Bringing Cognitive Psychology to Schools Through Technology

- **Abstract:** Cognitive Tutor software combines Psychology and Artificial Intelligence to advance learning theory and improve student achievement across the country. Extending this approach, the Pittsburgh Science of Learning Center is providing an infrastructure to support researchers in more easily creating, running, and analyzing microgenetic data from controlled experiments in classrooms.

- **Bio:** Ken Koedinger is a professor of Human-Computer Interaction and Psychology at Carnegie Mellon. He is co-founder of Carnegie Learning, a company developing and distributing science and technology based courses to more than 2000 schools. He is also a director of the Pittsburgh Science of Learning Center, a $25 million NSF funded center that is advancing a practical theory of “robust learning”. At LearnLab.org researchers will find a technical and social infrastructure that can support them in creating, running, and mining data from classroom experiments with real students and content.
Bringing Cognitive Psychology to Schools Through Technology

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Real World Impact of Learning Science & Technology

Cognitive Tutor Algebra

- Based on computational models of student thinking & learning
- Full course used in over 2000 schools!

Spin-off: Carnegie Learning

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?

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

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

Equation
\[ x \times 6 + 66 = 81.90 \]
Algebra Student Results: Story Problems are Easier!

An experimental aircraft has sunk off the coast of South Africa at a depth of 12,760 feet. The military have located the aircraft and are in the process of raising it to the surface. It is currently 7825 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.

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
Field studies show better student learning

- 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.

- Many other studies ...

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
In vivo studies
• Part of real class
• Chapter length

• Control: As-is instruction
• Treatment: Change in teaching practices, materials, and/or technology

Web site: LearnLab.org
Robust Learning Principles

"Toothbrush" Theories

Studies

LearnLab Courses

Enabling Technology

PSLC’s Interlocking Research & Development Activities

- Courses open for studies
  - Math: Algebra, Geometry
  - Science: Physics, Chemistry
  - Language: French, Chinese, English

- Agreements with 10+ high schools & colleges

- Open to all researchers
  - Like a particle accelerator or research hospital

Web site: LearnLab.org
LearnLab: Have us test your learning principle in real classrooms!

- Technology-enhanced, highly “instrumented” courses
- Tutors, simulations, video, chat rooms, peer collaboration, reading, lecture ...

French Culture Tutor

- A 2000-kg car in neutral at the top of a driveway 20.0 m long slips its parking brake and rolls down. Assume that the driveway is frictionless.

What is the magnitude of the velocity of the car when it hits the garage door?

Answer: ___________

Physics intelligent tutor

Chemistry virtual lab

Algebra Cognitive Tutor lab
PSLC’s Interlocking Research & Development Activities

Theoretical Framework
- Common concepts & terms
- Mechanisms for sharing
- Live *wiki* -- researchers are authoring framework & connections to their studies
Toward a theoretical framework for robust learning

Get beyond:

• Education: Grand debates & false dichotomies
  – Direct instruction vs. constructivism
  – Individual vs. social learning
  – Skills vs. understanding

• Psychology of learning:
  – Everyone’s own “toothbrush theory”
  – Knowledge-lean studies & theories

Instead:

• Experimental basis for resolving debates
• Develop a shared vocabulary, knowledge-rich studies & theories
## PSLC is supporting many *in vivo* studies

Different domains, experimental treatments, analyses, measures

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### Key

**Macro:** Treatment Variables
- **Micro:** Analysis
- **Learning:** Measures

- **V&M** = Visualization & multi-media sources
- **E&E** = Examples & explanations
- **v** = varied between control and treatment conditions
- **=** = project includes measure
- **b** = present in both control and treatment conditions
- **+=** = project includes measure and innovative research on measure

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**PSLC** is supporting many *in vivo* studies. Different domains, experimental treatments, analyses, measures.
Shallow learning problem ...

Shallow inference in action:
If angles look equal, then they are equal.

3. Segment EB is perpendicular to Line AS. If the measure of Angle 1 is 59° and the measure of Angle 2 is 22°, find the measure of Angle 4.

\[ \text{m}/3: \quad 40° \quad \text{Reason: supplementary} \]
\[ \text{m}/4: \quad 59° \quad \text{Reason: supplementary} \]
How to get more robust learning?

