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Cognitive Principles in Tutor & e-Learning Design

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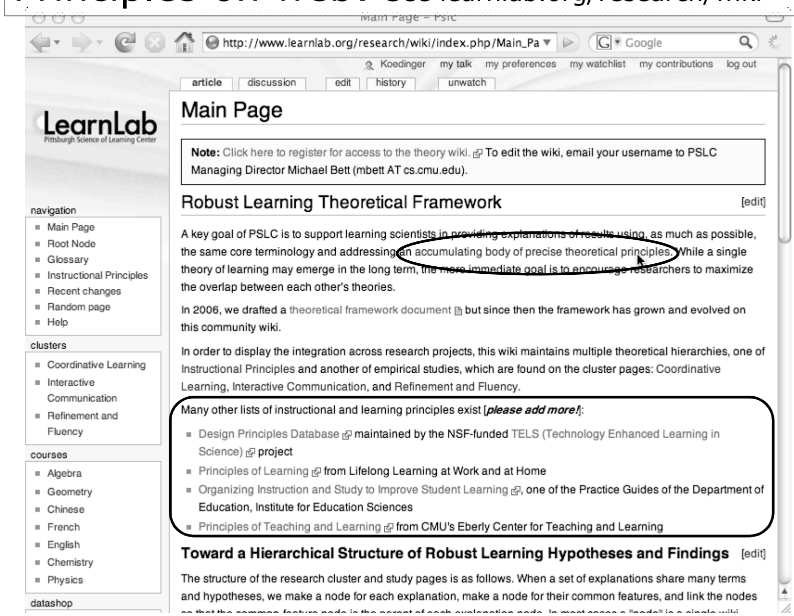
Lots of Lists of Principles 1

- Cognitive Tutor Principles
  - Koedinger, K. R. & Corbett, A. T. (2006). Cognitive Tutors: Technology bringing learning science to the classroom. *Handbook of the Learning Sciences*.
  - Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *The Journal of the Learning Sciences*, 4 (2), 167-207.
- Multimedia & eLearning Principles
  - Mayer, R. E. (2001). *Multimedia Learning*. Cambridge University Press.
  - Clark, R. C., & Mayer, R. E. (2003). *e-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning.* San Francisco: Jossey-Bass.
- How People Learn Principles
  - Donovan, M. S., Bransford, J. D., & Pellegrino, J.W. (1999). *How people learn: Bridging research and practice.* Washington, D.C.: National Academy Press.
- Progressive Abstraction or "Bridging" Principles
  - Koedinger, K. R. (2002). Toward evidence for instructional design principles: Examples from Cognitive Tutor Math 6. Invited paper in *Proceedings of PME-NA*.
- Other lists on the web …
  - See learnlab.org/research/wiki

Principles on web: See learnlab.org/research/wiki



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Overview

- Cognitive Tutor Principles
- Multimedia Principles
  - Theoretical & Experimental evidence
- Building on prior knowledge
  - Need empirical methods to apply
- Summary

Cognitive Tutor Principles

1. Represent student competence as a production set
2. Provide instruction in the problem-solving context
3. Communicate the goal structure underlying the problem solving
4. Promote an abstract understanding of the problem-solving knowledge
5. Minimize working memory load
6. Provide immediate feedback on errors

1. Represent student competence as a production set

- Accurate model of target skill to:
  - Inform design of
    - Curriculum scope & sequence, interface, error feedback & hints, problem selection & promotion
  - Interpret student actions in tutor

- Knowledge decomposition!
  - Identify the components of learning

6. Provide immediate feedback on errors

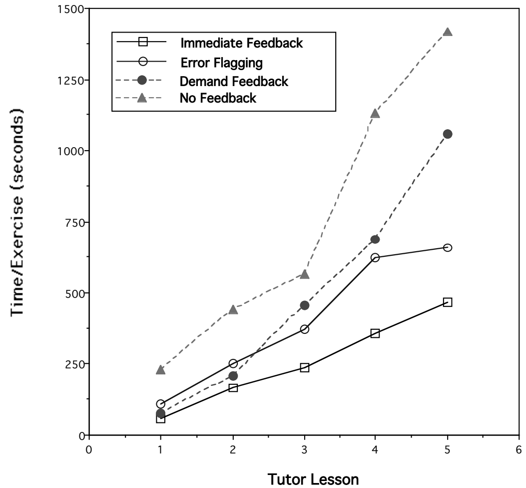
- Productions are learned from the examples that are the product of problem solving

