for 3 class periods (volume and surface areas for spheres and right prisms), took paper pre-test before and post-test after
- Experimental condition: Skill Diary
- Control condition: Control Diary (no self-assessment)

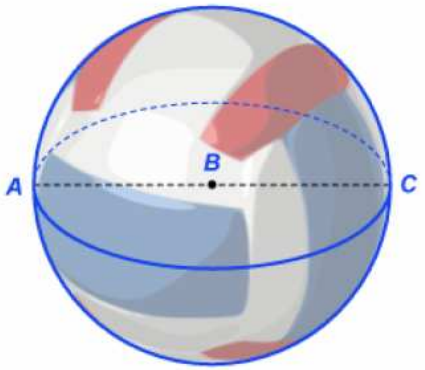
Control Diary

3. Look at problems A, B, C and D below (do NOT solve them!). Check if you have seen each problem in this unit so far.

A. You play volleyball in gym class. A volleyball is a sphere. The radius of the volleyball is 10 centimeters.

What is the VOLUME of the volleyball?

☐ Yes ☐ No



Summary of Findings

- Post-Test:
  - Skill Diary group better on near-transfer problems than Control Diary group
  - Especially among lower-performing students
- Across conditions, higher-performing students have more accurate self-assessment
- In the Skill Diary condition, accuracy of SA improves from Pre to Post for lower-performing students
- Skill Diary students used the tutor in a more deliberate manner

Post-Test: Experimental Group Better on Reproduction Problems

	Mean Test Scores (SD)			
	Pre-Test Reproduction	Post-Test Reproduction	Pre-Test Transfer	Post-Test Transfer
Exp. Group	0.55 (.34)	0.62 (.29)	0.50 (.28)	0.58 (.26)
Ctrl. Group	0.46 (.44)	0.49 (.33)	0.46 (.22)	0.57 (.24)

$F(1, 93) = 3.86$, $p = .052$, $\eta^2 = .040$

Caveat: when pre-test score is used as co-variate, the difference between two groups on reproduction problems was on the borderline of significance ($F(1, 92) = 2.75$, $p = .101$, $\eta^2 = .029$)

Post-test: Lower Performing Students Who Used Skill Diaries Did Better

	Test Scores on Reproduction Problems (SD)			
	Pre-Test		Post-Test	
	Exp	Ctrl	Exp	Ctrl
Lower-Performing Group	0.35 (.45)	0.16 (.35)	0.53 (.47)	0.30 (.39)
Higher-Performing Group	0.74 (.41)	0.74 (.75)	0.71 (.38)	0.68 (.41)

($F(1, 44) = 4.586$, $p = .038$, $\eta^2 = .094$; pre-test reproduction problem score was used as co-variate)

Measuring Self-assessment Accuracy on Pre- and Post-Tests

Problem 1: How confident are you that you can solve this problem? (**Circle one number**: 1= Not Confident, 7=Very Confident.)

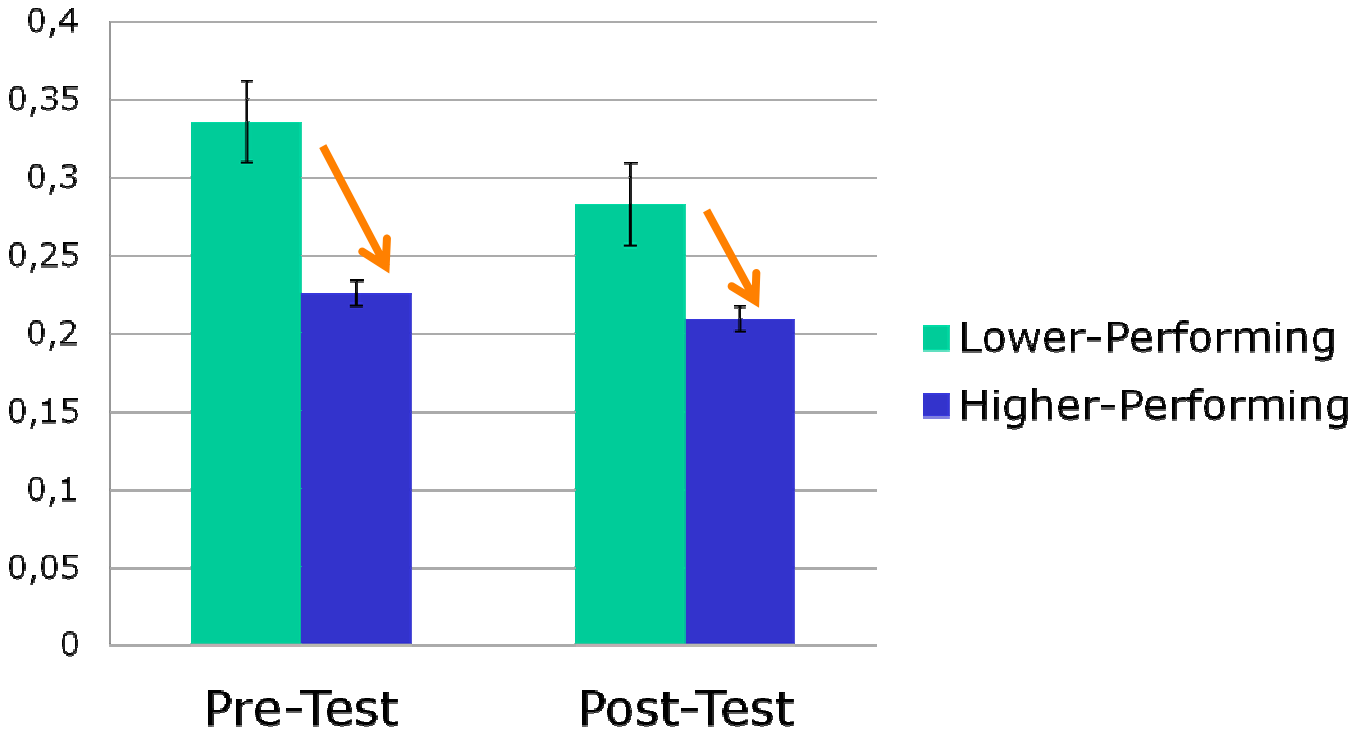
Not Confident						Very Confident
1	2	3	4	5	6	7

$$\text{Absolute Accuracy Index} = \frac{1}{N}\sum_{i=1}^{N}(c_i - p_i)^2$$ (Schraw, 2009)

- Measures the *discrepancy* between self-assessed and actual performance.

