What can CTAT do for you?
Overview of the CTAT track

Vincent Aleven and the CTAT team

4th Annual PSLC LearnLab Summer School
Pittsburgh,
July 7-11, 2008

CTAT CognitiveTutorAuthoringTools

LearnLab Pittsburgh Science of Learning Center

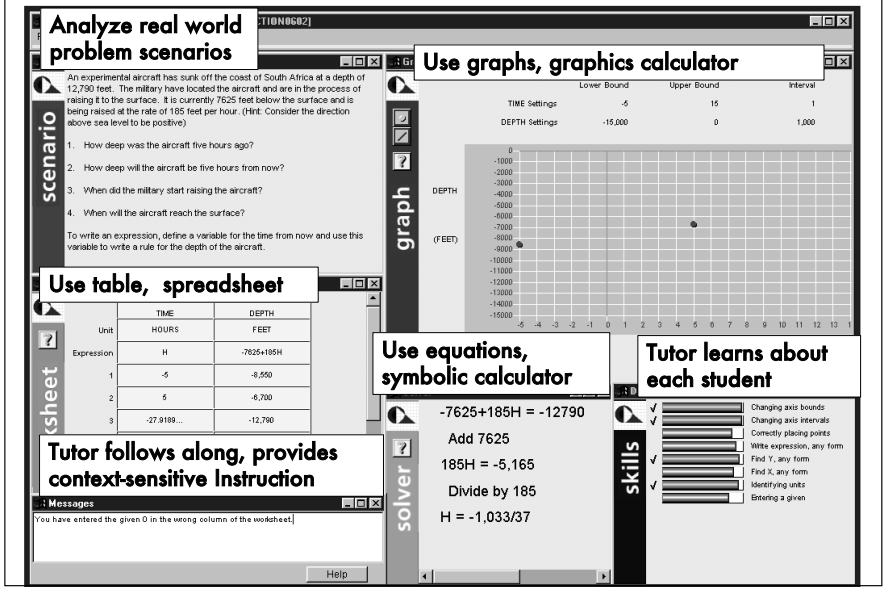
Overview

- What is "a tutor?"
  - How is it different from other forms of computer-based instruction?
  - How do we know tutors work?
- What can you do with CTAT?
  - Short movie of authoring with CTAT
  - Examples of projects that have used CTAT
- Planned activities in the CTAT track

If you are not in the CTAT track, should you listen to this talk?

- CTAT relevant to most other tracks:
  - TuTalk: TuTalk dialogue tutor agent and CTAT intelligent tutor would make an awesome duo!
  - *In Vivo:* could do an *in vivo* experiment with CTAT-based tutors (happens all the time!)
  - Data Shop: many data sets in the Data Shop were generated using CTAT-built tutors
  - TagHelper: Hmm.... think-aloud data of how people learn with tutors may bolster a theoretical explanation for differences in robust learning caused by different tutor versions used in an *in vivo* experiment
- Track hopping is allowed!
  - E.g., if in the *In Vivo* track, could attend CTAT sessions

Algebra Cognitive Tutor



A simple example: Fraction Addition

- Interact with the fraction addition tutor on the CTAT web site …

ITSs v. Other Instruction

- First, compare Conventional Teaching and Computer-Aided Instruction (CAI)

Eberts, R. E. (1997). Computer-based instruction. In Helander, M. G., Landauer, T. K., & Prabhu, P. V. (Ed.s) *Handbook of Human-Computer Interaction*, (pp. 825-847). Amsterdam, The Netherlands: Elsevier Science B. V.

Chabay, R. W., & Sherwood, B. A. (1992). A practical guide for the creation of educational software. In Larkin, J. H. and Chabay, R. W. (Eds.), *Computer-Assisted Instruction and Intelligent Tutoring Systems: Shared Goals and Complementary Approaches*. Hillsdale, NJ: Lawrence Erlbaum Associates.