- Benefits:
  - Cuts down time students spend in error states
  - Eases interpretation of student problem solving steps

- Evidence: LISP Tutor

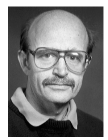
- *Smart* delayed feedback can be helpful
  - Excel Tutor

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



Time to Complete Programming Problems in LISP Tutor

Immediate Feedback Vs Student-Controlled Feedback



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Tutoring Self-Correction of Errors

- Recast delayed vs. immediate feedback debate as contrasting "*model of desired performance*"

- Expert Model
  - Goal: students should not make errors
- Intelligent Novice Model
  - Goal: students can make some errors, but recognize them & take action to self-correct

- *Both* provide *immediate feedback*
  - Relative to different models of desired performance

Mathan, S. & Koedinger, K. R. (2003). Recasting the feedback debate: Benefits of tutoring error detection and correction skills. In Hoppe, Verdejo, & Kay (Eds.), *Proceedings of Artificial Intelligence in Education* (pp. 13-18). Amsterdam, IOS Press. [Best Student Paper.]

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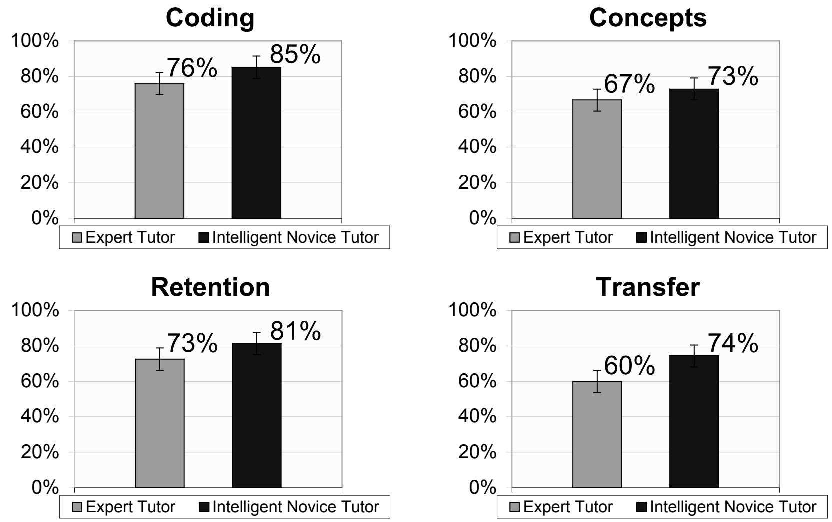
Intelligent Novice Condition Learns More



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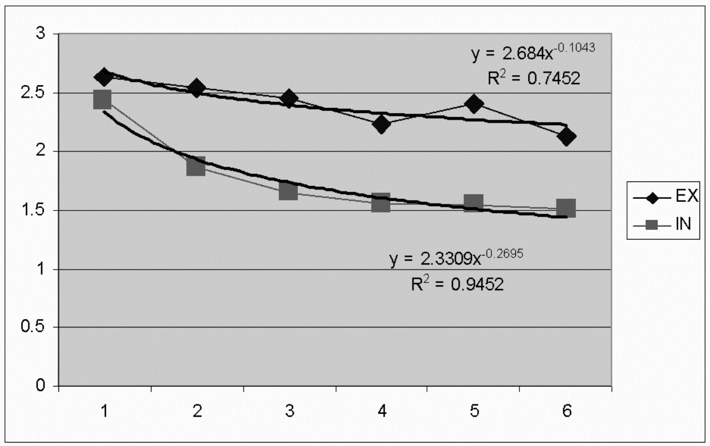
Learning Curves: Difference Between Conditions Emerges Early

- Number of attempts at a step
  by opportunities to apply a production rule



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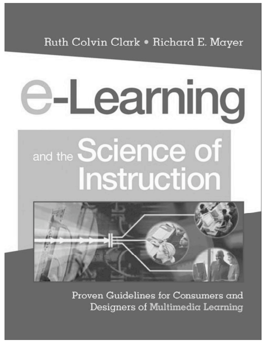
Overview

- Cognitive Tutor Principles
- Multimedia Principles
  - Theoretical & Experimental evidence
- Instructional Bridging Principles
  - Need empirical methods to apply
- PSLC Principles