Self-Assessment Accuracy

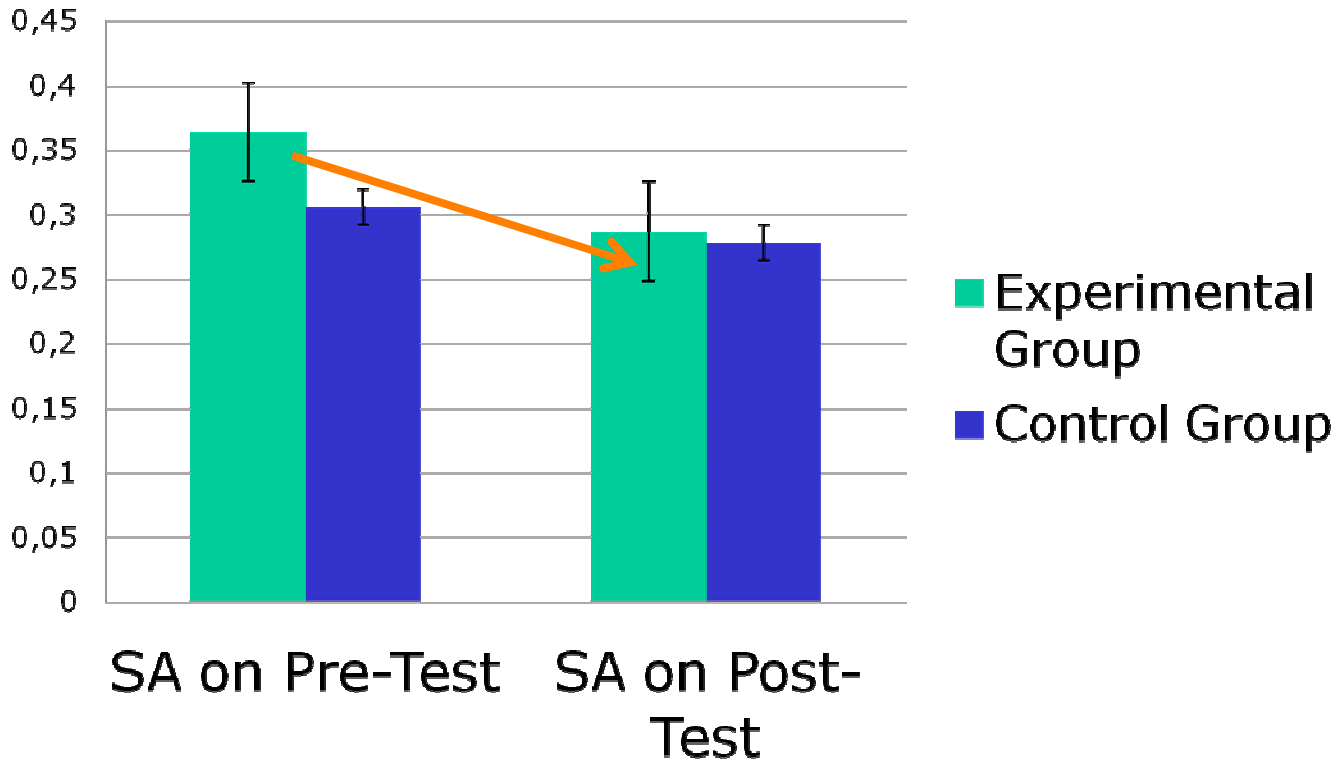
Absolute Accuracy Index



- Higher performing students have more accurate self-assessment

Self-Assessment Accuracy of Lower-Performing Students

Absolute Accuracy Index



- Accuracy of SA improves from Pre to Post for lower-performing students

$t(23) = 2.257$, $p = .034$

Process Measures

	Correlations	
	Pre-Test	Post-Test
Number of Hints	-.56**	-.47**
Time Spent on Each Hint	.20	.34**
Number of Incorrect Attempts	-.35**	-.32**
Assistance Score	-.52**	-.47**
Time Spent on Each Step	-.19	-.20

* $p < .05$

** $p < .01$

Process Measures

	Correlations		Condition Differences		
	Pre-Test	Post-Test	Exp	Ctrl	η^2
Number of Hints	-.56**	-.47**	.054	.082	.049*
Time Spent on Each Hint	.20	.34**	17.5	12.4	.037*
Number of Incorrect Attempts	-.35**	-.32**	.085	.092	.031
Assistance Score	-.52**	-.47**	.140	.174	.055*
Time Spent on Each Step	-.19	-.20	15.4	14.4	.027

* $p < .05$

** $p < .01$

Contributions
of the Skill Diary Study

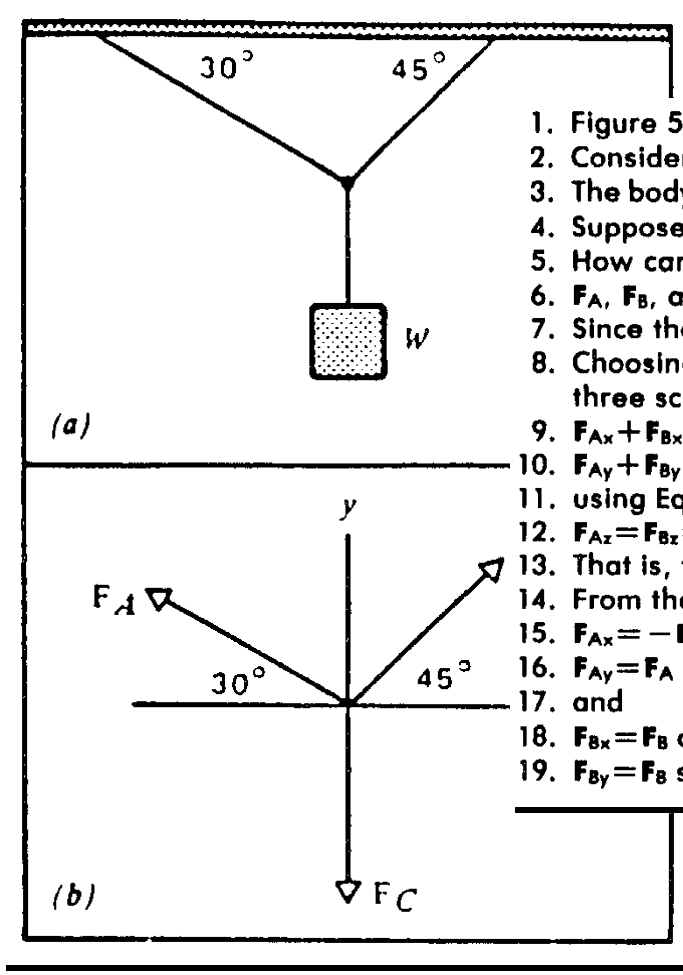
- Skill Diaries practical way of supporting effective self-assessment for lower-performing students
- Demonstrates a beneficial role of self-assessment in students' learning of problem-solving tasks with an ITS

Overview

- Cognitive Tutors
- Supporting metacognition with Cognitive Tutors
  - Self-Assessment
  - Self-Explanation
- Non-Programmer Authoring Tools for creating tutor

Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science, 26*(2), 147-179.

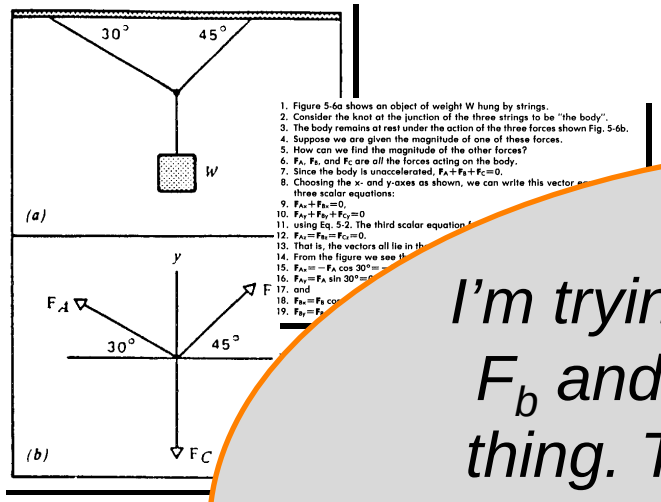
A typical self-explanation scenario



1. Figure 5-6a shows an object of weight W hung by strings.
2. Consider the knot at the junction of the three strings to be "the body".
3. The body remains at rest under the action of the three forces shown Fig. 5-6b.
4. Suppose we are given the magnitude of one of these forces.
5. How can we find the magnitude of the other forces?
6. F_A, F_B, and F_C are *all* the forces acting on the body.
7. Since the body is unaccelerated, $F_A + F_B + F_C = 0$.
8. Choosing the x- and y-axes as shown, we can write this vector equation as three scalar equations:
9. $F_{Ax} + F_{Bx} = 0$,
10. $F_{Ay} + F_{By} + F_{Cy} = 0$
11. using Eq. 5-2. The third scalar equation for the z-axis is simply
12. $F_{Az} = F_{Bz} = F_{Cz} = 0$.
13. That is, the vectors all lie in the x-y plane so that they have no z-components.
14. From the figure we see that
15. $F_{Ax} = -F_A \cos 30° = -0.866F_A$,
16. $F_{Ay} = F_A \sin 30° = 0.500F_A$,
17. and
18. $F_{Bx} = F_B \cos 45° = 0.707F_B$,
19. $F_{By} = F_B \sin 45° = 0.707F_B$.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-Explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13, 145-182.*

A typical self-explanation scenario



1. Figure 5-6a shows an object of weight W hung by strings.
2. Consider the knot at the junction of the three strings to be "the body".
3. The body remains at rest under the action of the three forces shown Fig. 5-6b.
4. Suppose we are given the magnitude of one of these forces.
5. How can we find the magnitude of the other forces?
6. F_A, F_B, and F_C are *all* the forces acting on the body.
7. Since the body is unaccelerated, $F_A + F_B + F_C = 0$.
8. Choosing the x- and y-axes as shown, we can write this vector e… three scalar equations:
9. $F_{Ax} + F_{Bx} = 0$,
10. $F_{Ay} + F_{By} + F_{Cy} = 0$
11. using Eq. 5-2. The third scalar equation …
12. $F_{Az} = F_{Bz} = F_{Cz} = 0$.
13. That is, the vectors all lie in th…
14. From the figure we see th…
15. $F_{Ax} = -F_A \cos 30° = $ …
16. $F_{Ay} = F_A \sin 30° = 0$
17. and
18. $F_{Bx} = F_B$ co…
19. $F_{By} = F_B$ …

I'm trying to think where Forces F_b and F_a are going to get the thing. They'd just be the force, the rest mass of the thing holding it up would be the force … it's the resistance to weight W. It would all be equal.

Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-Explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13, 145-182.*

Classic Cognitive Science Results on Self-Explanation

- People learn better when they explain materials to themselves (Chi et al., 1989)
  - Google Scholar: 1657 citations (Sep 17, 2011)
- Prompting helps (Chi et al., 1994), but even so many students do not provide good self-explanations (Renkl et al., 1997).
- Instruction in self-explanation helps (Bielaczyc et al., 1995), but individual differences remain

- How can we support self-explanation, beyond simple prompting?

Hypothesis

- Supporting self-explanation in an ITS results in deeper understanding:
  - Less shallow procedural knowledge
  - More general declarative knowledge

- Consequences:
  - Better reason giving
  - Near transfer as good or better
  - Better far transfer

VA4

stuff like number of subjects ?

length of time

done in a school

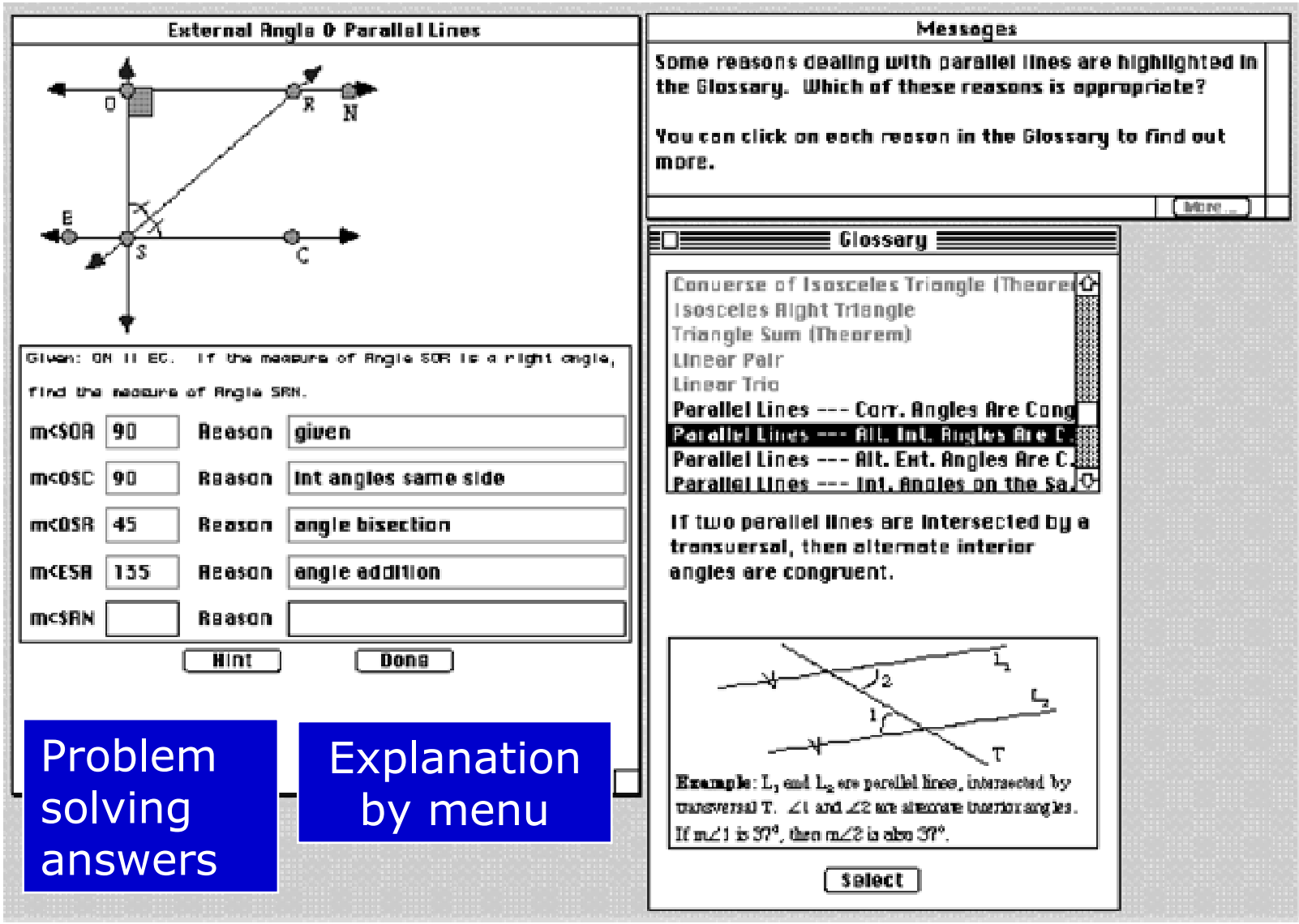
etc

--> realism!

Vincent Aleven; 17.09.2011

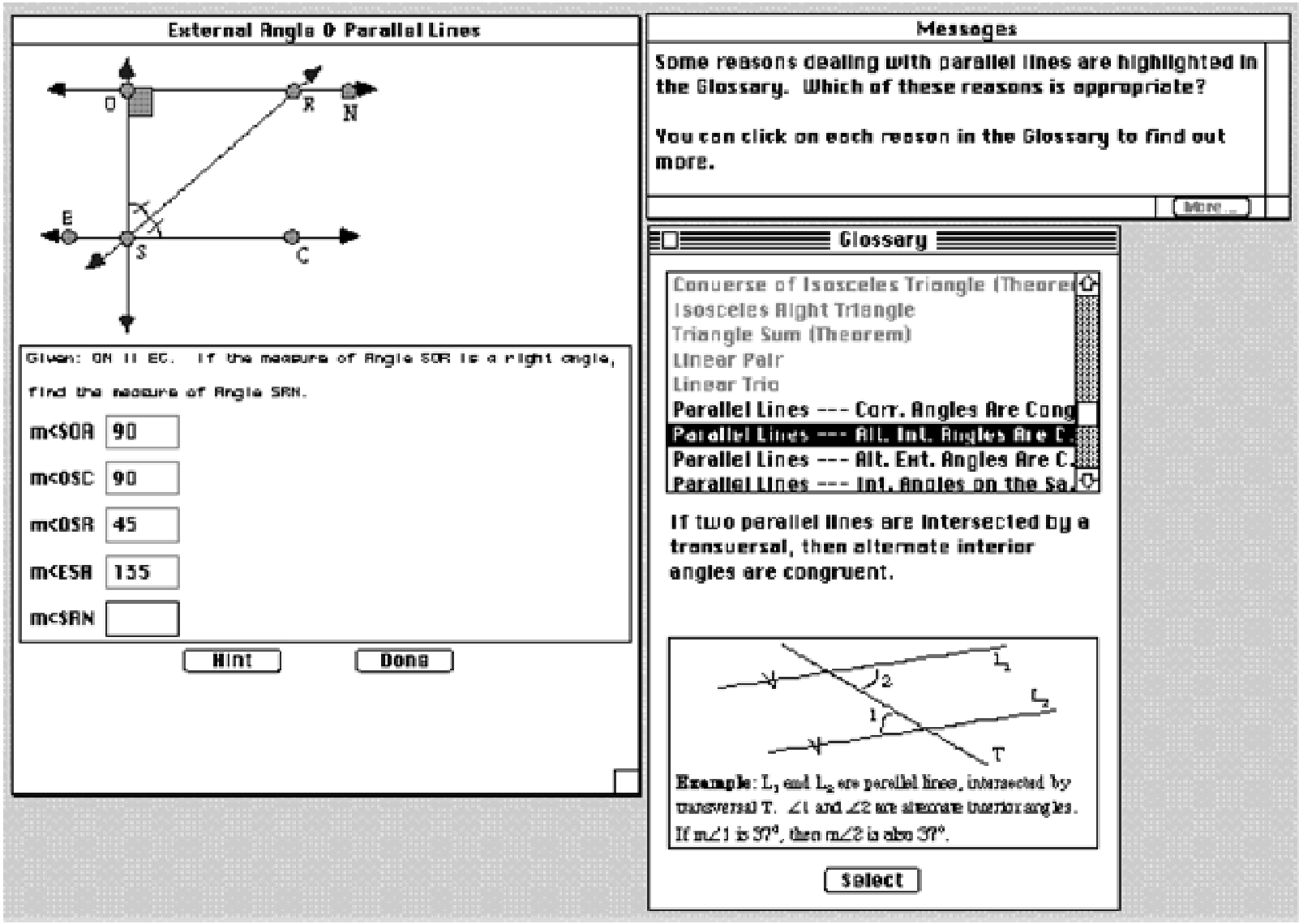
Explanation Condition

(Experimental condition)



