Simulated Students and Classroom Use of Model-Based Intelligent Tutoring

by

Kenneth R. Koedinger

Simulated Students & Classroom Use of Model-Based Intelligent Tutoring Systems

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Modeling & simulation to enhance education

- Two paths:
  1. Students create models & use simulations
  2. Researchers create models of learners to guide materials development
- #1 is great way to *potentially* enhance learning, however,
- Understanding student learning (#2) is critical to effective design & use

Real World Impact of *HCI & Learning Technologies*

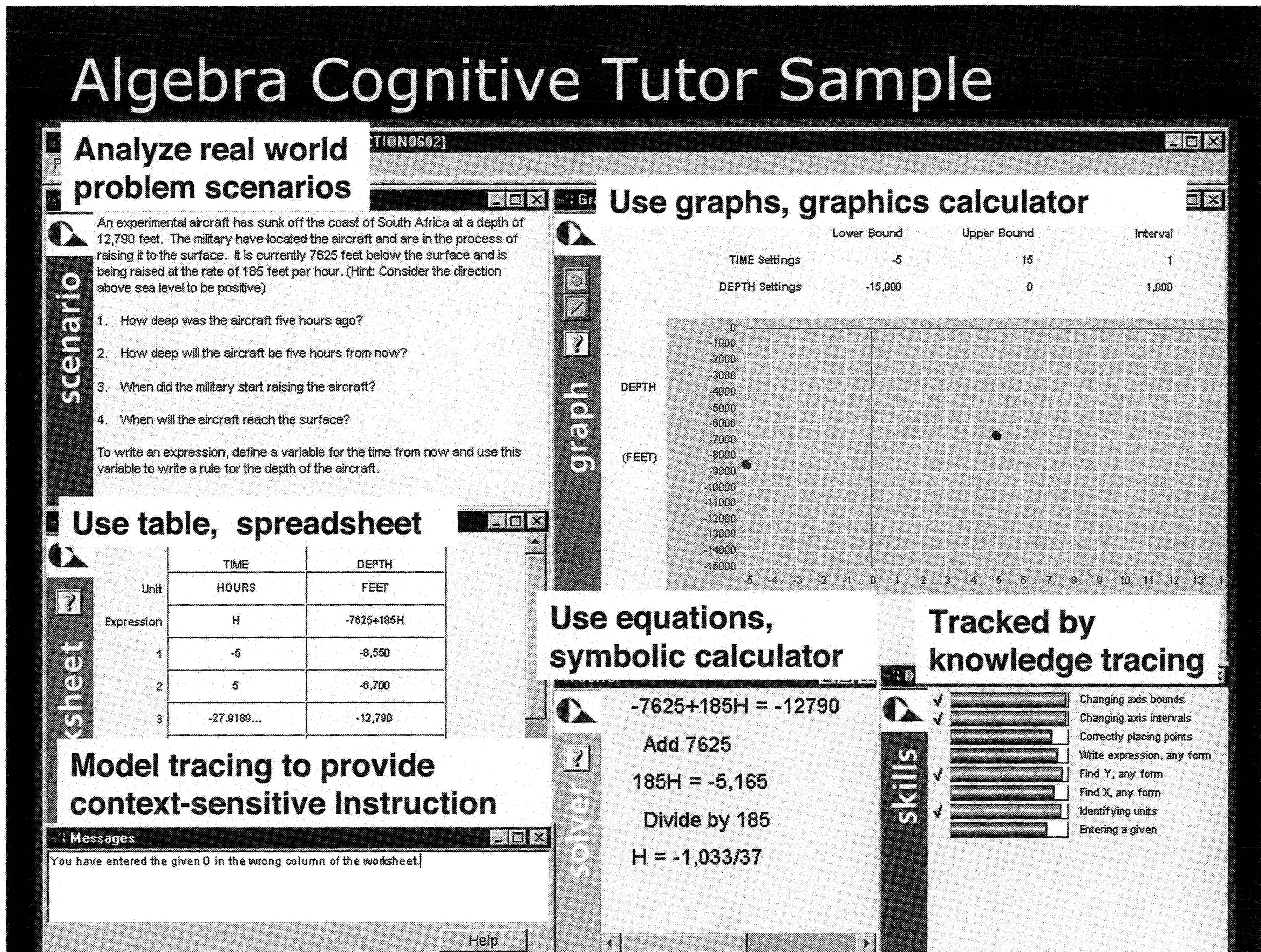
Algebra Cognitive Tutor

- Based on computational models of student thinking & learning
- Course used nation wide
  - Over 4000 schools, 35 states, 475K students use for 80 minutes per week
- Spin-off: Carnegie Learning™ THE COGNITIVE TUTOR® COMPANY

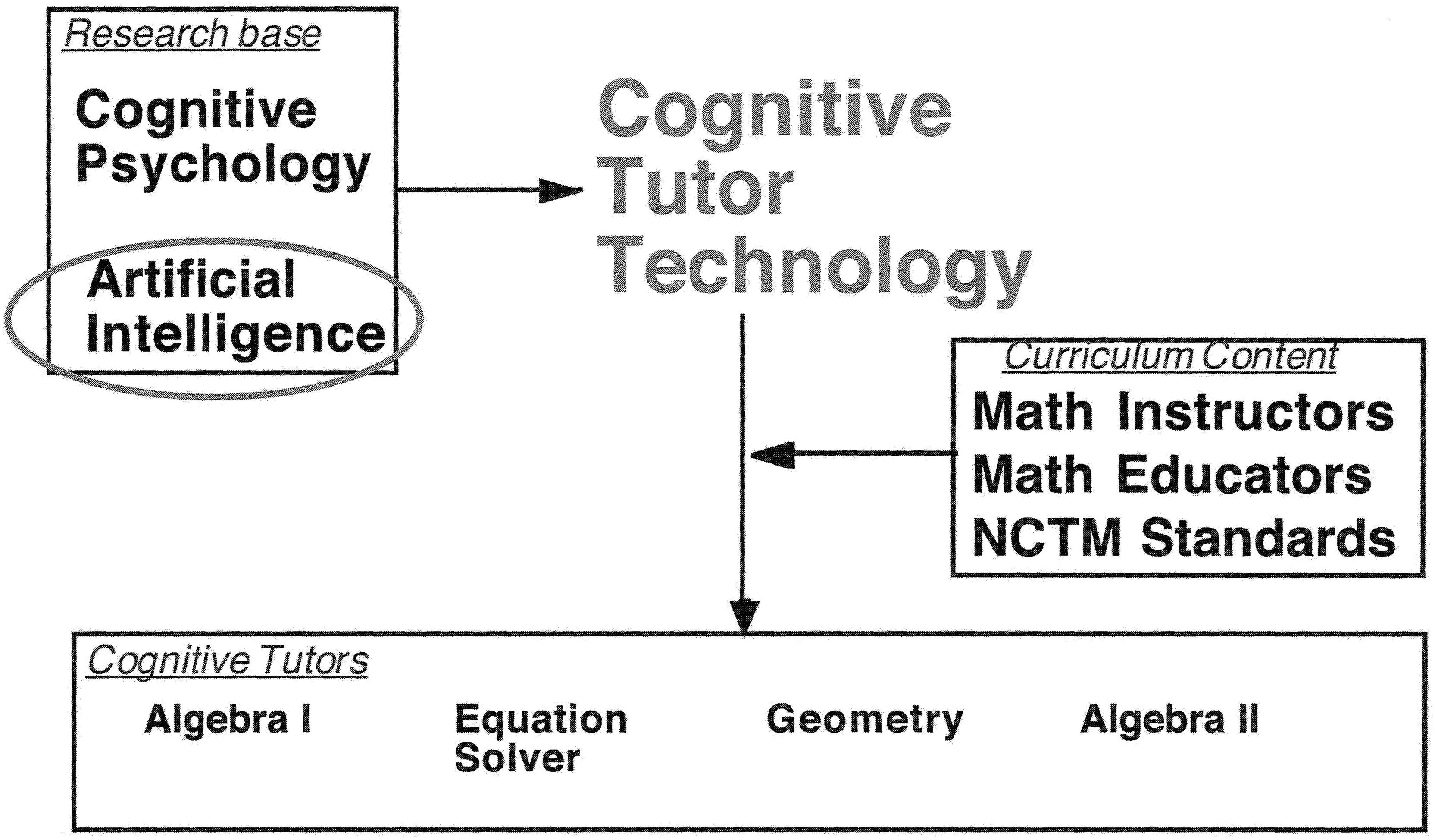
Koedinger, Anderson, Hadley, & Mark (1997). Intelligent tutoring goes to school in the big city.