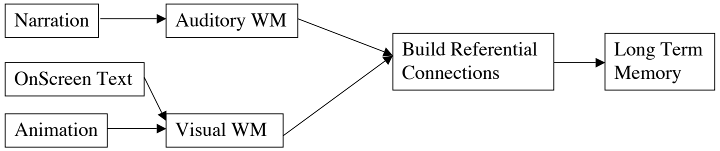
Media Element Principles of E-Learning

1. Multimedia
2. Contiguity
3. Coherence
4. Modality
5. Redundancy
6. Personalization



Cognitive Processing of Instructional Materials

- Instructional material is:
  - Processed by our eyes or ears
  - Stored in corresponding working memory (WM)
- Must be integrated to develop an understanding
- Stored in long term memory



Multimedia Principle

Which is better for student learning?

A. Learning from words and pictures

B. Learning from words alone

Example: Description of how lightning works with or without a graphic

A. Words & pictures

Why?

Students can mentally build both a verbal & pictorial model & then make connections between them

Coherence Principle

Which is better for student learning?

A. When extraneous, entertaining material is included

B. When extraneous, entertaining material is excluded

Example: Including a picture of an airplane being struck by lightning

B. Excluded

Why?

Extraneous material competes for cognitive resources in working memory and diverts attention from the important material

Modality Principle

Which is better for student learning?

A. Spoken narration & animation

B. On-screen text & animation

Example: Verbal description of lightning process is presented either in audio or text

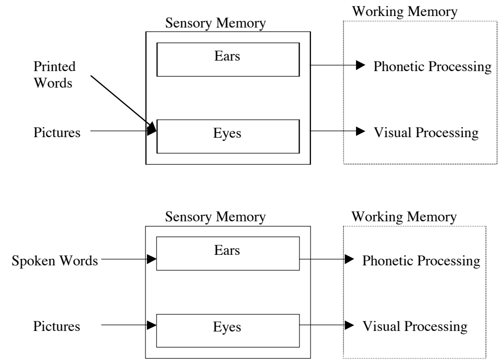
A. Spoken narration & animation

Why?

Presenting text & animation at the same time can overload visual working memory & leaves auditory working memory unused.

Working Memory Explanation of Modality

- When visual information is being explained, better to present words as audio narration than onscreen text



Summary of Media Element Principles of E-Learning

1. Multimedia: Present both words & pictures
2. Contiguity: Present words within picture near relevant objects
3. Coherence: Exclude extraneous material
4. Modality: Use spoken narration rather than written text along with pictures
5. Redundancy: Do not include text & spoken narration along with pictures
6. Personalization: Use a conversational rather than a formal style of instruction

Scientific Evidence (mostly lab) that Principles Work

Summary of Research Results from the Six Media Elements Principles. (From Mayer, 2001)

Principle	Percent Gain	Effect Size	Number of Tests
Multimedia	89	1.50	9 of 9
Contiguity	68	1.20	5 of 5
Coherence	82	1.17	10 of 11
Modality	80	1.17	4 of 4
Redundancy	79	1.24	2 of 2
Personalization	67	1.24	5 of 5

Applying principles depends on a quality domain analysis

- Example: See Davenport pages on PSLC wiki
- Three studies indicate dependency
  - Applied multimedia principle in College Chemistry course -- added diagrams to existing text
    - No impact on learning!
  - Did cognitive task analysis of domain & redesigned course materials
    - Big impact on learning!
  - Reapplied multimedia principle with new materials -- added diagrams to modified text
    - New principle worked: Big impact on learning

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How People Learn Principles

How People Learn book

1. Build on prior knowledge
2. Connect facts & procedures with concepts
3. Support meta-cognition

Bransford, Brown, & Cocking (1999). *How people learn: Brain, mind, experience and school*. D.C.: National Academy Press.

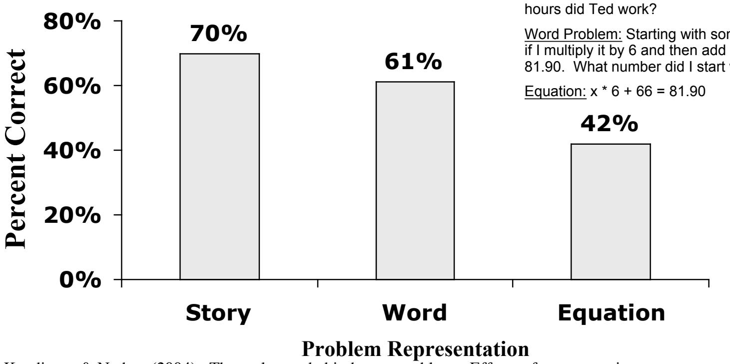
But:
What prior knowledge do students have?
How can instruction best build on this knowledge?