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 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

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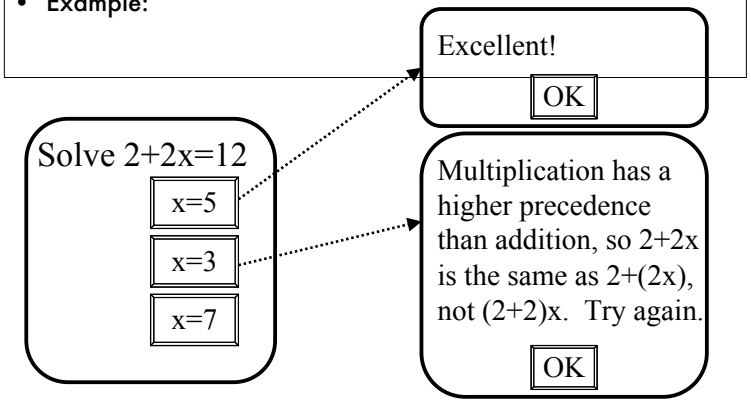
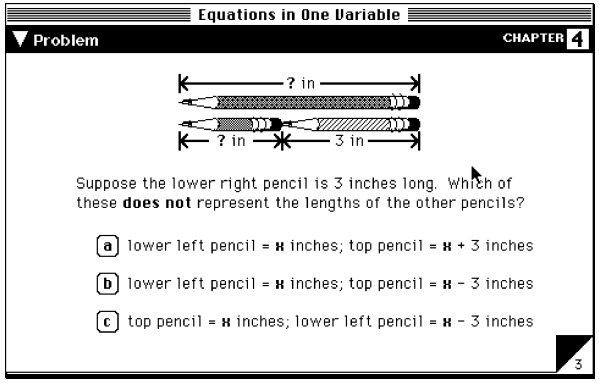
Computer Aided Instruction (CAI)

- Underlying technology: Hypertext & Behaviorism
- Pedagogy: Didactic feedback on answers.
- Example:

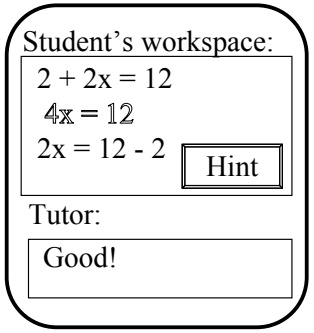


Simple CAI Example



Intelligent Tutoring Systems (ITS)

- Underlying technology: Artificial intelligence & cognitive psy
- Pedagogy: Assistance on problem solving steps, not just final answers
- Example:
  - Tutor: Solve 2+2x=12
  - Student: <enters 4x=12>
  - Tutor: Not quite. Try again.
  - Student: <clicks on "hint" button>
  - Tutor: Think about operator precedence.
  - Student: <enters 2x=12-2>
  - Tutor: Good!



The nested loops of CAI

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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

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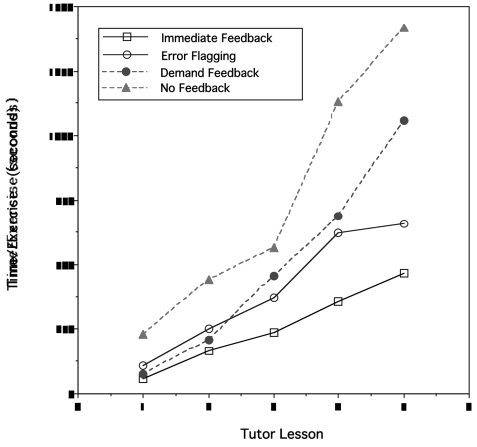
Feedback Studies in LISP Tutor (Corbett & Anderson, 1991)



Time to Complete Programming Problems in LISP Tutor

Immediate Feedback
Vs
Student-Controlled Feedback

Inner loop options - within-problem guidance offered by ITS

+	Minimal feedback on steps (classifies steps as correct, incorrect, or suboptimal)	
+		Immediate
+/–		Delayed (not built in, but some forms can be authored)
–		Demand
+	Error-specific feedback	
+	Hints on the next step	
+	Assessment of knowledge	
–	End-of-problem review of the solution	

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

–	CTAT supports it
(+)	CTAT will soon support it
+/–	CTAT supports a limited form of it
–	CTAT does not support it