Overview

- Background: Cognitive Tutors
  - Simulating tutoring
  - Data crucial to create accurate model
- Pittsburgh Science of Learning Center
  - Generalizing learning science & technology
- Examples of advanced modeling efforts
  - Simulating student learning
  - Modeling metacognition, help-seeking
  - Machine learning detectors of student engagement


Algebra Cognitive Tutor Sample
Analyze real world problem scenarios
scenario
An experimental aircraft has sunk off the coast of South Africa at a depth of 12,790 feet. The military have located the aircraft and are in the process of raising it to the surface. It is currently 7625 feet below the surface and is being raised at the rate of 185 feet per hour. (Hint: Consider the direction above sea level to be positive)
1. How deep was the aircraft five hours ago?
2. How deep will the aircraft be five hours from now?
3. When did the military start raising the aircraft?
4. When will the aircraft reach the surface?
To write an expression, define a variable for the time from now and use this variable to write a rule for the depth of the aircraft.
Use graphs, graphics calculator
graph
Lower Bound
Upper Bound
Interval
TIME Settings -5 15 1
DEPTH Settings -15,000 0 1,000
DEPTH
(FEET)
Use table, spreadsheet
TIME
DEPTH
Unit HOURS FEET
Expression H -7625+185H
1 -5 -8,550
2 5 -6,700
3 -27.9189... -12,790
Use equations, symbolic calculator
solver
-7625+185H = -12790
Add 7625
185H = -5,165
Divide by 185
H = -1,033/37
Tracked by knowledge tracing
skills
Changing axis bounds
Changing axis intervals
Correctly placing points
Write expression, any form
Find Y, any form
Find X, any form
Identifying units
Entering a given
Model tracing to provide context-sensitive Instruction
Messages
You have entered the given 0 in the wrong column of the worksheet.
Help

Multi-Disciplinary Approach



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

$$3(2x - 5) = 9$$

If goal is solve a(bx+c) = d
Then rewrite as abx + ac = d

If goal is solve a(bx+c) = d
Then rewrite as bx+c = d/a

If goal is solve a(bx+c) = d
Then rewrite as abx + c = d

$6x - 15 = 9$ $\quad$ $2x - 5 = 3$ $\quad$ $6x - 5 = 9$

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

55

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

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

$3(2x - 5) = 9$

If goal is solve $a(bx+c) = d$
Then rewrite as $abx + ac = d$

Hint message: "Distribute <u>a</u> across the parentheses."

Known? = 85% chance

Known? = 45%

If goal is solve $a(bx+c) = d$
Then rewrite as $abx + c = d$

Bug message: "You need to multiply c by a also."

$6x - 15 = 9$ $\quad$ $2x - 5 = 3$ $\quad$ $6x - 5 = 9$

- 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

Multi-Disciplinary Approach

Research base

Cognitive Psychology

Artificial Intelligence

Cognitive Tutor Technology

Curriculum Content

Math Instructors
Math Educators
NCTM Standards

Cognitive Tutors

Algebra I | **Equation Solver** | **Geometry** | **Algebra II**

What prior knowledge do algebra students have?

Which problem type is most difficult for beginning Algebra students?

<u>Story Problem</u>

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?

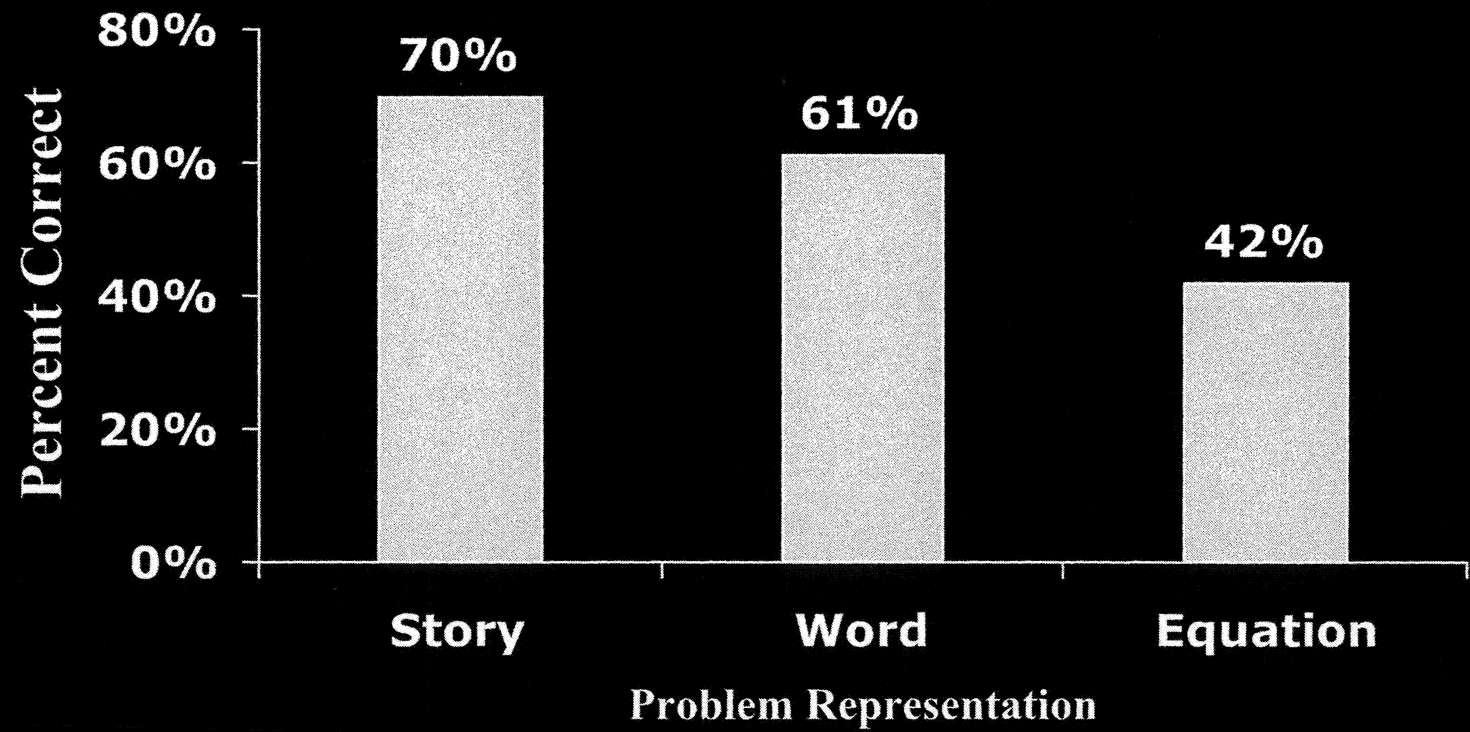
<u>Word Problem</u>

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

<u>Equation</u>

$x * 6 + 66 = 81.90$

Algebra Student Results: Story Problems are Easier!



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.

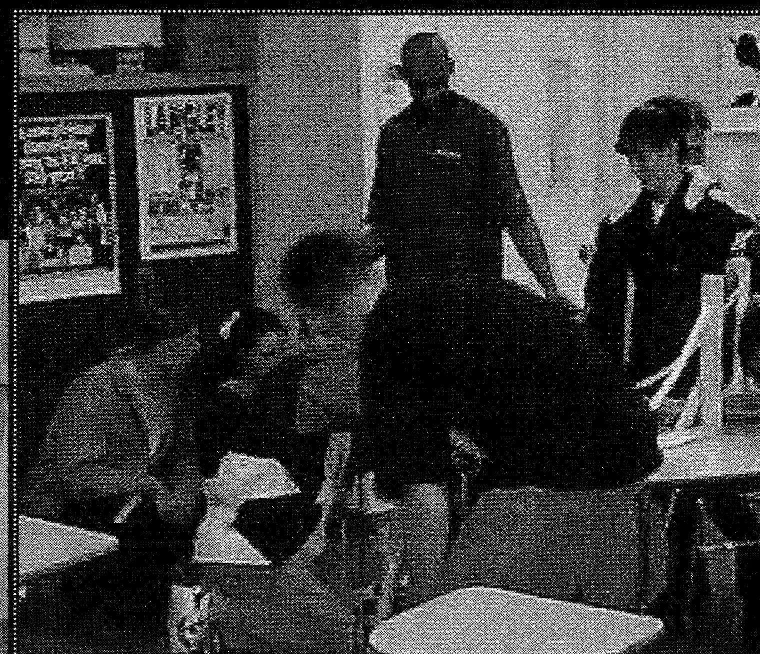
Practical & Theoretical Implications of Surprising Results

