Cognitive Tutors
NAPLeS Webinar, Feb 2014

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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

MathTutor: free web-based tutors for middle-school math
with Bruce McLaren
http://mathtutor.web.cmu.edu

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

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
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

- Analyze real world problem scenarios
- Use graphs, graphics calculator
- Use table, spreadsheet
- Use equations, symbolic calculator
- Model tracing to provide context-sensitive Instruction
- Tracked by knowledge tracing
Cognitive Tutor Geometry

Given:

\[
\begin{align*}
\ell_2 & \parallel \ell_3 \\
\ell_2 & \parallel \ell_4 \\
m\angle GBW &= 117^\circ
\end{align*}
\]

Use the Diagram Tool to enter the measures and reasons to justify each step needed to calculate \( m\angle XBZ \).

○ The measure of \( \angle XBZ \) can be calculated.

\[
m\angle XBZ = \underline{117}^\circ
\]

○ The measure of \( \angle XBZ \) cannot be calculated because:

Diagram Notes:

\[
m\angle GEW \text{ is given; } m\angle GEW = 117^\circ
\]

\[
m\angle BGJ = 117^\circ, \quad \angle BGJ \text{ and } \angle GEW \text{ are corresponding angles.}
\]

\[
m\angle XBZ = 117^\circ.
\]
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

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

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

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

Software Tutors Offer Help and Customized Hints

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

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)
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

\[ 3(2x - 5) = 9 \]

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

\[ 6x - 15 = 9 \]

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

\[ 2x - 5 = 3 \]

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

\[ 6x - 5 = 9 \]

• Model Tracing: Follows student through their individual approach to a problem -> context-sensitive instruction
<table>
<thead>
<tr>
<th>SoCS2</th>
<th>animate one by one?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vincent Aleven; 17.12.2010</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>SoCS3</th>
<th>red for bug rule?</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
</tbody>
</table>
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 \(a\) across the parentheses.”

  Known? = 85% chance

  \[
  6x - 15 = 9 \quad 2x - 5 = 3 \quad 6x - 5 = 9
  \]

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

  Known? = 45%

- **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
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

• Feedback

• Bayesian Knowledge Tracing and Cognitive Mastery
Overview

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

Self-Regulated Learning: Great Theoretical Diversity

Azevedo’s (2005) Model of SRL in HLEs

Zimmerman’s (2000) Model of SRL

Pintrich’s (2004) SRL Model


Boekaerts’ (2000) Model of Adaptable Learning

Winne & Hadwin’s (1998) SRL Model
Background: Self-Regulated Learning

Monitoring and Control
- Self-Assessment
- Help Seeking
- Self-Explanation

Planning
- Goal Setting
- Study Choice

Evaluating
- Self-Explanation

- 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

Your younger cousin likes playing with blocks. One type of block is a right rectangular prism.

Answer each question using the given information.

1. In the prism, \( CD = 6.4 \) centimeters, \( AD = 6 \) centimeters, and \( DH = 12.5 \) centimeters. What is the volume of the block?

2. In the prism, \( CD = 4.9 \) centimeters, \( AD = 4.7 \) centimeters, and \( DH = 9.7 \) centimeters. What is the volume of the block?

Skillometer
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.

- Enter given prism height
- Enter given rectangular prism dimension of base
- Enter given triangular prism dimension of base
- Find area of base of rectangular prism
- Find area of base of triangular prism
- Find rectangular prism volume
- Find triangular prism volume
- Work with prism in context
- Work with prism out of context
- Work with rotated triangular prism
- Work with triangular prism in standard position
Skill Diary, Part 2

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

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

<table>
<thead>
<tr>
<th></th>
<th>Mean Test Scores (SD)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test Reproduction</td>
<td>Post-Test Reproduction</td>
<td>Pre-Test Transfer</td>
</tr>
<tr>
<td>Exp. Group</td>
<td>0.55 (.34)</td>
<td>0.62 (.29)</td>
<td>0.50 (.28)</td>
</tr>
<tr>
<td>Ctrl. Group</td>
<td>0.46 (.44)</td>
<td>0.49 (.33)</td>
<td>0.46 (.22)</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th></th>
<th>Test Scores on Reproduction Problems (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Test</td>
</tr>
<tr>
<td></td>
<td>Exp</td>
</tr>
<tr>
<td>Lower-Performing</td>
<td>0.35 (.45)</td>
</tr>
<tr>
<td>Group</td>
<td></td>
</tr>
<tr>
<td>Higher-Performing</td>
<td>0.74 (.41)</td>
</tr>
<tr>
<td>Group</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-Test</td>
</tr>
<tr>
<td></td>
<td>Exp</td>
</tr>
<tr>
<td>Lower-Performing</td>
<td>0.53 (.47)</td>
</tr>
<tr>
<td>Group</td>
<td></td>
</tr>
<tr>
<td>Higher-Performing</td>
<td>0.71 (.38)</td>
</tr>
<tr>
<td>Group</td>
<td></td>
</tr>
</tbody>
</table>