Problem Solving Condition

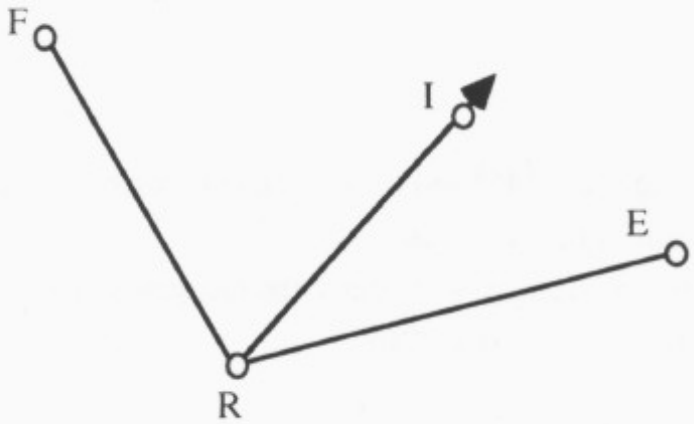
(Control condition)



Pre/Post Test Items

- Problem-solving items
  - Numerical Steps - Finding unknown quantities
- Items associated with deeper understanding
  - Reason - Explain answers by citing geometry rule
  - Not Enough Info - Transfer items where students are asked to judge if there is enough information to find quantities, and the answer is “No”.

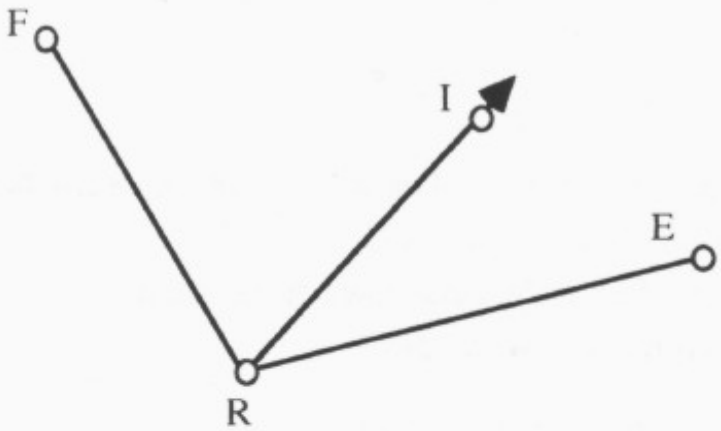
Assessing Transfer: "Not Enough Info" Item



1. If the measure of Angle IRE is 55°, do you have enough information to find the measure of angle FRI?
If there is enough information to find the measure of Angle FRI, write down the measure and a reason for your answer. If there is not enough information, write "No."

m∠FRI : NO Reason: need to know ∠FRE

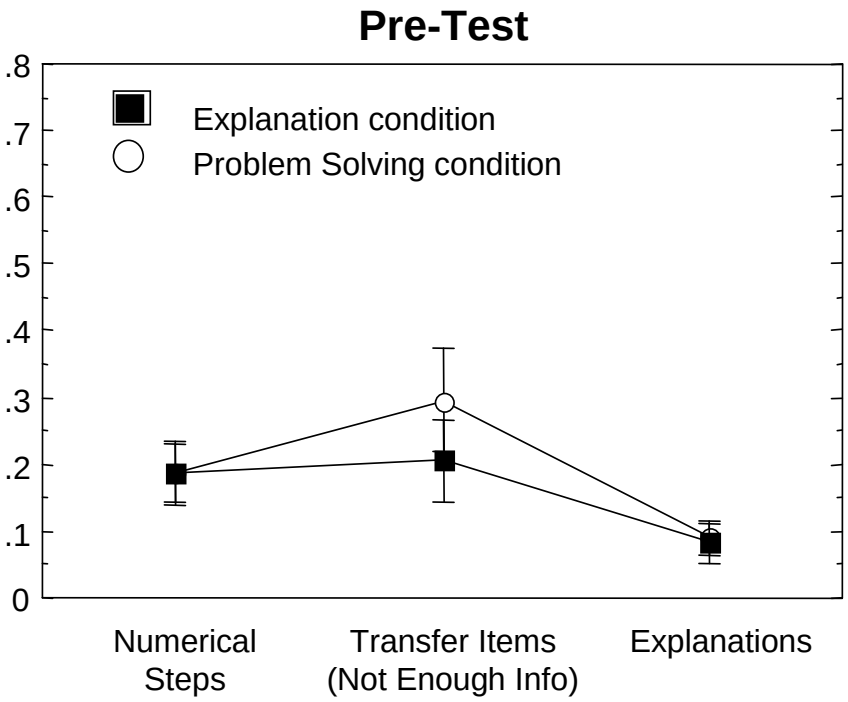
Assessing Transfer: Incorrect Over-generalization

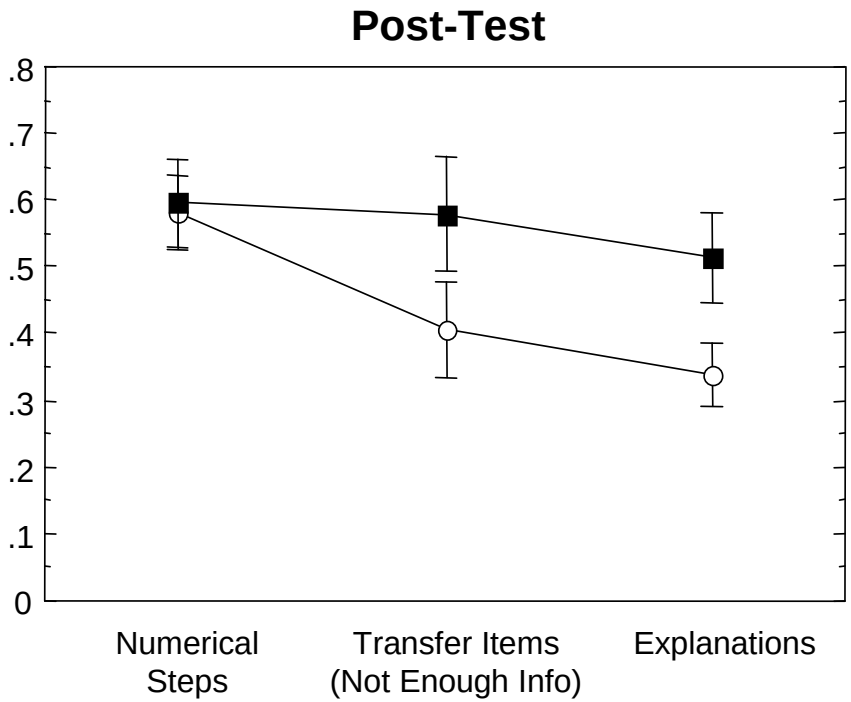


1. If the measure of Angle IRE is 55°, do you have enough information to find the measure of angle FRI?
If there is enough information to find the measure of Angle FRI, write down the measure and a reason for your answer. If there is not enough information, write "No."

m∠FRI : 125° Reason: Supplementary

Results





Aleven, V., & Koedinger, K. R. (2002). An effective meta-cognitive strategy: Learning by doing and explaining with a computer-based Cognitive Tutor. *Cognitive Science, 26*(2), 147-179.

VA5 Can we make real error bars?

Vincent Aleven; 17.09.2011

Objectives in Supporting Metacognition

Ido Roll

Improve future domain learning

Improve future metacognitive strategies

Improve current domain learning in the supported environment

Improve metacognitive strategies in the supported environment

After the metacognitive intervention

During the metacognitive intervention

Koedinger, K. R., Aleven, V., Roll, I., & Baker, R. (2009). In vivo experiments on whether supporting metacognition in intelligent tutoring systems yields robust learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *The Educational Psychology Series: Handbook of metacognition in education* (pp. 897-964). London: Routledge Press.