Outer loop - problem selection options offered by ITS

–	Student picks
+	Fixed sequence
(+)	Mastery learning
(+)	Macroadaptation

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

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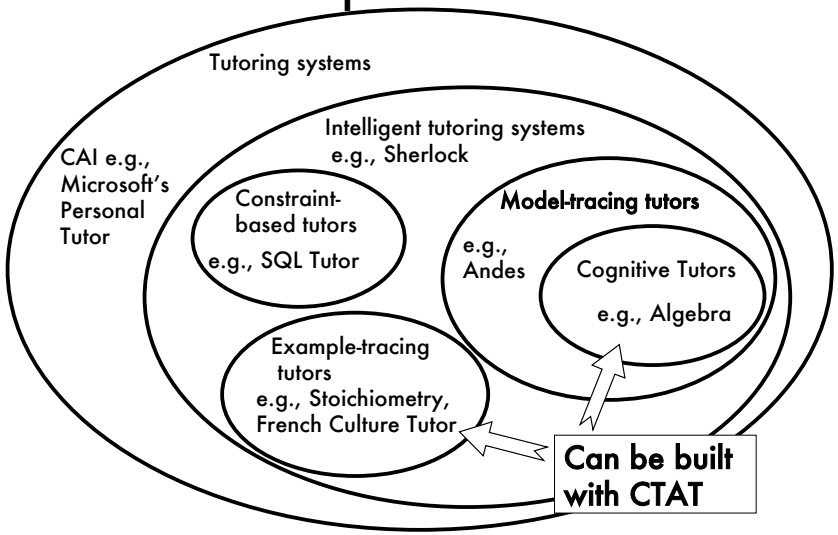
Kinds of Computer Tutors



Cognitive Tutors: Real-world success of Intelligent Tutoring Systems technology

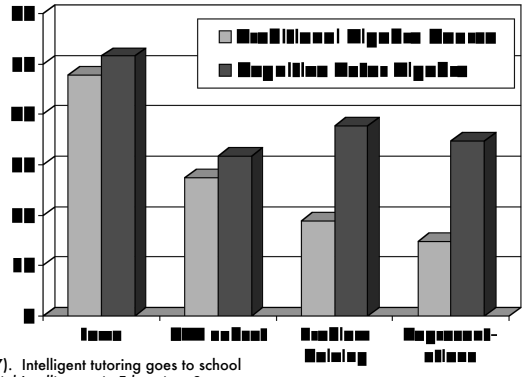
- Cognitive Tutor Courses
  - Goal: Improve quantitative literacy & fluency
  - Computer-based one-to-one tutoring
    - Based on computational models of student thinking
    - Based on the concept of *Model Tracing*
- Used by many students in many schools
  - *Algebra Cognitive Tutor:* In over 2,000 schools in the USA, 300,000 students per year
  - *Geometry Cognitive Tutor:* In 350 schools
  - Most widely used intelligent tutoring system?
- University created a company, Carnegie Learning, to disseminate

Carnegie Learning™
THE COGNITIVE TUTOR® COMPANY

Replicated Field Studies

- 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, Anderson, Hadley, & Mark (1997). Intelligent tutoring goes to school in the big city. *International Journal of Artificial Intelligence in Education*, 8.

ACT-R: A Cognitive Theory of Learning and Performance

- Big theory … key tenets:
  - Learning by doing, not by listening or watching
  - Production rules represent performance knowledge:

These units are:	Instruction implications:
• modular	→ isolate skills, concepts, strategies
• context specific	→ address "when" as well as "how"

Anderson, J.R., & Lebiere, C. (1998). *The Atomic Components of Thought*. Erlbaum.

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:

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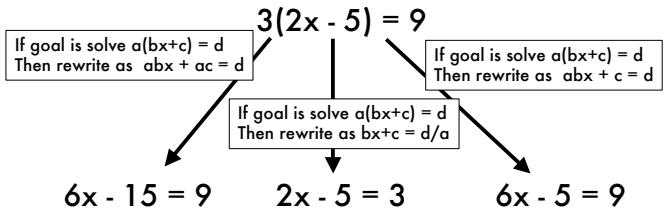

- Model Tracing: Follows student through their individual approach to a problem -> context-sensitive instruction

Cognitive Tutor Technology:

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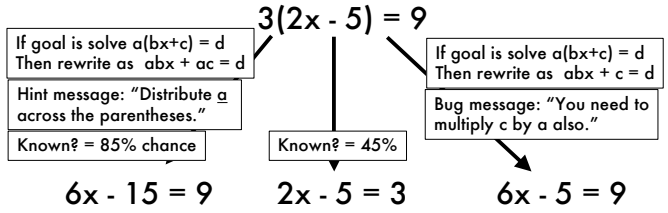


- Model Tracing: Follows student through their individual approach to a problem -> context-sensitive instruction
- Knowledge Tracing: Assesses student's knowledge growth -> individualized activity selection and pacing

CTAT motivation: Make tutor development easier and faster!

- Development costs of instructional technology are high
  - E.g., ~300 dev hours per hour of instruction for Computer Aided Instruction (Murray, 1999)
- 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
- Solution: Easy to use Cognitive Tutor Authoring Tools (CTAT) - makes authoring possible for non-programmers and 4 to 8 times more cost effective

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 goal: broaden the group of targeted authors

- Instructional technology developers (e.g., instructional media dept. at university, or developers of on-line courses)
- Researchers interested in intelligent tutoring systems
- Instructors (e.g., computer-savvy college professors)
- Learning sciences researchers interested in using computer-based tutors in their experiments
  - Within the PSLC, CTAT-based tutors are often used in *in vivo* experiments

How to reduce the authoring cost?

- Less programming, more automation
  - Drag & drop interface construction
  - Demonstration-based programming
  - New: Machine learning and data mining
- Human-Computer Interaction (HCI) methods
  - User studies, summer schools, informal & formal comparison studies
- Exploit tools already in use
  - Component-based architecture with "standard" tool-tutor protocol
  - Off-the-shelf tools and languages (e.g., Netbeans, Eclipse, Flash, Jess)

CTAT supports two types of tutors

- Cognitive Tutors and Example-Tracing Tutors
- Behavior is similar though not identical
  - Cognitive Tutors handle more sophisticated dependencies between steps, and more subtle ordering constraints
- Technology and development are very different
  - Example-Tracing Tutors: built through "programming by demonstration"
  - Cognitive Tutors: built by AI programming (much harder)

Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (under review). Example-tracing tutors: A new paradigm for intelligent tutoring systems. Document submitted for publication.

Aleven, V., McLaren, B. M., Sewall, J., & Koedinger, K. R. (2006). The Cognitive Tutor Authoring Tools (CTAT): Preliminary evaluation of efficiency gains. In M. Ikeda, K. D. Ashley, & T. W. Chan (Eds.), *Proceedings of the 8th International Conference on Intelligent Tutoring Systems (ITS 2006)*, (pp. 61-70). Berlin: Springer Verlag.

Movie Showing How an Example-Tracing Tutor is built

Authoring an Example-Tracing Tutor

Step 1: Create a User Interface
- Create the graphical user interface (GUI) used by the student

Step 2: Demonstrate Behavior
- Demonstrate correct, alternative correct, and incorrect solutions

Step 3: Generalize
- Specify how demonstrated behavior could vary within given problem
  - allowed order of steps
  - allowed variants for a given step

Step 4: Annotate the Graph
- Annotate solutions steps in the resulting "behavior graph" with:
  - hint messages,
  - error messages,
  - labels for concepts or skills associated with actions