- Guided Cognitive Tutor Algebra design
  - Success due in part to smoothly bridging from students' existing common sense

- Inspired basic *cognitive modeling* work to explain these results
  - Coded student solutions for alternative strategies & errors
  - Model could generate both & fit student data on frequency of both

Cognitive Tutor Algebra ***Course***

- Integrated tutor, text, and teacher training
- In computer lab 2 days/week, classroom 3 days/week
- Learn by doing:
  - Project-based
  - Student-centered
  - Cooperative learning
  - Teacher as facilitator



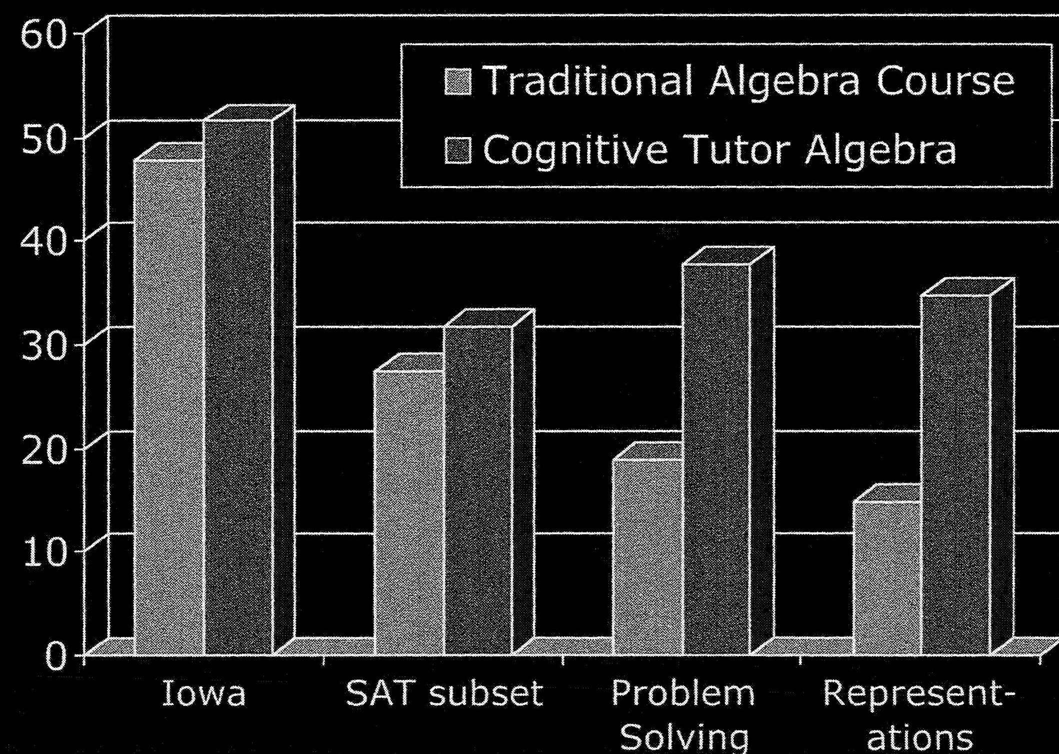
Original Field Study Results

- Full year classroom experiments with comparison classes
- 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.



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Many other studies of Cognitive Tutor Algebra

- 11 study reports available
  - From 1994 to present, 11 different districts
  - More than 8000 students in these studies
  - Most run independently of Carnegie
- Significant positive results in all but 1 case (which was a tie)
- See www.carnegielearning.com/results/reports

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Transition to Pittsburgh Science of Learning Center

Past Success:

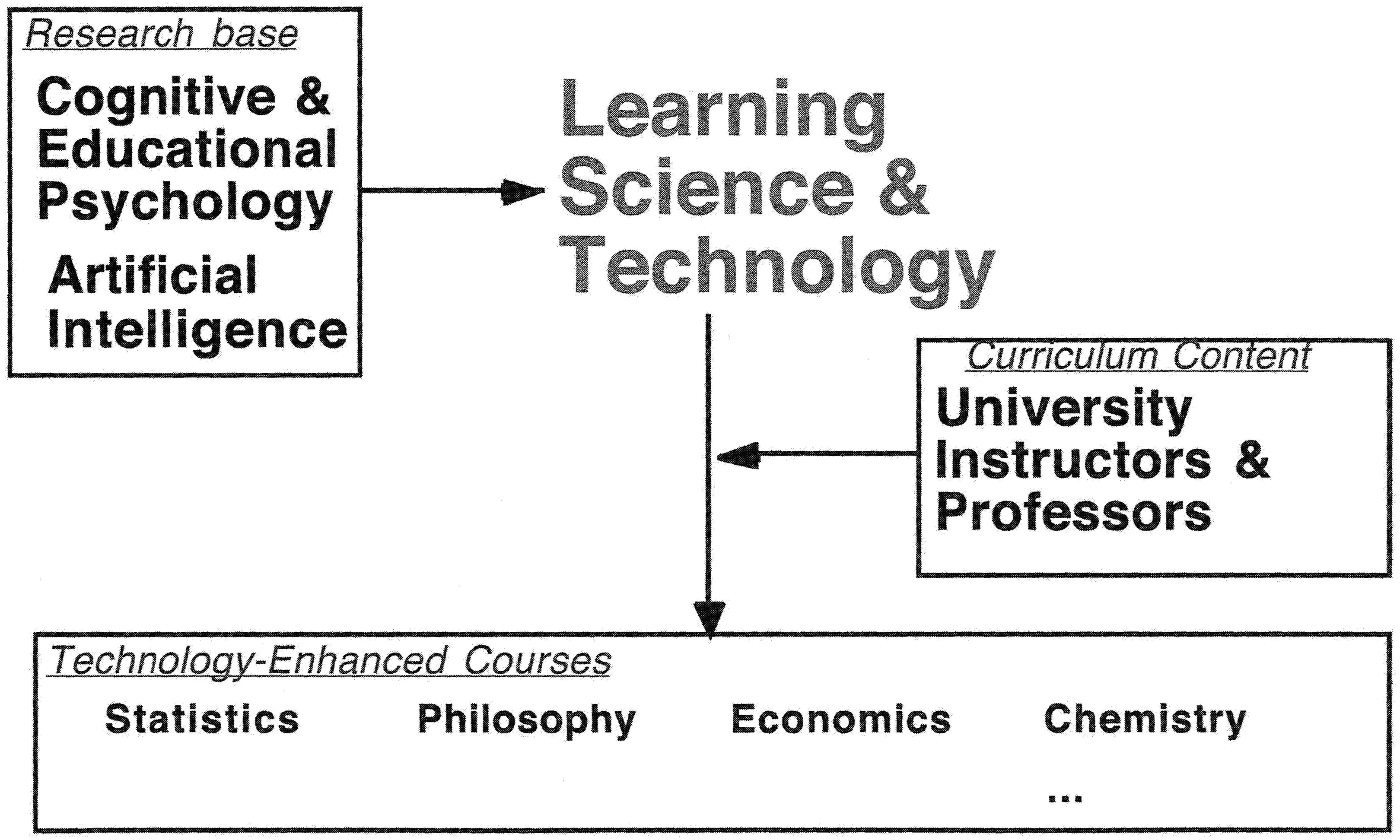
- Cognitive Tutors as delivery vehicle
  - Bring *existing* Learning Science to classroom

New Goal:

- Cognitive Tutors as research platform
  - Create *new* Learning Science & Technology
- 5 year, $25 million research center:

LearnLab
Pittsburgh Science of Learning Center

Generalizing Cognitive Tutor Approach



Pittsburgh Science of Learning Center (PSLC)

- *Problem*: Inadequate theory to engineer courses to be provably effective in raising student achievement
- *Solution*: PSLC's theory & facility development
  - Theory: Unified effort toward *robust learning* theory
  - Facility: *LearnLab's* courses, technology, DataShop
- Scientific merit & broad impact
  - Advance a practical learning theory, evidence-based education, fast & natural dissemination