Folie 58

SoCS7 Take the top of the pyramid?
Vincent Aleven; 17.12.2010

SoCS8 illustrate which layers will be addressed in each study?
Vincent Aleven; 17.12.2010

Overview

- Cognitive Tutors
- Supporting metacognition with Cognitive Tutors
  - Self-Assessment
  - Self-Explanation
- Non-Programmer Authoring Tools for creating tutor

Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (2009). A new paradigm for intelligent tutoring systems: Example-Tracing tutors. *International Journal of Artificial Intelligence in Education, 19*(2), 105-154.

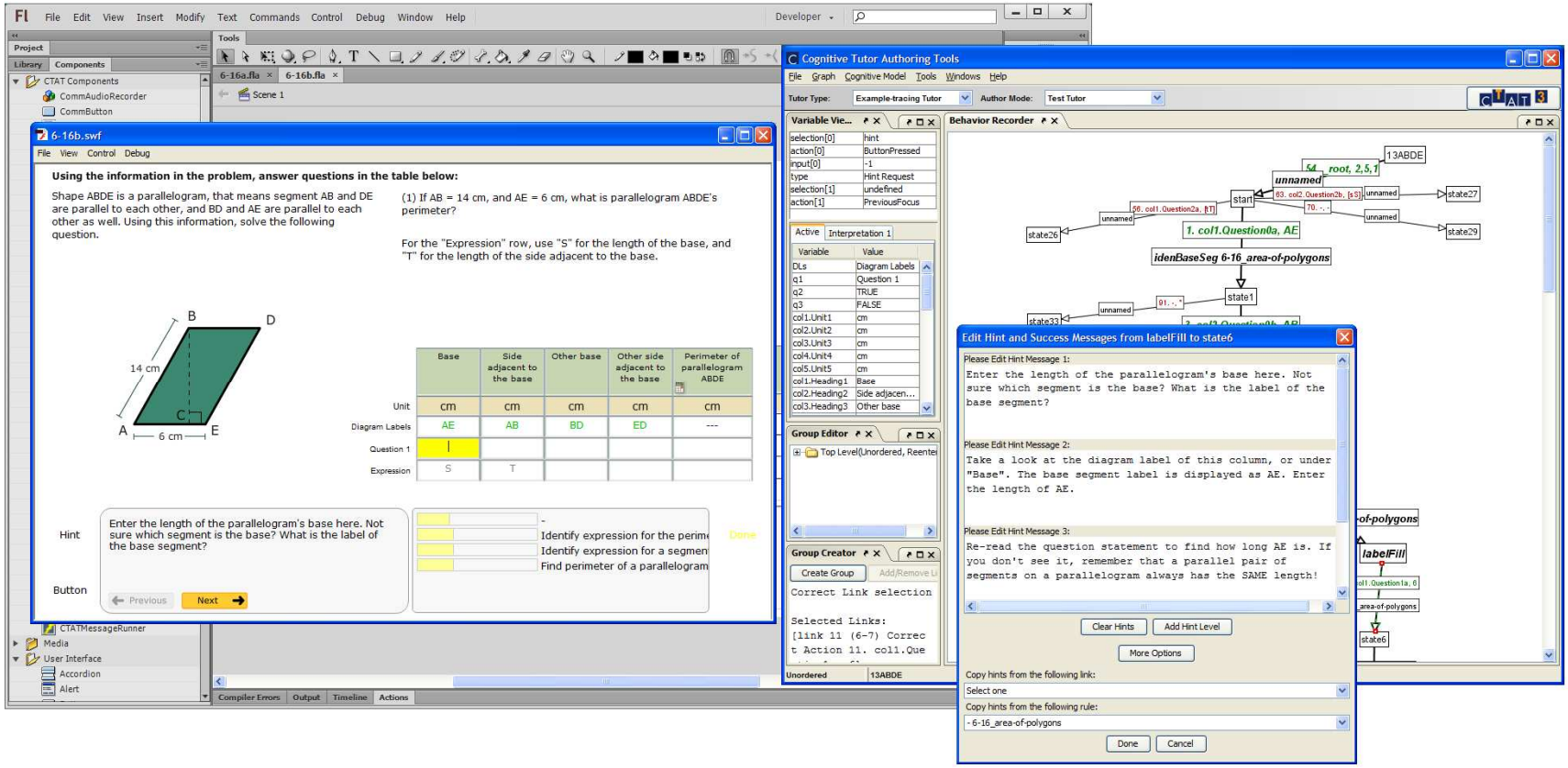
CTAT motivation: Make tutor development easier and faster!

- Cognitive Tutors:
  - Large student learning gains as a result of detailed cognitive modeling
  - ~200 dev hours per hour of instruction (Koedinger et al., 1997)
  - Requires PhD level cog scientists and AI programmers
- Development costs of instructional technology are, in general, quite high
  - E.g., ~300 dev hours per hour of instruction for Computer Aided Instruction (Murray, 1999)

Murray, T. (1999). Authoring Intelligent Tutoring Systems: An Analysis of the state of the art. *The International Journal of Artificial Intelligence in Education, 10*, 98-129.

Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. A. (1997). Intelligent tutoring goes to school in the big city. *The International Journal of Artificial Intelligence in Education, 8,* 30-43.

CTAT: Cognitive Tutor Authoring Tools



Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (2009). A new paradigm for intelligent tutoring systems: Example-Tracing tutors. *International Journal of Artificial Intelligence in Education*, *19*(2), 105-154.

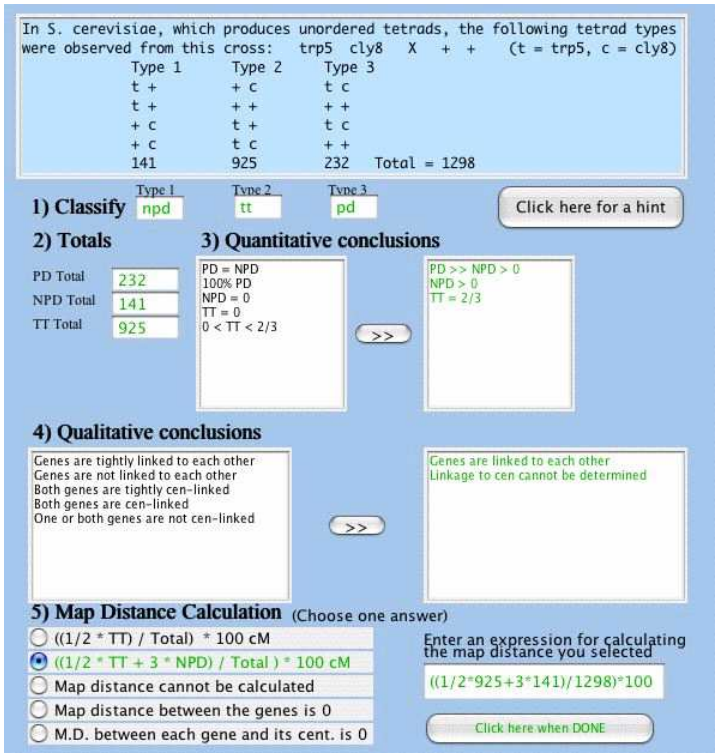
Tutors supported by CTAT

- Cognitive Tutors
  - Use rule-based cognitive model to guide students
  - Difficult to build; for AI programmers
  - Can handle problems with a large solution space (e.g., algebra, computer programming)
- Example-Tracing Tutors
  - Use generalized examples to guide students
  - (Relatively) novel ITS technology
  - Much easier to build; for non-programmers
  - For problem types with a limited number of solution paths (there are many!)
  - End-user programming techniques: Programming by demonstration