Algebra Student Results: Story Problems are Easier!

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 * 6 + 66 = 81.90



Koedinger & Nathan (2004). The real story behind story problems: Effects of representations on quantitative reasoning. In *International Journal of the Learning Sciences*.

What do these results imply for instruction?

- Focus instruction on story problems
- Focus instruction on equations
- Start with story then go to equations
- There are no direct implications
- Other?

Instructional Bridging Principles

1. *Situation-Abstraction*
   Concrete situational <-> abstract symbolic reps
2. *Action-Generalization*
   Doing with instances <-> explaining with generalizations
3. *Visual-Verbal*
   Visual/pictorial <-> verbal/symbolic reps
4. *Conceptual-Procedural*
   Conceptual <-> procedural

Koedinger, K. R. (2002). Toward evidence for instructional design principles: Examples from Cognitive Tutor Math 6. Invited paper in *Proceedings of PME-NA*.

Recent results suggest going abstract yields better transfer

Kaminski, Sloutsky, & Heckler (2008). The advantage of learning abstract examples in learning math. *Science*.

- Idea: Abstractions help students develop deeper encodings that better transfer
- Are abstractions always better? Is there are role for concrete examples?

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Assistance Dilemma

- How to optimize learning outcomes?
  - Can there be too little instructional assistance (i.e., too hard for students)?
  - Can there be too much assistance (i.e., too easy)?
- Yes to both, yields inverted U function

Koedinger. & Aleven (2007). Exploring the assistance dilemma in experiments with Cognitive Tutors. *Educational Psychology Review*.

Koedinger, Pavlik, McLaren, & Aleven (2008). Is it better to give than to receive? The assistance dilemma as a fundamental unsolved problem in the cognitive science of learning and instruction. *Proceedings of Cognitive Science*.

- Open questions:
  - What is the shape of this function?
  - What parameters & conditions drive it?

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General form of "assistance formula"

- If `P` = probability of success *during* instruction then:

  `Robust Learning Efficiency gain =`

  $$\frac{P * SuccessBenefit + (1-P)*FailureBenefit}{P * SuccessCost + (1-P)*FailureCost}$$

  `P, SuccessBenefit`, ... depend on level of assistance

- Assumptions that yield inverted U
  - Higher the assistance
    - => *higher* chance of success (`P`)
    - => *lower* benefit of succeeding (`SuccessBenefit`)
  - `SuccessBenefit > FailureBenefit`
  - `SuccessCost <= FailureCost`

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Bridge from concrete to abstract

- Combining abstract text & diagrams (concrete) enhances transfer (Mayer, 2002)
  - Non-dependent info from alternative sources reduces ambiguity in constructing concepts
  - Like co-training theory (Blum & Mitchell, 1998)
- Progressive formalization/concreteness fading (Goldstone & Son, 2005; Kotovsky & Gentner, 1996; Nathan, 1998)
  - Gradually shift from concrete to abstract
  - Goldstone: "Initial concrete grounding facilitates interpretation of model elements"
  - Subsequent abstraction helps stress deep features

"Bridging assumption": Partially correct concept created from concrete instruction reduces credit assignment ambiguity in processing abstract instruction

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Applying assistance formula to concrete-abstract dimension

- Success *during* instruction is higher for concrete (Pc > Pa)
  - Success means understanding instruction or getting practice exercises correct
- If success, *robust learning* is higher for abstract (SBa > SBc)
  - Abstract encoding is more general
- Often, robust learning is better for abstract (Pa*SBa > Pc*SBc)
- How about concreteness fading?
  - Is concrete to abstract: Pc*SBc + (Pa+(1-Pa)B)*SBa
    better than 2 abstract: 2*Pa*SBa

Depends on bridging assumption!

Study 1: Bridge from concrete to abstract

Koedinger, K. R., & Anderson, J. A. (1997). Illustrating principled design: The early evolution of a cognitive tutor for algebra symbolization. *Interactive Learning Environments*.