LearnLab
Pittsburgh Science of Learning Center

PLSC Focus on Robust Learning

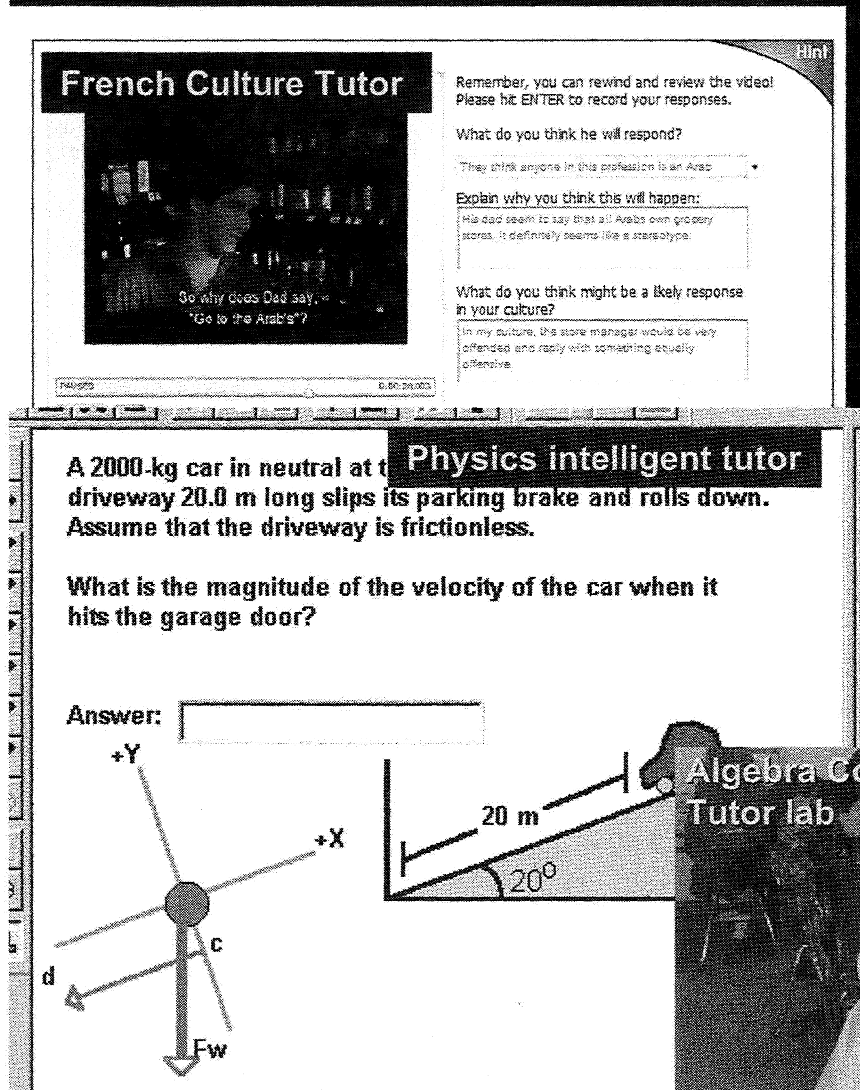
- Other Intelligent Tutoring Systems yield better learning on immediate post-tests
  - Woolf, Graesser, VanLehn, ours ...
- Push to address *robust learning*
  - *Transfer* beyond isomorphic probs
  - *Long term retention*
  - Preparation for better *future learning*
- Address both sides of ed wars
  - Basic fluency & deep conceptual understanding
- Tutor at meta-cognitive level

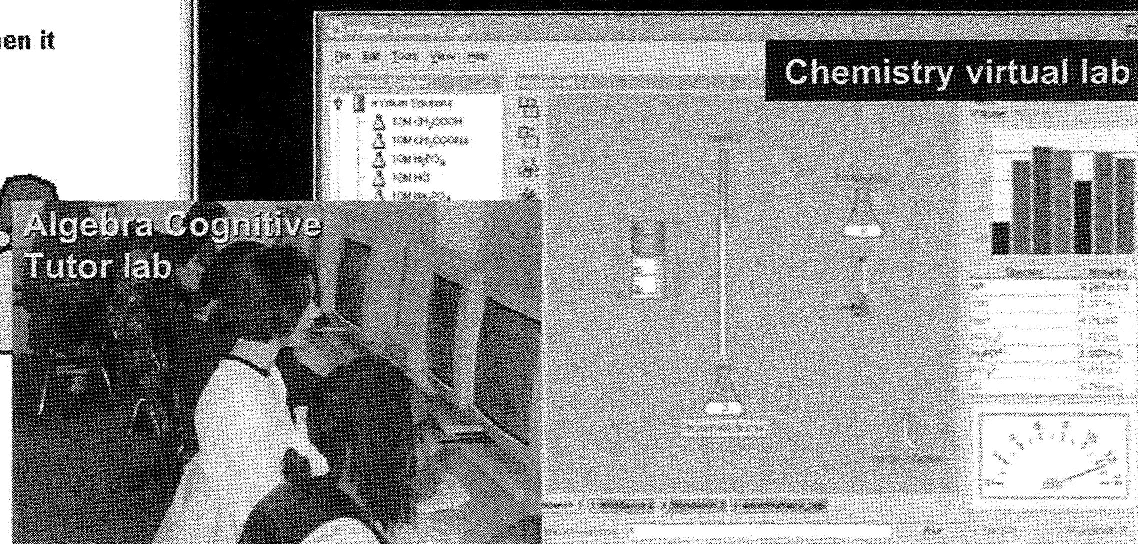
PSLC's Resources

- 7 Technology-enhanced courses where researchers can run studies
  - Algebra, Geometry, Chemistry, Physics, French, Chinese, English
- *Data Shop*
  - A repository of student learning data sets
  - Reporting, export, & analysis tools
- Tools for authoring tutors …

LearnLab: 7 testbed courses open for studies

- Technology-enhanced courses:
  - 2 math, 2 science, 3 language courses
- Tutors, simulations, video, chat rooms, multimedia …





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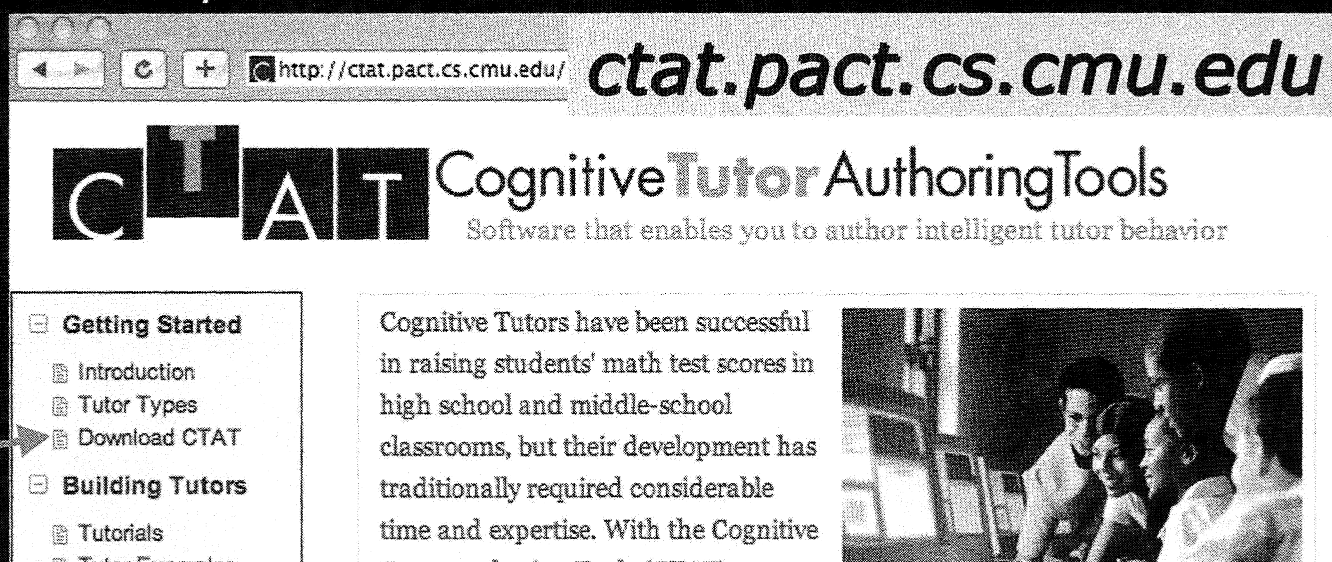
Cognitive Tutor Authoring Tools (CTAT)

- Easier authoring of Tutoring Systems
  - Non-programmer methods
  - General plug-and-play architecture
- Tutors created in a variety of domains:
  - Chemistry, Thermodynamics, Genetics, Law, French culture …



FREE!