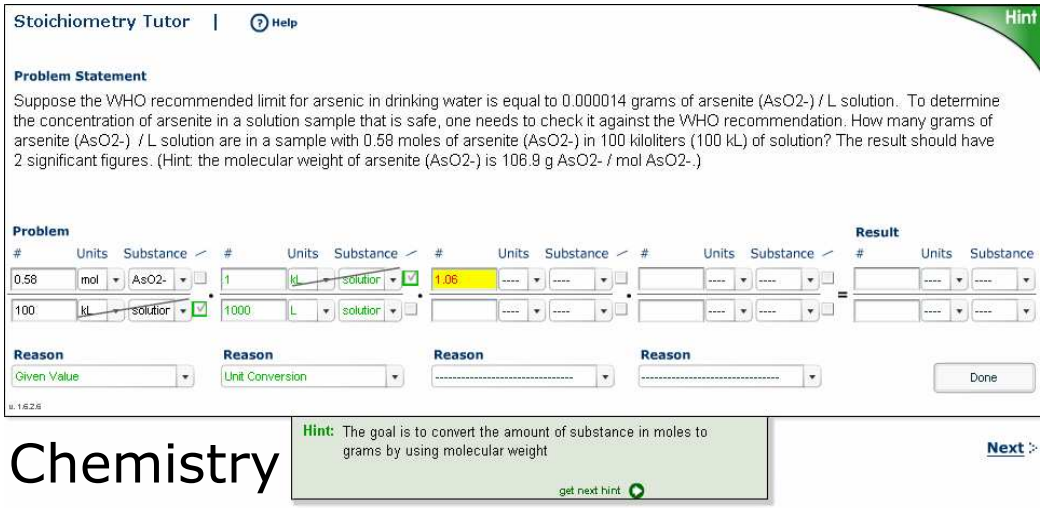
Vote-with-your-feet evidence of CTAT's utility

- Over 500 CTAT users in summer schools, courses, workshops, research, and tutor development projects
  - Domains: mathematics, chemistry, genetics, French culture, Chinese, ESL, thermodynamics
  - At least 44 research studies used CTAT to build tutors and deploy them in real educational settings
- In the past two years
  - CTAT was downloaded 6,600 times
  - the CTAT website drew over 2.9M hits from 164k unique visitors
  - URL: http://ctat.pact.cs.cmu.edu

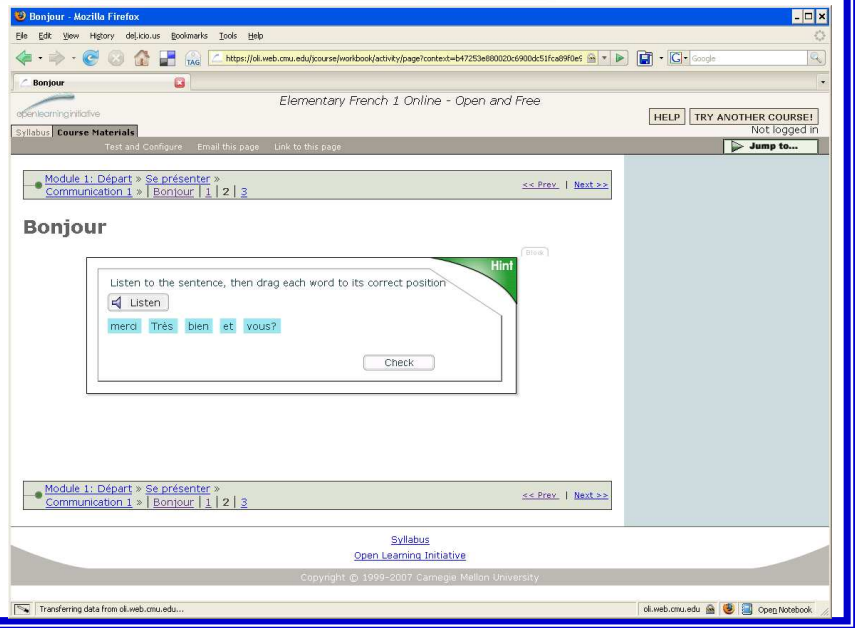
Some CTAT tutors used in online courses and research