Inductive Support idea

Use activities that bridge from *existing concrete* modes of thinking to *more sophisticated abstract* modes of thinking

Test in domain of “algebra symbolization”

Forester Textbook Problem

Drane & Route Plumbing Co. charges $42 per hour plus $35 for the service call.

1. Create a variable for the number of hours the company works. Then, write an expression for the number of dollars you must pay them. ⇨ Symbolize

2. How much you would pay for a 3 hour service call?

3. What will the bill be for 4.5 hours? ⇨ Arithmetic (find y)

4. Find the number of hours worked when you know the bill came out to $140. ⇨ "Algebra" (find x)

Inductive Support Version

Drane & Route Plumbing Co. charges $42 per hour plus $35 for the service call.

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4. Find the number of hours worked when you know the bill came out to $140. ⇨ "Algebra" (find x)

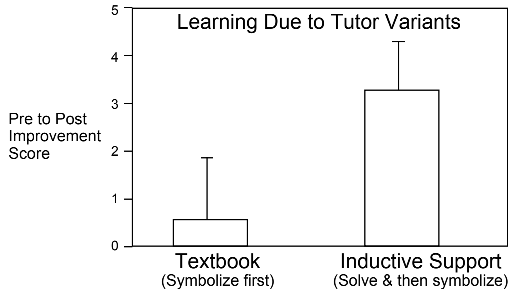
Unpacking *bridging assumption* in algebra symbolization domain

Story: "... charges $42 per hour plus $35 for the service call"

42x+35

- Story -> algebra symbols
  - Requires A) english comprehension, B) combining operations, C) producing symbols
  - Learning all 3 at once: big credit assignment challenge
- Concrete solution requires only A & B
- Hardest is learning C (Heffernan & Koedinger, 1998)
  - Shallow algebra "grammar" knowledge can produce simple expressions, 3*42, 126+35, but not 3*42+35
- Concrete first means C is isolated in abstract phase, credit assignment is much easier

Inductive support (C->A) yields greater learning gains



Textbook (Symbolize first)	Inductive Support (Solve & then symbolize)
1. 35 + 42h = d	1. 35 + 42*3 = d
2. 35 + 42*3 = d	2. 35 + 42*4.5 = d
3. 35 + 42*4.5 = d	3. 35 + 42h = d
4. 35 + 42h = 140	4. 35 + 42h = 140

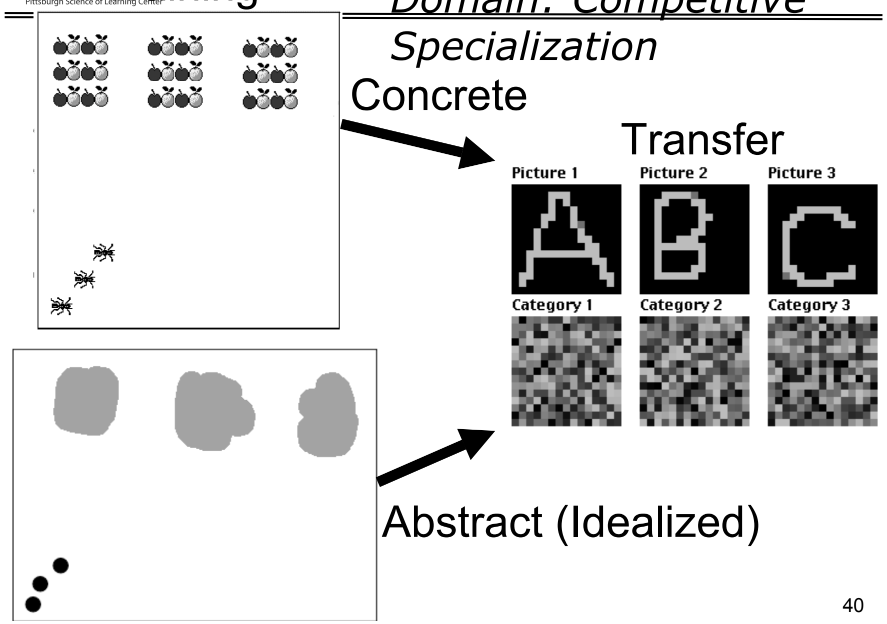
Koedinger, K. R., & Anderson, J. R. (1997). Illustrating principled design: The early evolution of a cognitive tutor for algebra symbolization. *Interactive Learning Environments.*

Study 2: Bridge from concrete to abstract

Goldstone, R. L., & Son, J. Y. (2005).
The transfer of scientific principles using concrete and idealized simulations.
The Journal of the Learning Sciences.