71

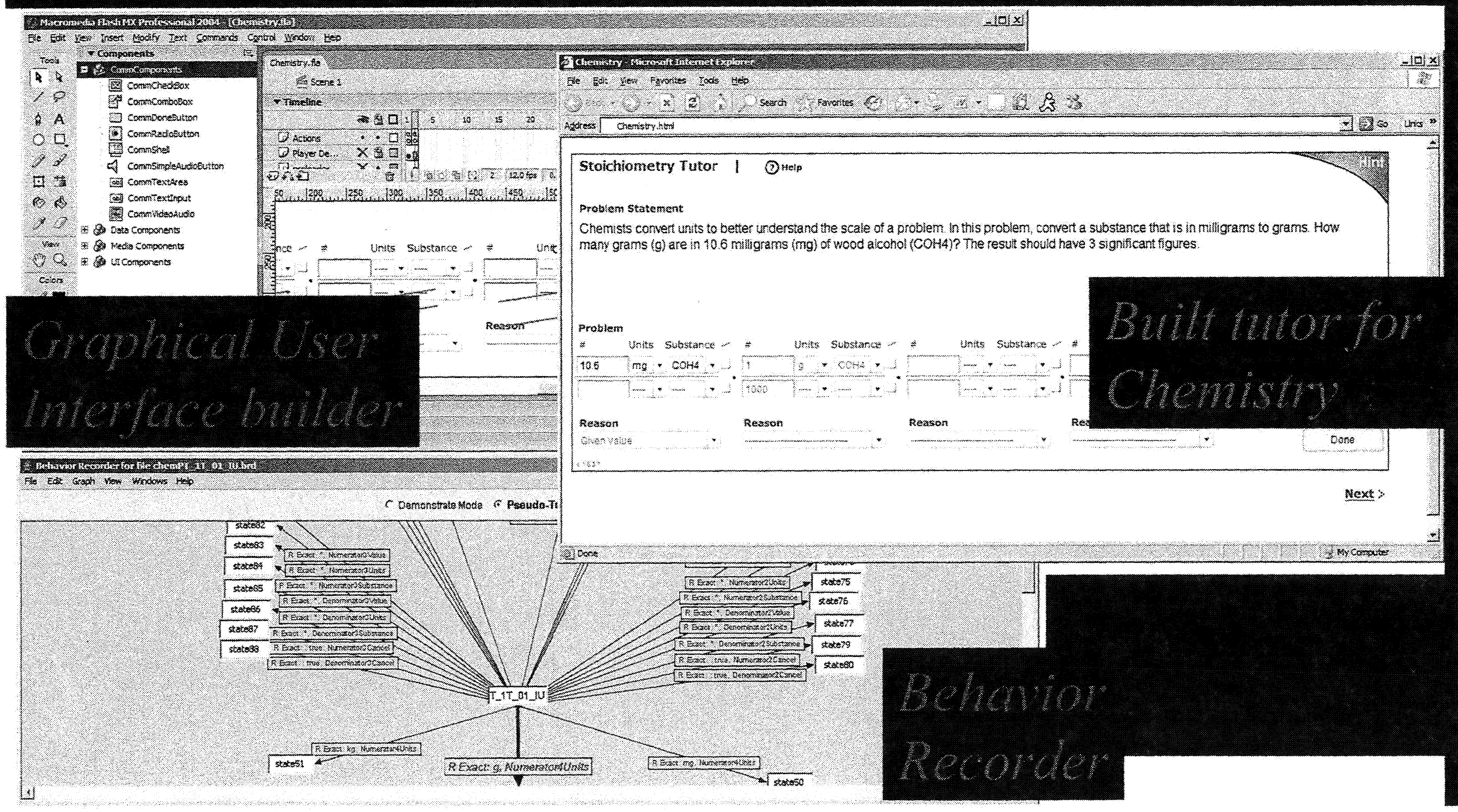
Aids for Building Cognitive Tutors

- Iterative design-&-test for GUI
  - Building, testing, and modifying a prototype
  - Cycling quickly and easily
- Cognitive Modeling
  - Generating a cognitive model without programming
  - Human friendly testing & debugging

Solution

- Integrated intelligent authoring environment
  - CTAT: Cognitive Tutor Authoring Tools
  - Simulated Student: Machine learning agent that learns cognitive skills

CTAT: Cognitive Tutor Authoring Tools



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SimStudent

- Work with Noboru Matsuda & William Cohen
- Learn production rules by demonstration
- 3 parts: What, how, and when
  - What to operate on
  - How to operate
  - When to do it

Structure of a Production Rule

If

such and such *constraints* hold

When

among this and that *GUI elements*

What

Left Hand Side (LHS)

Then

do *actions* with the GUI elements

How

Right Hand Side (RHS)

Structure of a Production Rule

```
(defrule trans-lr-lhs
  ?problem <- (problem (interface-elements ?table1 ? ? ?))
  ?table1 <- (table (columns ?column1))
  ?column1 <- (column (cells $?m1 ?cell0 $?))
  ?cell0 <- (cell (value ?val0&~nil))

  ?problem <- (problem (interface-elements ? ?table2 ? ?))
  ?table2 <- (table (columns ?column2))
  ?column2 <- (column (cells $?m2 ?cell1 $?))
  ?cell1 <- (cell (value ?val1&~nil))

  ?column1 <- (column (cells $?m3 ?cell2 $?))
  ?cell2 <- (cell (name ?selection) (value ?input))

  (test (consecutive-row ?cell0 ?cell2))
  (test (same-column ?cell0 ?cell2))
  (test (distinctive ?cell0 ?cell2))
  (test (consecutive-row ?cell1 ?cell2))
  (test (same-column ?cell1 ?cell2))
  (test (distinctive ?cell1 ?cell2))

  (test (polynomial ?val0))
  (test (not (has-var-term ?val1)))
=>
  (bind ?input (first-var-term ?val0))
  (modify ?cell2 (value ?input)) )
```

GUI elements

Working Memory Element (WME)

WME path

LHS

Topological constraints

WME conditions

Feature constraints

Constraints

Actions

RHS

Learning Techniques

```
(defrule trans-lr-lhs
  ?problem <- (problem (interface-elements ?table1 ? ? ?))
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  ?column1 <- (column (cells $?m1 ?cell0 $?))
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  (test (same-column ?cell0 ?cell2))
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  (test (polynomial ?val0))
  (test (not (has-var-term ?val1)))
=>
  (bind ?input (first-var-term ?val0))
  (modify ?cell2 (value ?input)) )
```

Focus of attention

Working Memory Element (WME)

WME path

LHS

Topological constraints

WME conditions

Feature constraints

FOIL

Brute Force Search

RHS

SimStudent demo ..

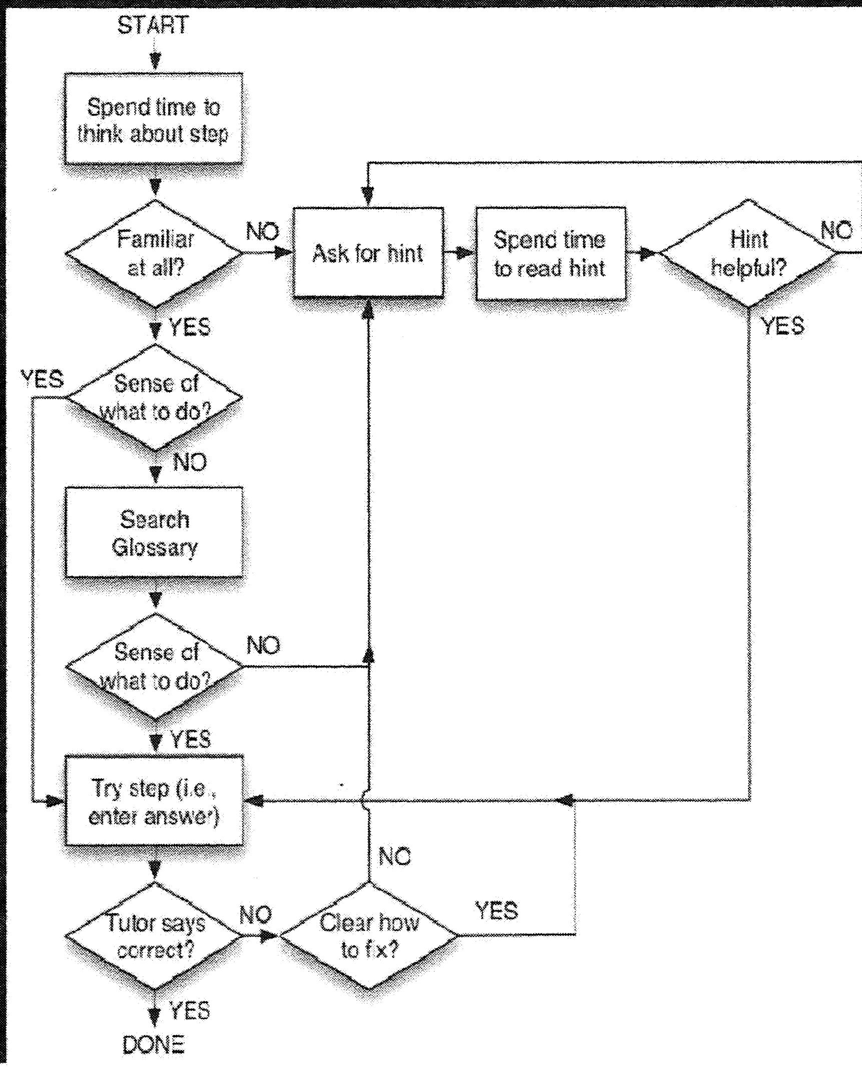
SimStudent Goals & Progress

- Improving tutor authoring
  - Works in multiple domains
    - Past: Multi-column addition & multiplication, Tic-Tac-Toe, fraction addition
    - Current: Equation solving, Stoichiometry
    - Future: Scientific reasoning
- Simulating human learning
  - Studies varying:
    - Alternative curriculum sequences
    - Human-like memory limitations
  - Surprising result: Hard-to-easy curriculum sequence better than easy-to-hard