Genetics



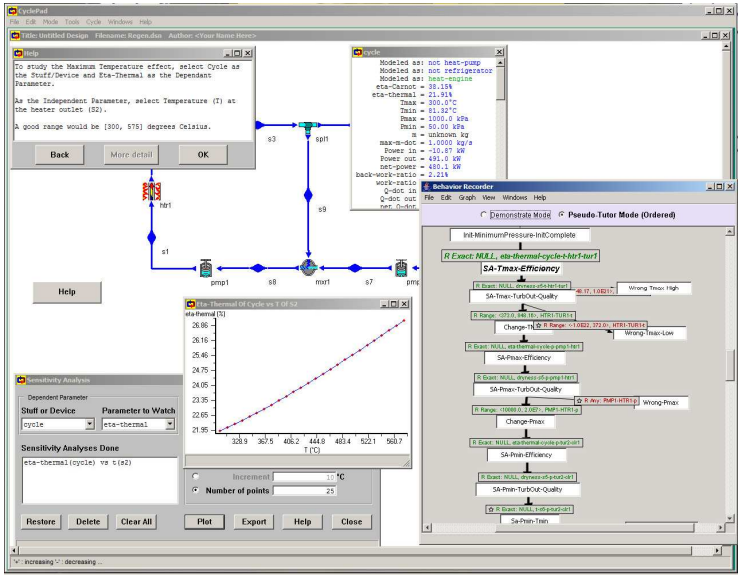
Chemistry

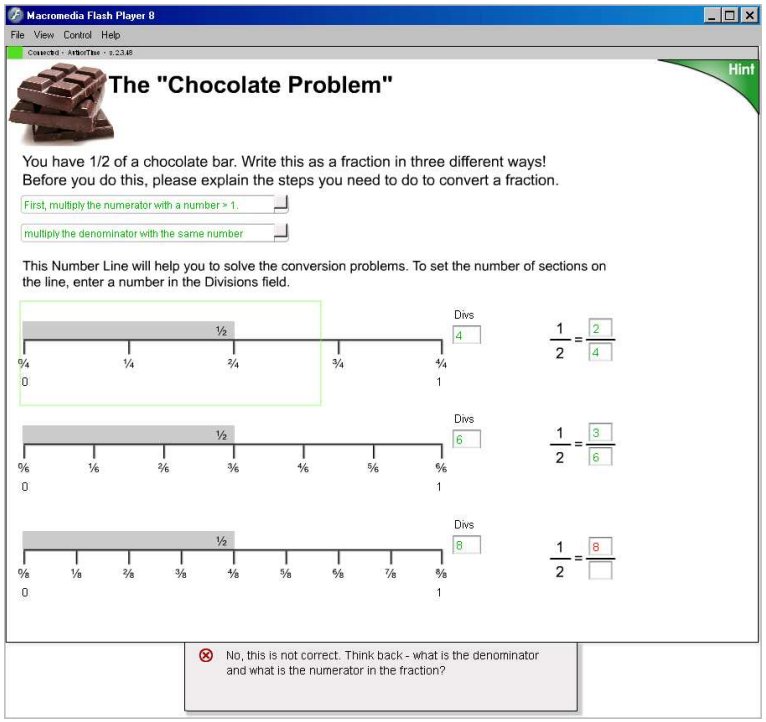


French

Some CTAT tutors used in research

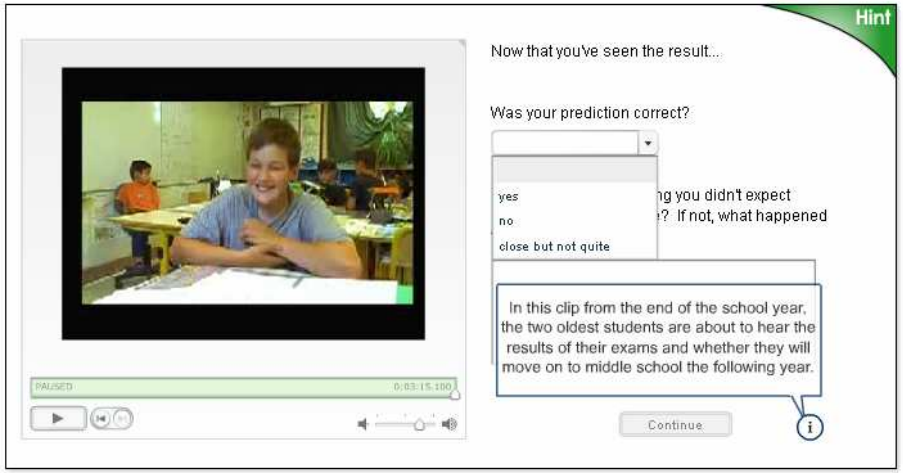
Thermo-dynamics





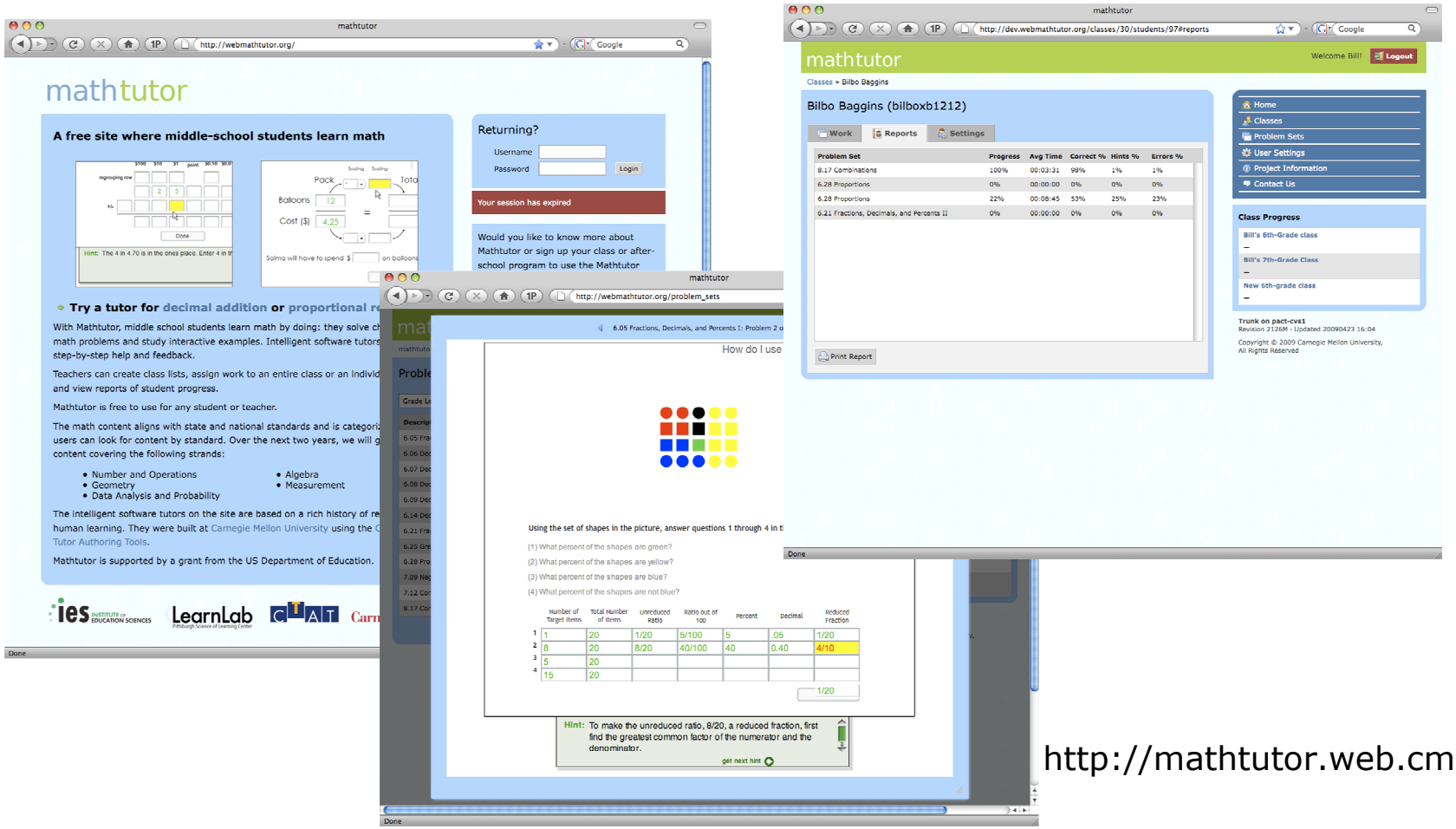
Elementary Math

French (intercultural competence)



Mathtutor: free web-based tutors for middle-school math

Vincent Aleven, Bruce McLaren



http://mathtutor.web.cmu.edu

Use of CTAT Tutors in Research

Learning Fractions by Yourself and with a Peer

Vincent Aleven

Nikol Rummel

Stacie Rohrbach

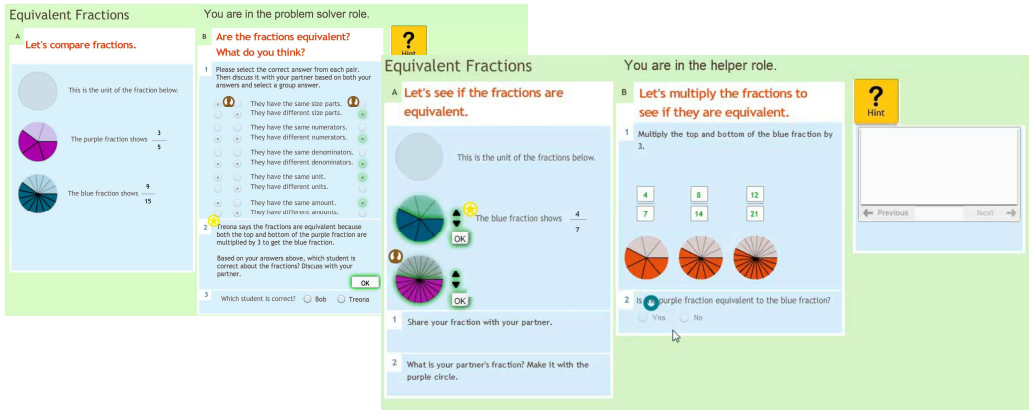
Daniel Belenky

Martina Rau

Jennifer Olsen

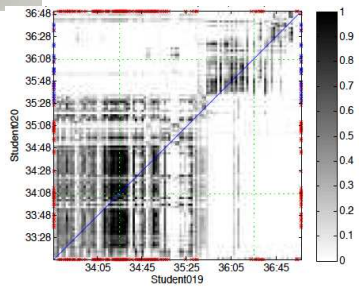
Mike Ringenberg

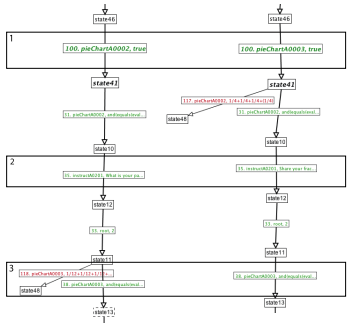
How can complementary strengths of individual and collaborative learning best be combined?



Fractions Tutor: intelligent tutoring system for 4th and 5th grade fractions learning used as platform for the research

Dual eye tracking: Gaze convergence to assess collaboration



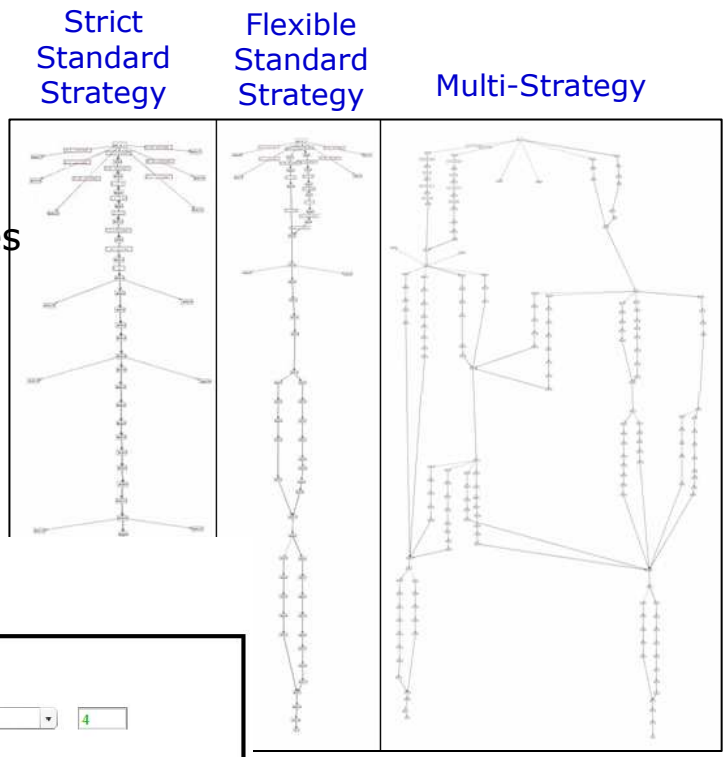


CTAT enhanced to support colloborative learning – dual synched tutors allow collaborators to have slightly different views of the same problem they work on

Grant: US Department of Education (IES, NCER-CASL) Award No. R305A120734, PI: Vincent Aleven, co-PI: Nikol Rummel. "Combining advantages of collaborative and individual learning with an intelligent tutoring system for fractions."