Test and Iterate on Steps 1-4 …

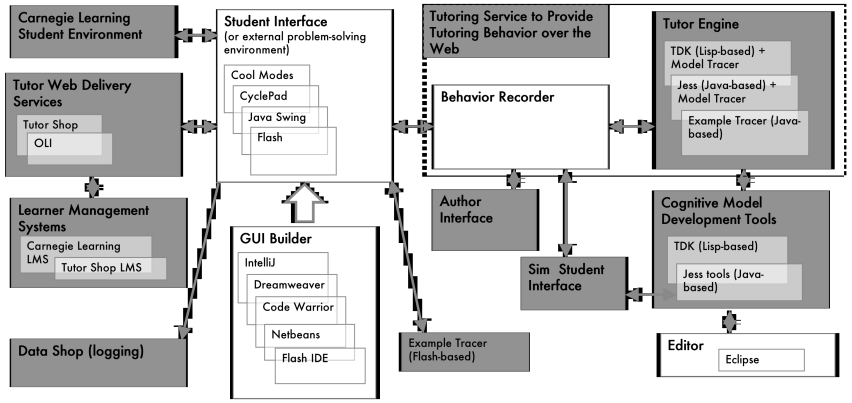
Step 5: Publish Tutor to Web

Vote-with-your-feet Evidence of CTAT's Utility

- Over 350 people have used CTAT
- CTAT tutors in regular use at CMU and elsewhere
- CTAT-built tutors were used in 20 research studies in real educational settings
- CTAT is freely available on the web
- In the past two years
  - CTAT was downloaded 4,300 times
  - the CTAT website drew over 1.5 million hits from over 100,000 unique visitors.

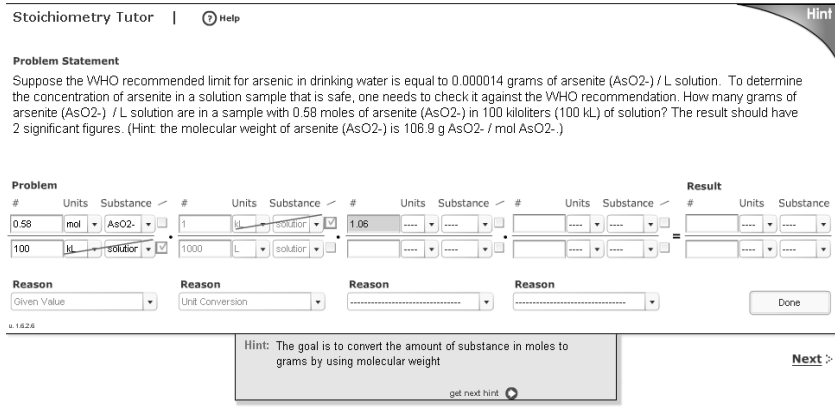
http://ctat.pact.cs.cmu.edu

CTAT Architecture

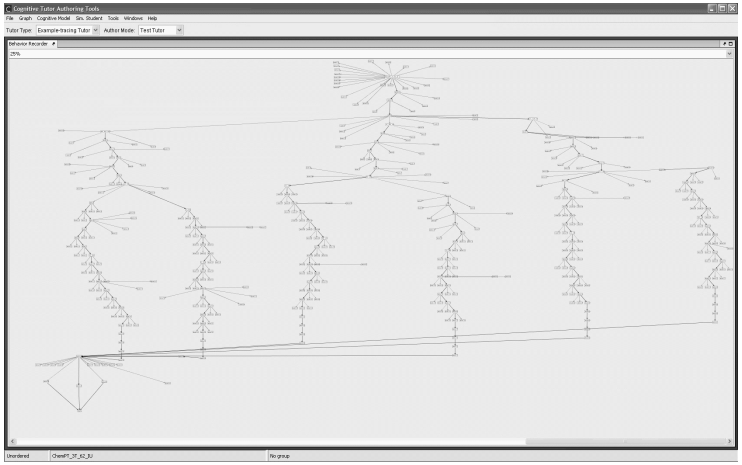


Chinese: tone study
Wang, Perfetti, Liu, et al.

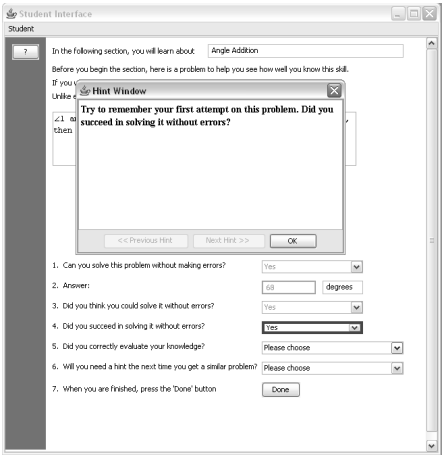
Stoichiometry study
McLaren et al.