- Can instruction produce effective interactions between declarative & procedural learning systems?
- Hypothesis:
  - Interleaved example study with problem solving practice yields more efficient & more robust learning
- Theoretical explanation:
  - Problem solving alone leads to shallow encoding & less robust learning
    - But breaks illusion of knowing
    - When examples are interleaved, motivates attentive example study
  - *Attentive* example study better engages declarative learning than does problem solving
    - More focus on discriminating relevant features
Problem Statement
Suppose you are an engineer responsible for a water supply which has become contaminated with alcohol (COH4). To determine the extent of the contamination, you need to determine the number of moles of alcohol / kg of H2O in a solution of 6.00 grams COH4 in 100.0g of H2O. Your result should have 3 significant figures. (Here is a hint to help you: the molecular weight of COH4 is 32.04 g COH4 / mol of COH4).
Prompted self-explanation following worked example in studies 2 & 3
In Vivo Study Characteristics

- Study 1
  - In Chemistry course at University of British Columbia
  - 60+ college students randomly assigned

- Studies 2 & 3
  - In Chemistry course at New Jersey High School
  - 60+ high school students
  - Self-explanation of worked examples added
Significant Learning Efficiency Gains

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<td>73 min (20)</td>
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- Worked examples group spent *significantly* less time
- Learned just as much -- no difference on post test
- Practical significance: *Problem-solving group took 15% to 50% longer!*
## Linking studies & framework

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- : Project includes measure and innovative research on measure
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Example condition 1

Wenn die Größe des Kreisbogens $BD$ gleich $34^\circ$ ist, gilt:

- $34^\circ + 326^\circ = 360^\circ$
- $360^\circ - 34^\circ = 326^\circ$
- Grund = $326^\circ$
Example condition 2

Gegeben: Kreis M, der Kreisbogenabschnitt ECA sowie die Winkelausschnitte 120.2° und 280.2°.

Ist die Winkelgröße des Kreisbogens ECA gleich 280.2°, die Größe des Kreisbogens ATC gleich 50°, wie groß ist dann der Winkel des Kreisbogens AC?

\[ \text{Winkel AC} = 50° \text{ Grund: Großer und kleiner Kreisbogen} \]

\[ \text{Kreisbogen AC} = 120.2° - (50° \cdot 2) \]

\[ \text{Kreisbogen AC} = 20.2° \text{ Grund: Großer und kleiner Kreisbogen} \]

**Glossar**

**Großer und kleiner Kreisbogen**

*Definition:*
Wenn man einen Kreis in zwei unterschiedlich große Kreisbögen teilt, dann ist die Summe der Winkelauschnitte dieser beiden Kreisbögen 360°. Der größere Kreisbogen wird dabei als großer Kreisbogen bezeichnet. Der kleinere Kreisbogen wird als kleiner Kreisbogen bezeichnet.

*Beispiel:*
Der Kreis M wird in die beiden Kreisbögen ABC und AC geteilt.

Der größere Kreisbogen ABC wird großer Kreisbogen genannt. Der kleinere Kreisbogen AC wird kleiner Kreisbogen genannt.
Problem condition
Experiment II: Learning time

$d = 1.17^*$
Experiment II: Learning outcomes

Percentage correct

Pretest  Conceptual knowledge  Transfer

d = .73 *
Think-aloud data during instruction

• Example group: More statements about "why"
  – This is a major and minor arc, this means the sum of both is 360 degrees
  – Angle ETF .... is an exterior angle of this circle
=> more declarative principle learning

• Problem group: More self-explanations about "how"
  – one can compute the measure of arc EF by subtracting 33.3 from 360
  – to compute angle ASC you have to re-arrange the equation
  – and then I can compute angle ETF by applying the exterior angle principle
=> more procedural learning
Many other PSLC studies in other domains ...

Just a few more examples

- **Physics**
  - Providing explanations does not increase robust learning
  - Prompting students to provide explanations does

- **English as 2nd language**
  - Giving students texts they are interested improves learning of vocabulary by example

- **Chinese**
  - Students can learn *without feedback* when given two input sources (audio & visual) but not when given just one
Summary

• Educational theory should be research-based, as medical theory is
  - Need to test educational practices to determine when they work & when they don’t
  - Need to connect to psychology theories of cognition, motivation, social interaction

• Pittsburgh Science of Learning Center:
  - Focusing on robust learning, on test results that matter
  - Replicable, practice-oriented theory
  - LearnLab facility to help bridge lab-to-field gap
    • Principle-testing, controlled studies as part of real courses

Web site: LearnLab.org