Tutoring Help-Seeking

Roll, Aleven, McLaren, Ryu, Baker, & Koedinger, (2006). The help tutor: Does metacognitive feedback improve students' help-seeking actions, skills and learning? In *Proceedings of the 8th International Conference on Intelligent Tutoring Systems.*

A model good student help-seeking behavior

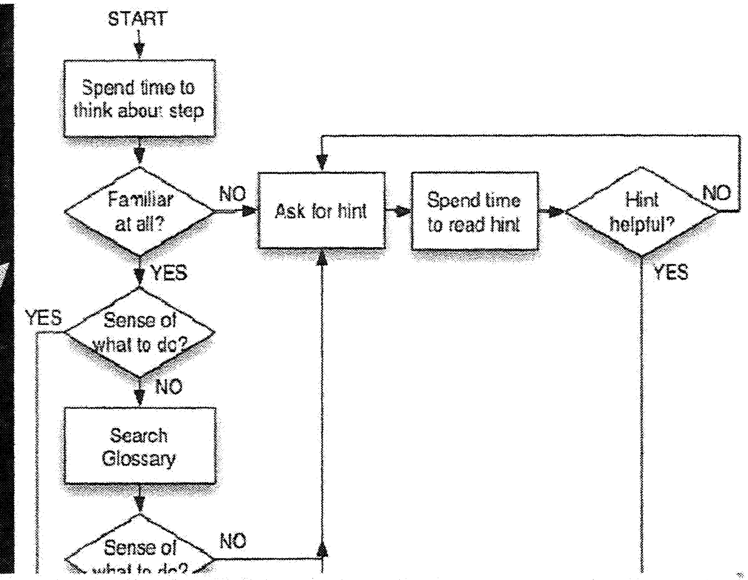


- Production system implementation
- About 50 rules

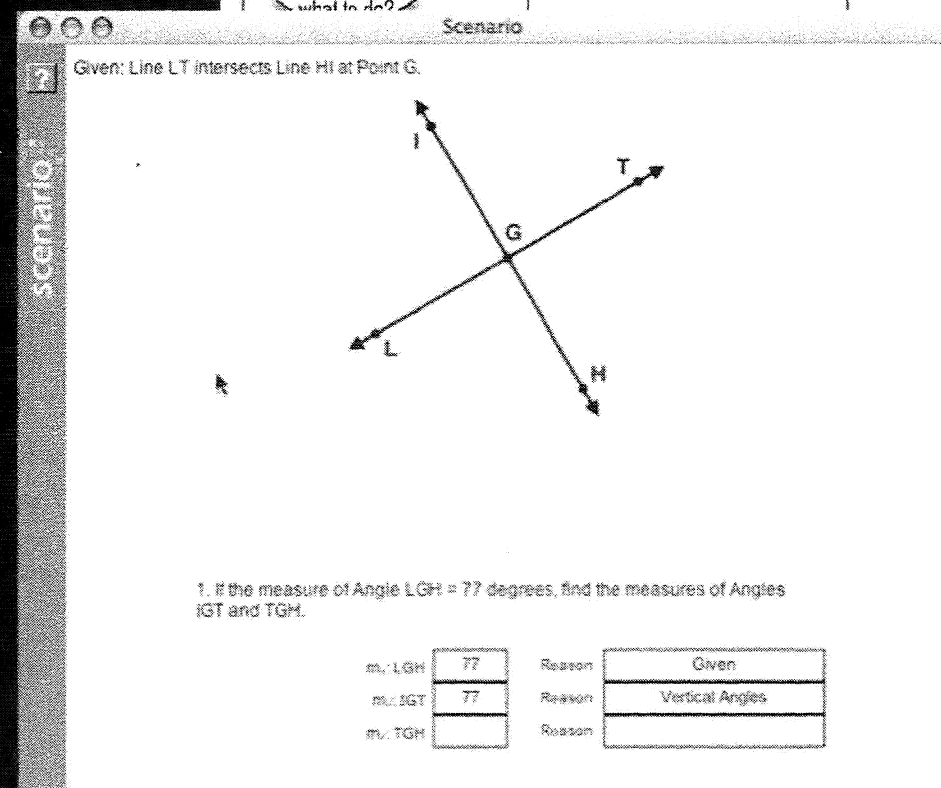
- Use same model tracing technique
- But at the "metacognitive" level
  - In addition to geometry tutor at cognitive level

Tutoring Help-Seeking

- Goal: Foster long-term *learner independence*
- Model of desired learning & help-seeking behaviors



- Provide tutoring relative to this model



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Another example of using ML

Adapting to When Students Game an Intelligent Tutoring System

Former Phd student Ryan Baker

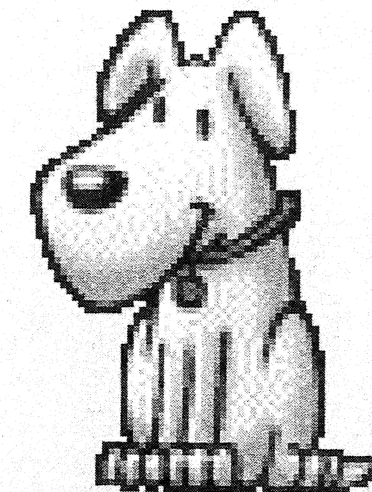
Gaming the System

"Attempting to get correct answers and advance in a curriculum by taking advantage of the software's help or feedback, rather than by actively thinking through the material"

For instance

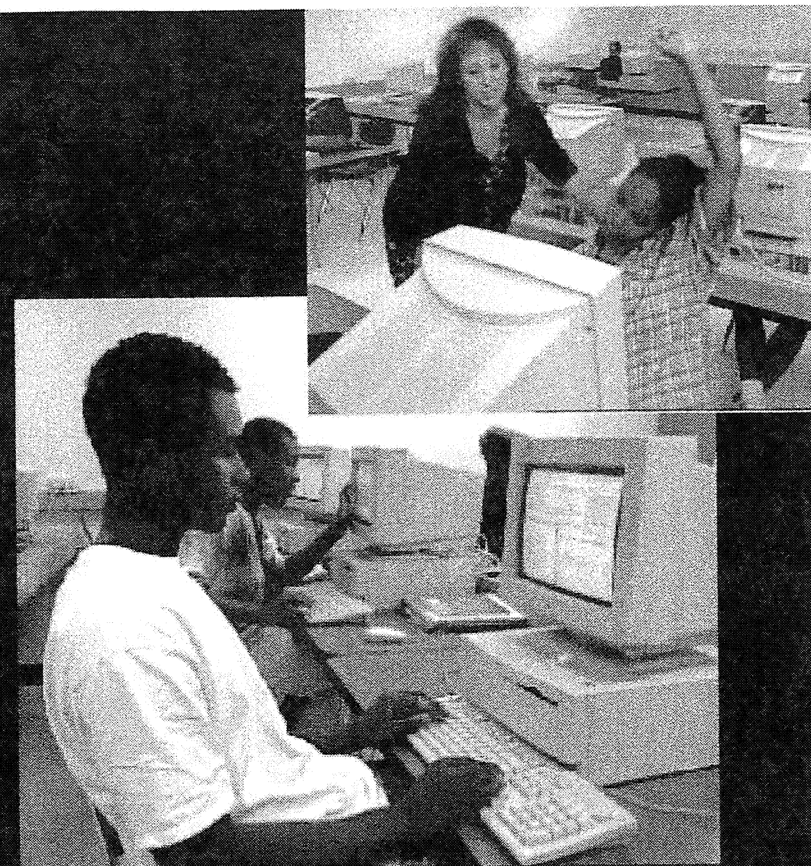
- Systematic Guessing
  (cf. Mostow et al 2002)
- Drilling through Hints
  (cf. Wood & Wood 2000, Aleven 2001)

"Scooter the Tutor"



- A tutor agent
- Uses a *machine learning "detector"* to recognize student gaming behavior
- Intended to reduce gaming & negative consequences for learning

Gaming detector construction



1. Collect data
   - Observe students in computer lab
     - Code off-task behaviors
   - Get tutor interaction log data from same sessions
2. Train a machine learning system using data
   - Techniques: Fast correlation-based filtering, forward selection on log data variables & interaction terms
   - Generalized & cross-validated across four tutor domains

scenario

Samantha is trying to find out what brand of dog food her dog Champ likes best. Each day she feeds him a different brand and sees how many bowls he eats. But then her mom says that maybe her dog just eats more on days when he exercises more.