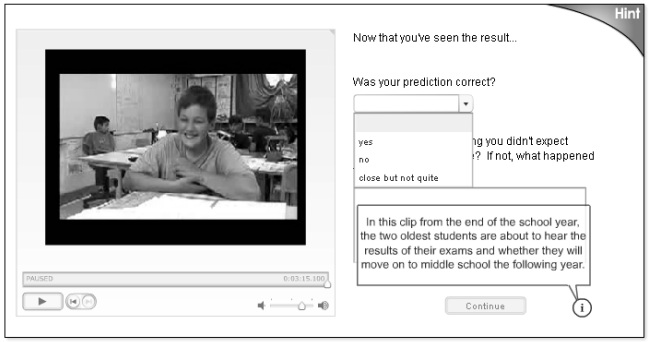
Behavior Graph for Stoichiometry Tutor



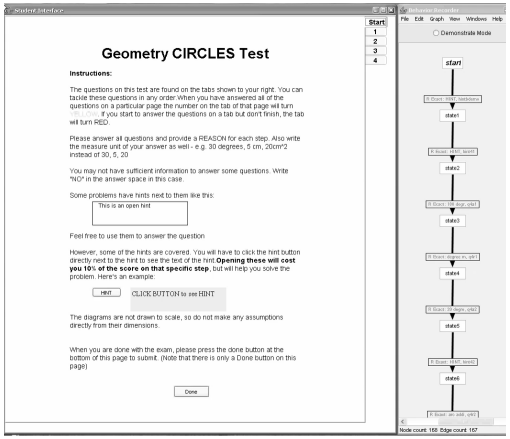
Geometry self-assessment tutor
Roll et al.



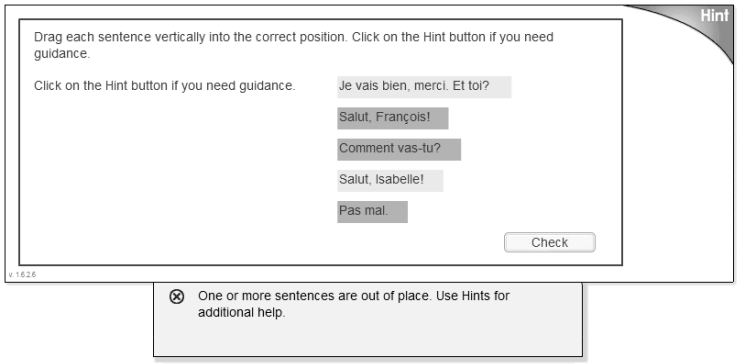
French culture
Ogan et al.



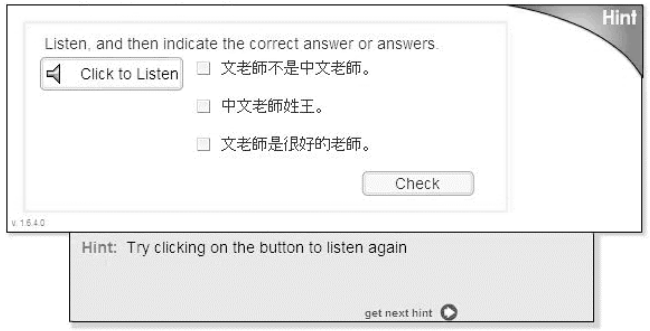
Help seeking
Aleven, McLaren, Roll, et al.



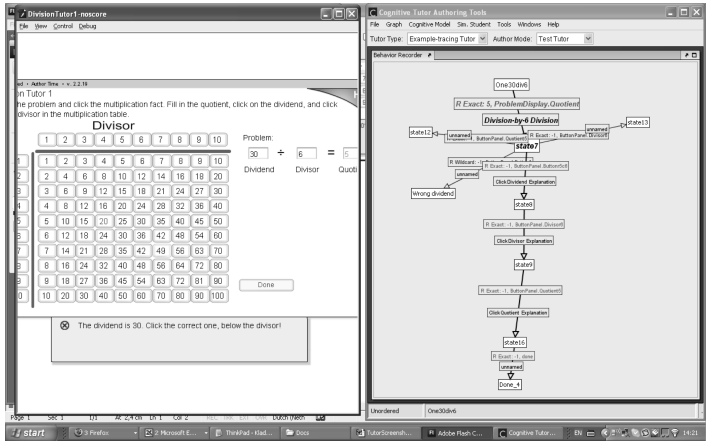
French
Jones et al.