Training

Domain: Competitive Specialization



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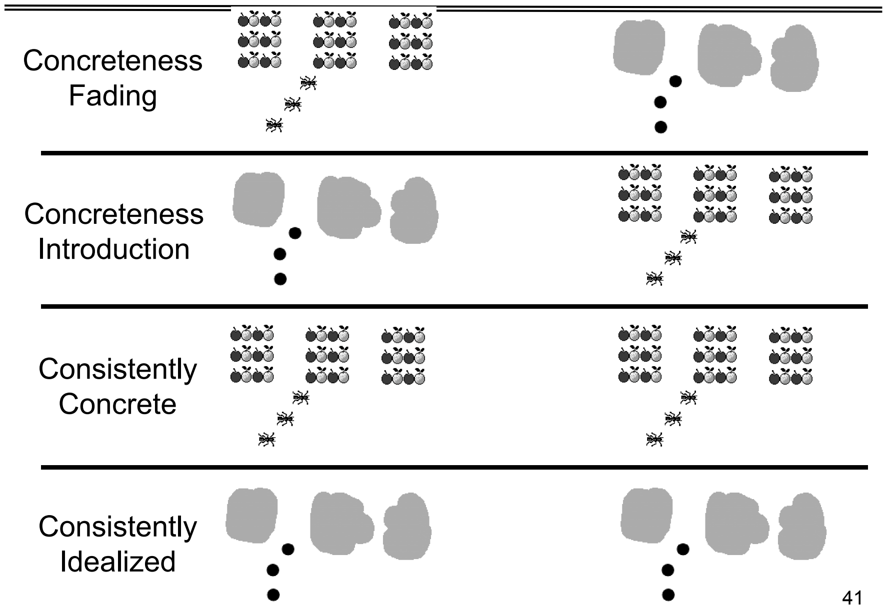

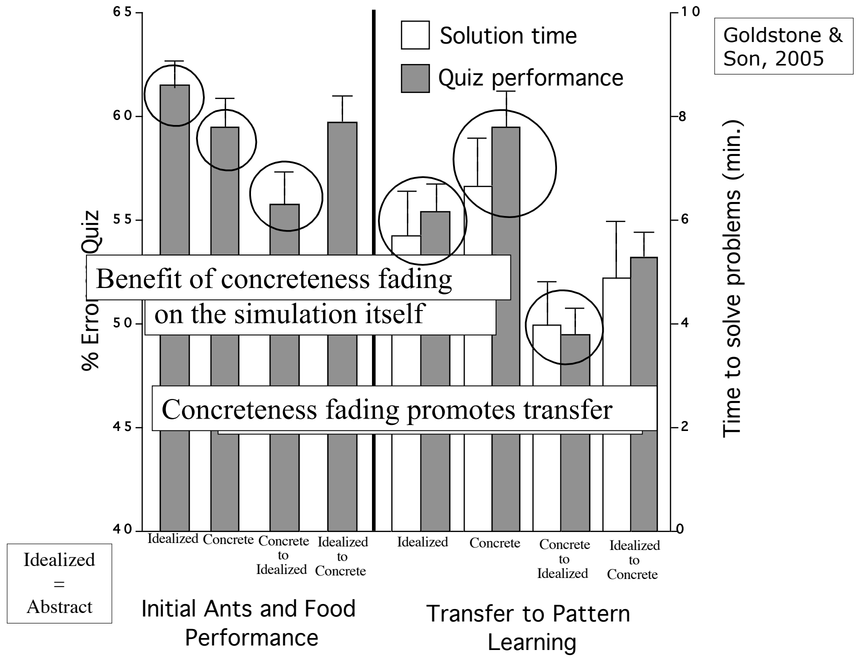

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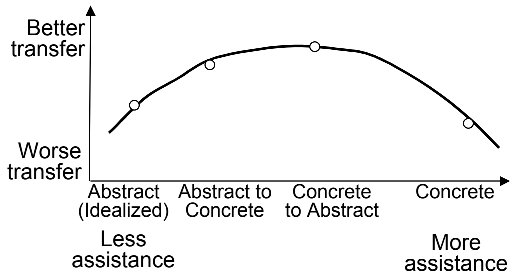
Goldstone & Son results on assistance curve



- Concreteness fading balances costs & benefits of instructional assistance/difficulty

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Do concrete tasks always provide more assistance than abstract ones?