Please draw a scatterplot to show how many bowls the dog eats, given the dog's level of exercise that day.

Problem SPLOT-DB-C-0-10-0-10

skills

- Understanding categorical variables
- Understanding numerical variables
- Determining whether a variable can be used in a bar graph
- Placing the independent variable on the X axis
- Placing the dependent variable on the Y axis
- Choosing the lower bound of an axis
- Finding the smallest value in a data set
- Finding the largest value in a data set
- Finding The range of a data set
- Choosing an appropriate scale
- Labeling the first value on the axis
- Labeling second value on the axis
- Labeling subsequent values on the axis
- Plotting the first point
- Plotting subsequent points

Worksheet

File Edit Tutor Windows Help

worksheet

Brand	Exercise (minutes)	Bowls
Bibbles and Kits	12	1
Barley's	25	0
Puppy Chew	28	3
Unleashed	5	0
Premium	18	1
Buster's	14	1
Delight	10	1
Tucker's Regular	38	3
Mad Dog	19	2
No Bones About It	27	2

Spreadsheet Calculation ON

Variable Type Tool

File Edit Tutor Windows Help

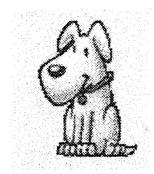
Brand

Exercise (minutes)

Bowls

Scooter the Tutor

File Edit Tutor Windows Help



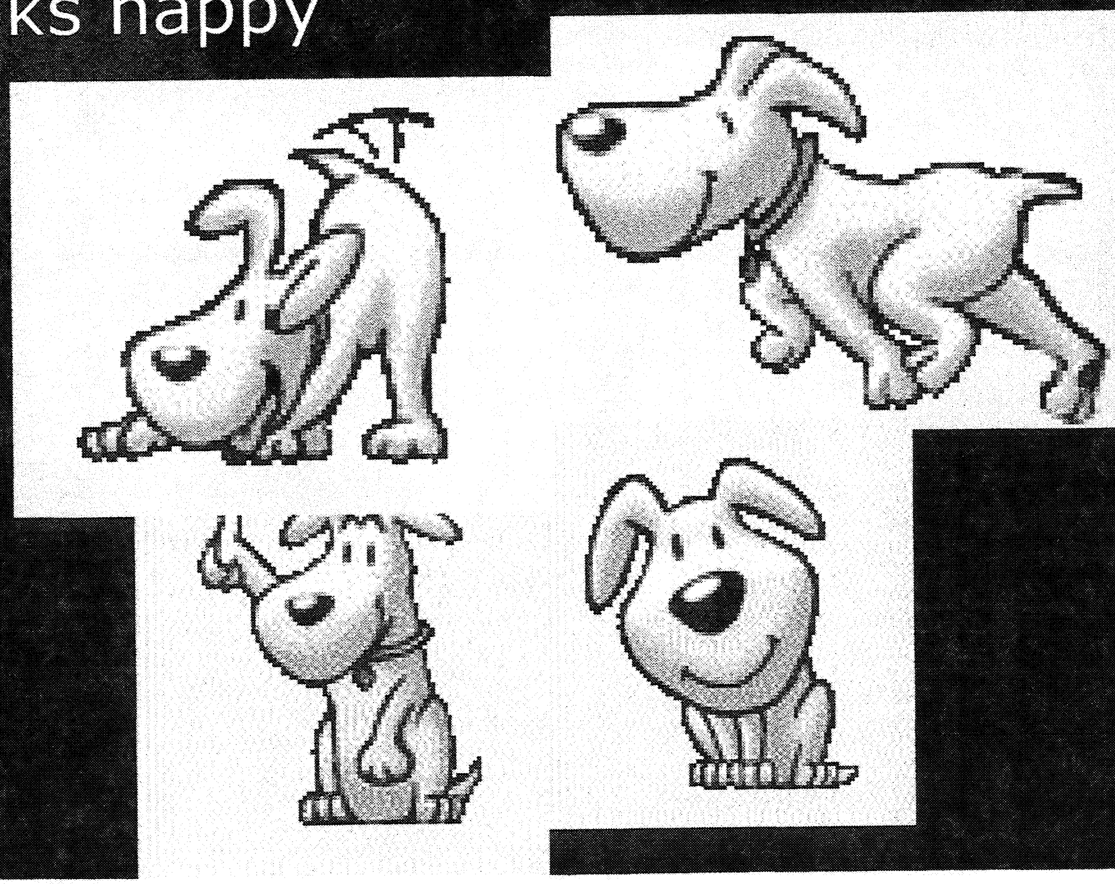
Hi! I'm Scooter the Tutor!
I'll try to help you learn how to learn!

During the Student's Tutor Use

- Scooter responds to gaming in two ways
  - Emotional expressions
  - Supplementary exercises