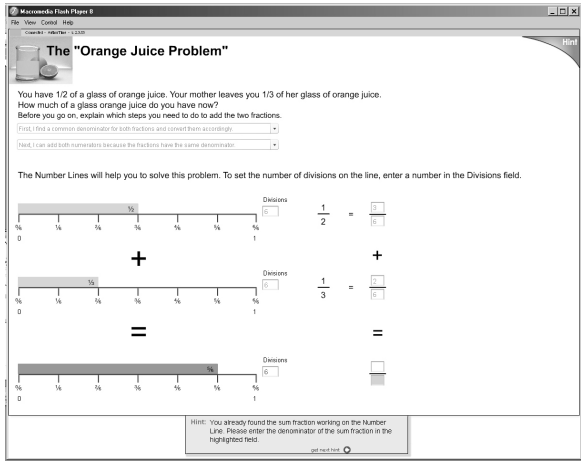
Chinese: listen and read
Mei, Haney, et al.



Division Tutor (Stefan King)

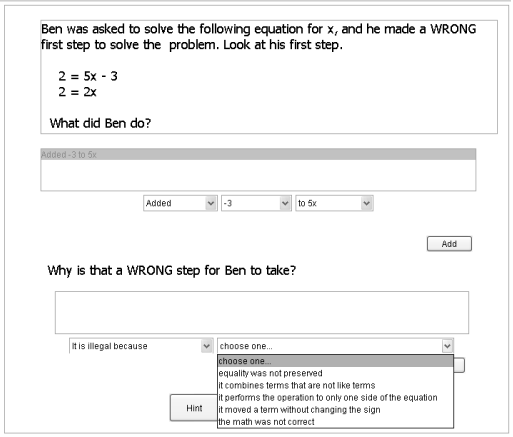


Fractions tutor (Martina Rau)

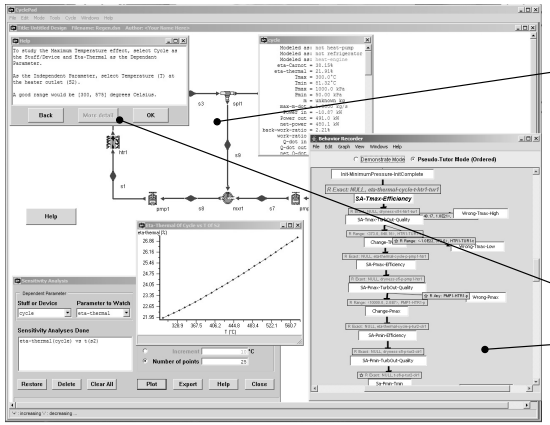


Middle-School Math Tutor Website

Self-explanation of incorrect examples Julie Booth et al.



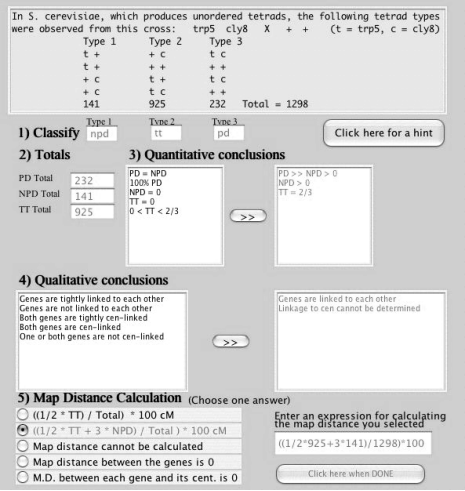
Another example - Thermodynamics



Simulator hooked up with CTAT

CTAT provides tutoring for analyzing power plant efficiency

Genetics Tutor - Corbett et al.



During the summer school

- The CTAT track will cover development of Cognitive Tutors *and* Example-Tracing Tutors
  - Number of "how to" lectures
  - In your project you could decide to focus mainly on example-tracing tutors
  - (Then again, this is your chance to get some mentoring as you build a Cognitive Tutor)
- If you are *not* in the CTAT track, but interested in learning to build tutors in limited time, it is best to focus on example-tracing tutors

Thank you!