\( F(1, 44) = 4.586, p = .038, \eta^2 = .094; \) 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.)

<table>
<thead>
<tr>
<th>Not Confident</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Very Confident</th>
<th>7</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Pre-Test</th>
<th>Post-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Hints</strong></td>
<td>-.56**</td>
<td>-.47**</td>
</tr>
<tr>
<td><strong>Time Spent on Each Hint</strong></td>
<td>.20</td>
<td>.34**</td>
</tr>
<tr>
<td><strong>Number of Incorrect Attempts</strong></td>
<td>-.35**</td>
<td>-.32**</td>
</tr>
<tr>
<td><strong>Assistance Score</strong></td>
<td>-.52**</td>
<td>-.47**</td>
</tr>
<tr>
<td><strong>Time Spent on Each Step</strong></td>
<td>-.19</td>
<td>-.20</td>
</tr>
</tbody>
</table>

* $p < .05$

** $p < .01$
## Process Measures

<table>
<thead>
<tr>
<th></th>
<th>Correlations</th>
<th>Condition Differences</th>
</tr>
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<tr>
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</table>

* \( p < .05 \)

** \( p < .01 \)
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

A typical self-explanation scenario

1. Figure 5.6b 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. $F_x$, $F_y$, and $F_z$ are all forces acting on the body.
7. Since the body is unaccelerated, $F_x + F_y + F_z = 0$.
8. Choosing the $x$- and $y$-axes as shown, we can write this vector equation as three scalar equations:
   9. $F_{Ax} = F_{Bx} = F_{Cx} = 0$.
10. $F_{Ay} + F_{By} + F_{Cy} = 0$.
11. Using Eq. 5-2, the third scalar equation for the $z$-axis is simply $F_{Az} = F_{Bz} = F_{Cz} = 0$.
12. Thus, the vectors all lie in the $x$-$y$ plane so that they have no $z$-components.
13. From the figure we see that $F_{Ax} = -F_A \cos 30^\circ = -0.666F_A$.
14. $F_{Ay} = F_A \sin 30^\circ = 0.500F_A$.
15. and $F_{Ay} = F_A \cos 45^\circ = 0.707F_A$.
16. $F_{Ay} = F_A \sin 45^\circ = 0.707F_A$.

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.

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
stuff like number of subjects?
length of time
done in a school
etc

--> realism!
Explanation Condition
(Experimental condition)

Problem solving answers

Explanation by menu
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”.

NAPLeS, Feb 2014
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.”

   $m\angle FRI: \text{No} \quad \text{Reason: need to know } \angle RFE$
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.”

   $m \angle FRI: 125^\circ$  
   Reason: Supplementary
Results

Can we make real error bars?
Vincent Aleven; 17.09.2011
Objectives in Supporting Metacognition

- 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

Take the top of the pyramid?
Vincent Aleven; 17.12.2010

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

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)


CTAT: Cognitive Tutor Authoring Tools

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

- **Chemistry**
  - Stoichiometry Tutor

- **Genetics**
  - In S. cerevisiae, which produces unordered tetrads, the following tetrad types were observed from this cross: trp5 ccd4. Type 1: t trp5. Type 2: t c ccd4. Type 3: t trp5 c ccd4. Type 4: t c ccd4.

- **French**
  - Bonjour

LearnLab, Pittsburg Science of Learning Center
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

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

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

CTAT Tutors in Research
Strategy use in linear equation solving

Log data: Students seldom use non-standard strategies

\[
\begin{align*}
2(x+1) & = 4 \\
2x + 2 & = 4 \quad \text{distribute} \\
2x & = 2 \quad \text{move} \\
x & = 1 \quad \text{divide}
\end{align*}
\]

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

**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**

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CTAT tutors interleaved with Carnegie Learning Cognitive 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
THE END