That is, are concrete tasks always easier than matched abstract tasks?

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Which is easier, situation or analogous abstract problem?

	Decimal place value	Decimal arithmetic	Factors & Multiples
Situation	Show 5 different ways that you can give Ben $4.07. [Place value table given.]	You had $8.72. Your grandmother gave you $25 for your birthday. How much money do you have now?	You work at a candy store. Your boss has asked you to figure out the different ways she could package the jelly beans and chocolate eggs, and she wants to know all the possible ways. If there are 64 jelly beans and 40 chocolate eggs and she wants each package to be the same, what are the different numbers of packages you could make?
Abstract	List 5 different ways to show the amount 4.07. [Place value table given.]	Add: 8.72 + 25	The common factors of 64 & 40 are:

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Situation	Show 5 different ways that you can give Ben $4.07. [Place value table given.]	You had $8.72. Your grandmother gave you $25 for your birthday. How much money do you have now?	You work at a candy store. Your boss has asked you to figure out the different ways she could package the jelly beans and chocolate eggs, and she wants to know all the possible ways. If there are 64 jelly beans and 40 chocolate eggs and she wants each package to be the same, what are the different numbers of packages you could make?
%correct	**61%**	**65%**	20%
Abstract	List 5 different ways to show the amount 4.07. [Place value table given.]	Add: 8.72 + 25	The common factors of 64 & 40 are:
%correct	20%	35%	**37%**

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Key Point: Design principles require empirical methods to successfully implement

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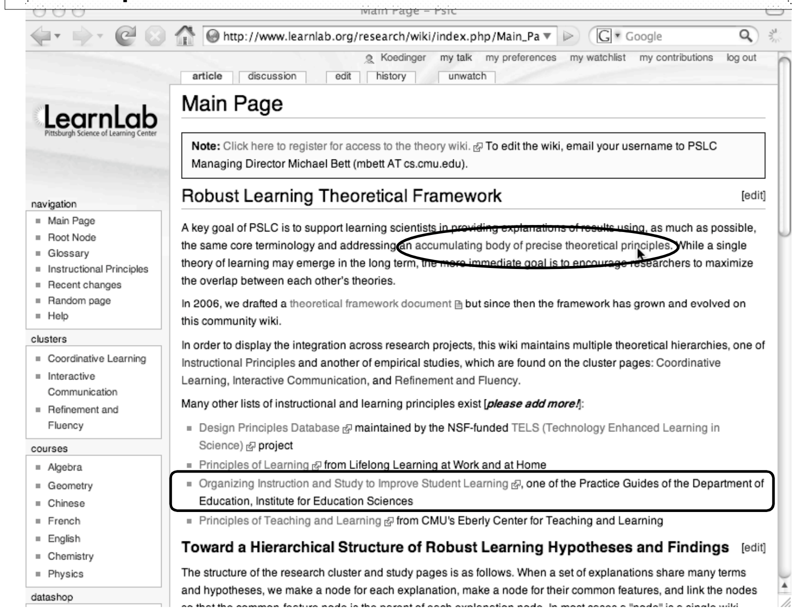
Summary of Learning Principles

- Lots of lists of principles …
  - 6 Cognitive Tutor Principles
  - 6 Multimedia Principles
  - See PSLC wiki for others …
- Should be Based on *both:*
  - Cognitive theory
  - Experimental studies
- Need *Cognitive Task Analysis* to apply
  - Domain general principles are not enough
  - Need to study details of how students think & learn in the domain you are teaching

Principles on web: See learnlab.org/research/wiki



Organizing Instruction and Study to Improve Student Learning

- Produced by US Department of Education, Institute for Education Sciences (IES)
  - Goal: Get *high quality* science into practice
- Expert panel goals
  - Extract recommendations from scientific literature
  - Be conservative, even painfully honest, about status of evidence

Panel:

Harold Pashler (Chair), University of California-SD
Patrice M. Bain, Columbia Middle School, Illinois
Brian A. Bottge, University of Wisconsin–Madison
Arthur Graesser, University of Memphis
Ken Koedinger, Carnegie Mellon University
Mark McDaniel, Washington University in St. Louis
Janet Metcalfe, Columbia University