CTAT Tutors in Research

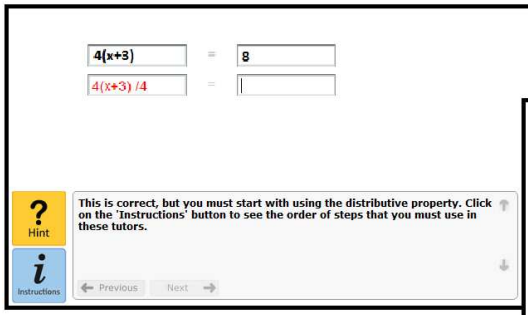
Strategy use in linear equation solving

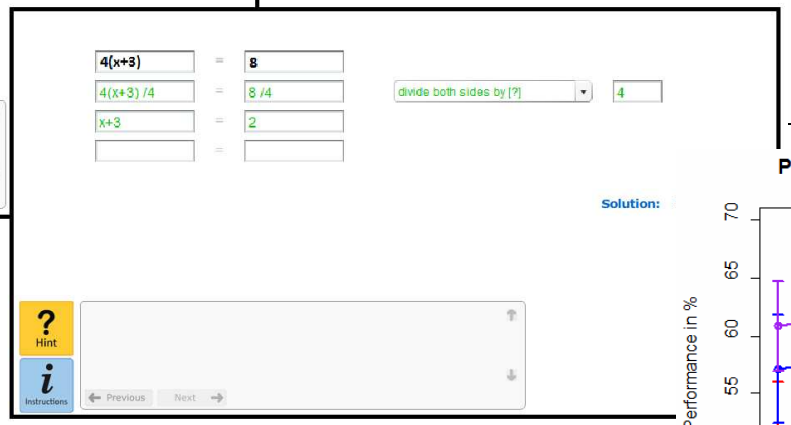


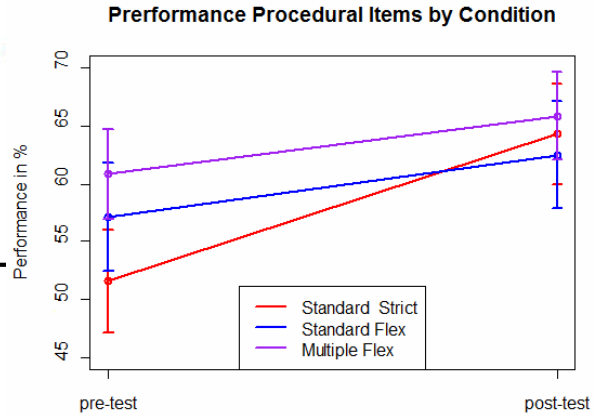
Log data: Students seldom use non-standard strategies

2(x+1)	= 4	
2x +2	= 4	distribute
2x	= 2	move
x	= 1	divide

E.g., in 2(x+1) = 4
Standard strategy used 96% of the time



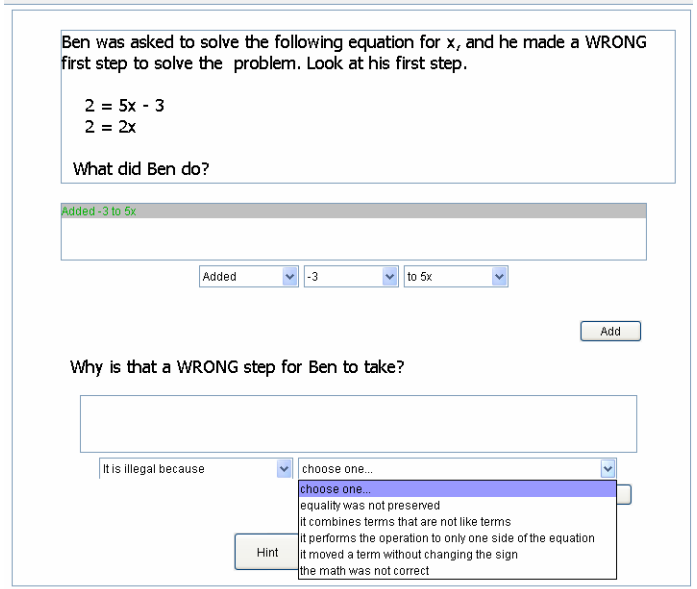




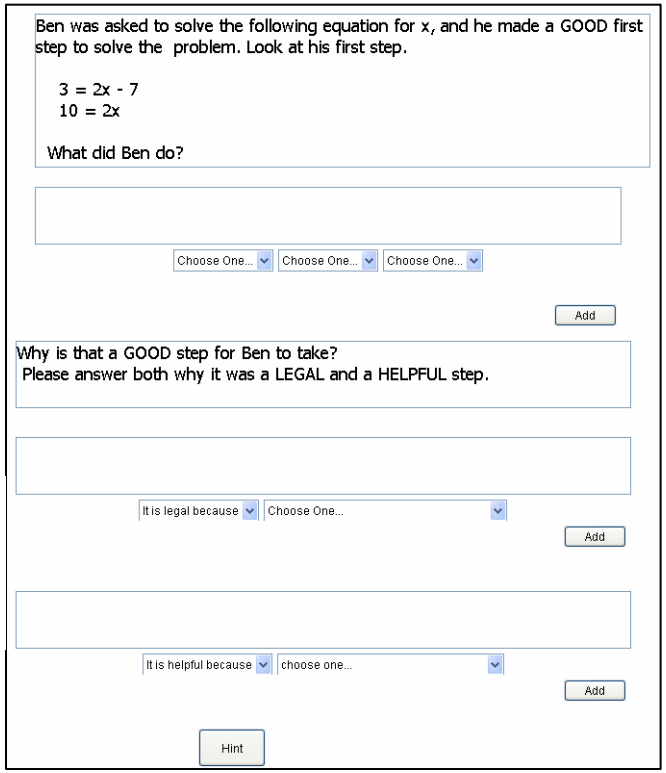
Waalkens, M., Aleven, V., & Taatgen, N. (2013). Does supporting multiple student strategies lead to greater learning and motivation? Investigating a source of complexity in the architecture of intelligent tutoring systems. *Computers & Education, 60*(1), 159–171.

In vivo study: Correct and incorrect worked examples in Algebra learning

Julie Booth, Ken Koedinger



Incorrect worked example with self-explanation prompt, built with CTAT



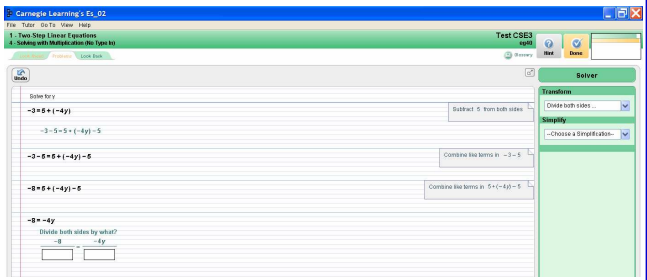
Correct worked example with self-explanation prompt, built with CTAT

Study Design

Self-Explanation of Correct Examples

Self-Explanation of Incorrect Examples	**No**	**Yes**
No	Control	Typical
Yes	Corrective	Typical + Corrective (half of each)

CTAT tutors interleaved with Carnegie Learning Cognitive Tutor



Booth, J. L., Lange, K. E., Koedinger, K. R., & Newton, K. J. (2013). Using example problems to improve student learning in algebra: Differentiating between correct and incorrect examples. *Learning and Instruction*, *25*, 24 - 34. doi:10.1016/j.learninstruc.2012.11.002

Take-Home Messages

- Cognitive Tutors
  - Practical application of cognitive science that demonstrably improves student learning in schools and has been commercially successful
  - Combination of cognitive theory, cognitive task analysis, cognitive modeling, AI technology, and math education expertise
  - Provides individualized, detailed guidance during complex problem solving
- Cognitive Tutors can support self-assessment and self-explanation effectively
  - Good to include metacognition and self-regulated learning in the theoretical perspective
- Non-programmer tools reduce authoring time and cost
  - Used widely for research purposes


THE END