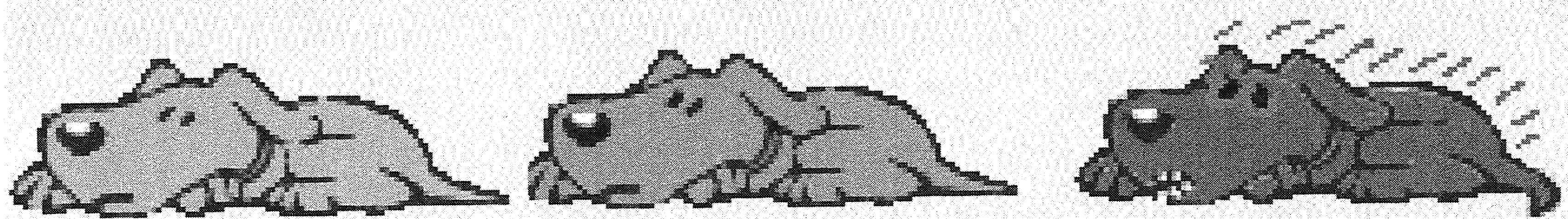
Emotional Expressions

- If the student never games, Scooter looks happy

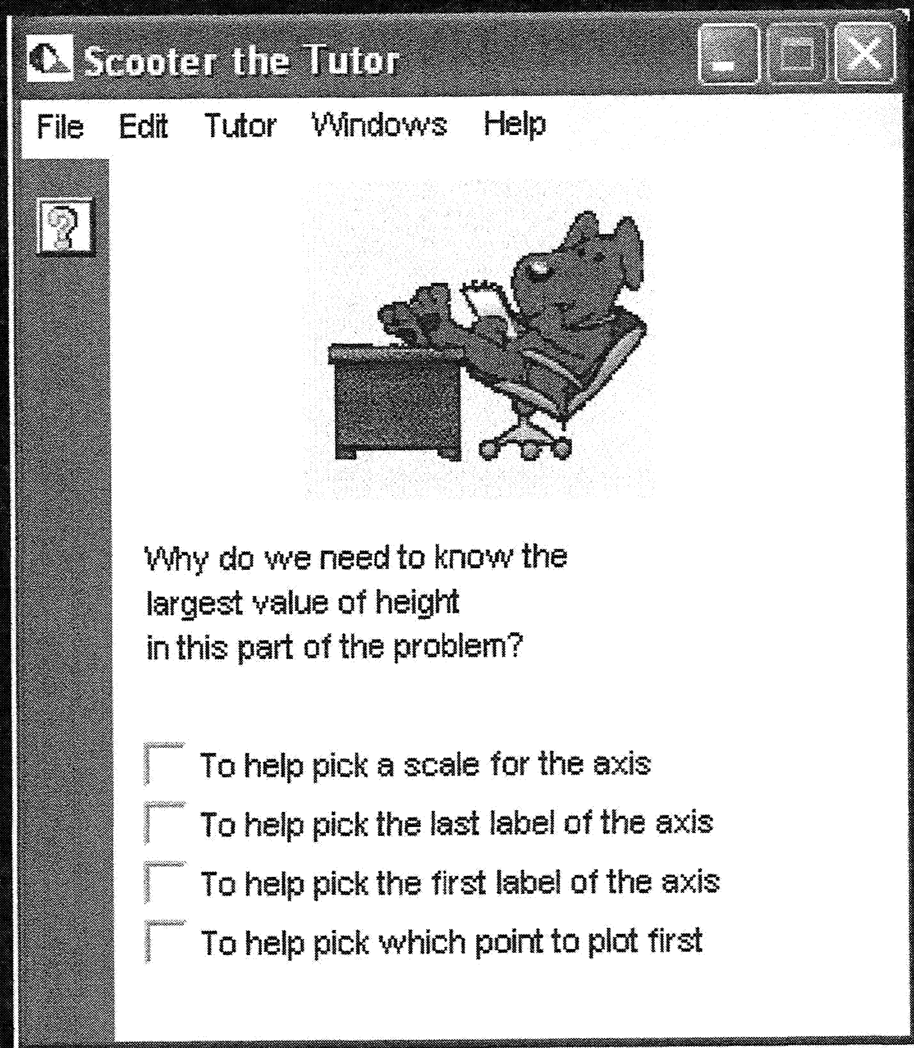


Emotional Expressions

- If the student appears to be gaming, Scooter looks increasingly displeased and becomes redder and redder



Supplementary exercises



- Multiple Levels
- If a student is wrong, receives another question

Scooter demo video ...

Scooter results

- Reduces gaming behavior
- Supplementary exercises increase learning
- Emotional responses do not

Baker et al. (2006).Adapting to When Students Game an Intelligent Tutoring System (*Best Paper at ITS06*)

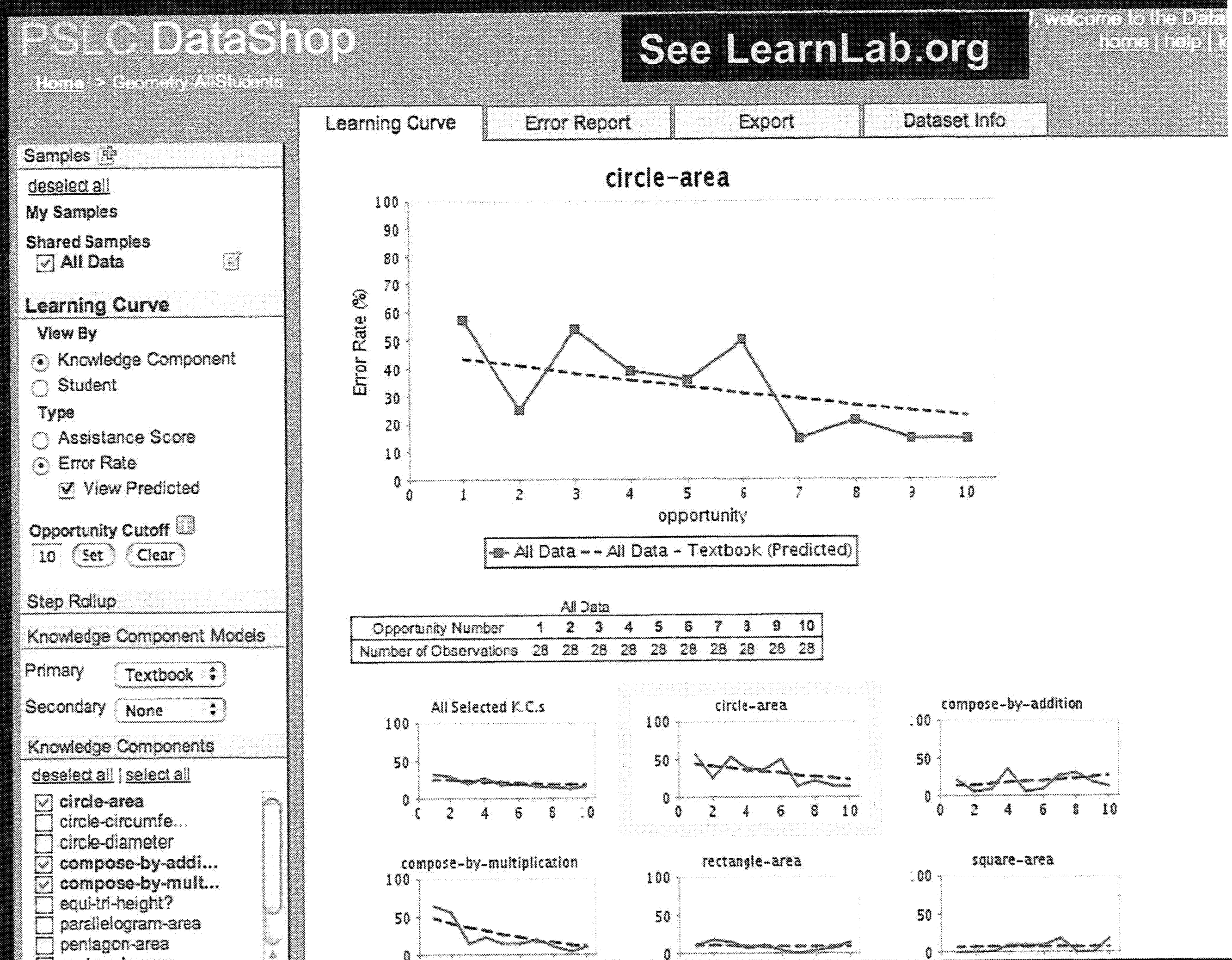
Two kinds of student modeling approaches

1. Rational approach
   - Analyze domain & code model that "makes sense"
   - Example: Help-seeking model
2. Empirical approach
   - Collect human data driven & use statistical machine learning to learn model
   - Example: Gaming detector

- Remember PSLC's resources
  - One is *DataShop*
  - It provides data needed for empirical approach

DataShop: Get data to build or test models of learning!

- Microgenetic log data of student learning over semester
- Data from math, science, language courses



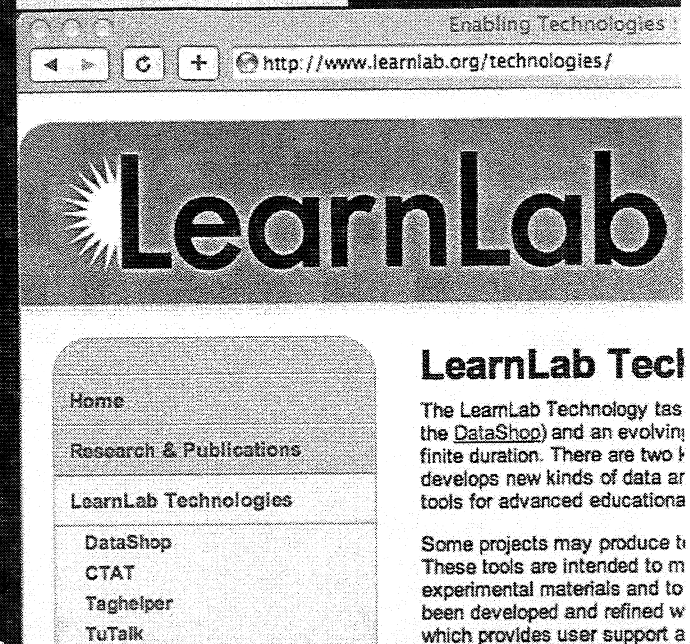
Conclusions

Summary

- Two educational uses of models & simulations
  1. Students create models & use simulations
  2. Researchers create models of learners to guide development of reliably effective materials
- Cognitive Tutors simulate & support tutoring
  - Data is crucial to create effective model
- Pittsburgh Science of Learning Center
  - Resources for modeling, authoring, experimentation
  - Repository of data & theory
- Examples of advanced modeling efforts
  - SimStudent learns rule-based model
  - Help-seeking model: Tutors metacognition
  - Scooter uses machine learning detectors of student engagement

Pittsburgh Science of Learning Center opportunities

LearnLab.org



- Propose a classroom study or attend summer school
- Analyze student data
  - TagHelper: Verbal data coding software
  - DataShop: Data sets, reporting & analysis tools
- Author a tutor or on-line activity
  - Cognitive Tutor Authoring Tutors
  - TuTalk: Authoring tutorial dialog
  - Open Learning Initiative
  - On-line assessments

ctat.pact.cs.cmu.edu

www.cmu.edu/oli

assistment.org