Cognitive Principles in Tutor & e-Learning Design

Ken Koedinger
Human-Computer Interaction & Psychology
Carnegie Mellon University

CMU Director of the Pittsburgh Science of Learning Center

Lots of Lists of Principles 1

- Cognitive Tutor Principles
- Multimedia & eLearning Principles
- How People Learn Principles
- Progressive Abstraction or "Bridging" Principles
- Other lists on the web...
  - See learnlab.org/research/wiki

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

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

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- 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

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

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


Learning Curves: Difference Between Conditions Emerges Early

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

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- Instructional Bridging Principles
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- 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

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**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

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**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.

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

<table>
<thead>
<tr>
<th>Principle</th>
<th>Percent Gain</th>
<th>Effect Size</th>
<th>Number of Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multimedia</td>
<td>89</td>
<td>1.50</td>
<td>9 of 9</td>
</tr>
<tr>
<td>Contiguity</td>
<td>68</td>
<td>1.20</td>
<td>5 of 5</td>
</tr>
<tr>
<td>Coherence</td>
<td>82</td>
<td>1.17</td>
<td>10 of 11</td>
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<tr>
<td>Modality</td>
<td>80</td>
<td>1.17</td>
<td>4 of 4</td>
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<tr>
<td>Redundancy</td>
<td>79</td>
<td>1.24</td>
<td>2 of 2</td>
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<tr>
<td>Personalization</td>
<td>67</td>
<td>1.24</td>
<td>5 of 5</td>
</tr>
</tbody>
</table>
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

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

Algebra Student Results:
Story Problems are Easier!

<table>
<thead>
<tr>
<th>Percent Correct</th>
<th>Story</th>
<th>Word</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>61%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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: \[ x \times 6 + 66 = 81.90 \]

What do these results imply for instruction?

a. Focus instruction on story problems
b. Focus instruction on equations
c. Start with story then go to equations
d. There are no direct implications
e. Other

Support for option b.
Focus instruction on equations

- Studies showing abstract instruction yields better transfer
- Abstractions help students develop deeper encodings
  - Deep encodings enhance transfer
- Concreteness can tempt students into shallow inferences

Support for option c.
Start with story then go to equations

- Studies showing concrete to abstract instruction yields better transfer
- “Initial concrete grounding facilitates interpretation of model elements”
- Subsequent abstraction helps stress deep features
**Domain: Competitive Specialization**

**Concrete**

**Transfer**

**Abstract (Idealized)**

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**Other evidence for bridging from concrete to abstract**

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Goldstone & Son, 2005

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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?

Which is easier, situation or analogous abstract problem?

<table>
<thead>
<tr>
<th></th>
<th>Decimal place value</th>
<th>Decimal arithmetic</th>
<th>Factors &amp; Multiples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation</td>
<td>Show 5 different ways that you can give Ben $4.07. [Place value table given.]</td>
<td>You had $8.72. Your grandmother gave you $25 for your birthday. How much money do you have now?</td>
<td>The common factors of 64 &amp; 40 are:</td>
</tr>
<tr>
<td>%correct</td>
<td>61%</td>
<td>65%</td>
<td>20%</td>
</tr>
<tr>
<td>Abstract</td>
<td>List 5 different ways to show the amount 4.07. [Place value table given.]</td>
<td>Add: 8.72 + 25</td>
<td></td>
</tr>
<tr>
<td>%correct</td>
<td>20%</td>
<td>35%</td>
<td>37%</td>
</tr>
</tbody>
</table>

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

Future work

What’s the best form of instruction? Two choices?

• More help vs. more challenge
  – Basics vs. understanding
  – Education wars in reading, math, science...
• Psychology likes binary oppositions too. Just produces a lot more of them!
  – Massed vs. distributed (Pashler)
  – Study vs. test (Roediger)
  – Examples vs. problem-solving (Sweller)
  – Re-explain vs. ask for explanation (Renkl)
  – Immediate vs. delayed (Anderson vs. Bjork)
  – Concrete vs. abstract (Uttal)
  – Direct instruction vs. discovery learning (Klahr)
  – ...

Koedinger & Aleven (2007). Exploring the assistance dilemma in experiments with Cognitive Tutors. Educational Psychology Review.
How many options are there really? And what works best when?

Focused practice
- Study examples
- 50/50 Mix
- Concrete

Gradually widening practice
- Study
- 50/50 Test
- Concrete

Distributed practice
- Study
- 50/50 Test
- Abstract

Immediate feedback
- Mixed
- Concrete

Delayed feedback
- Concrete

Interleave topics
- Fade
- Interleave topics

Explain
- Mix
- Ask for explanations

More help
- Basics
- More challenge

What's best?

Concrete Mix Abstract

Better learning

Worse learning

Less assistance

More assistance

Stronger assistance

Robust Learning Efficiency gain =

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

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

Assistance Dilemma

Do more learning science!

- Cumulative theory development
- Educational data mining
- In vivo experiments

205,891,132,094,649

Future work: Elaborate assistance formula on dimensions of instructional assistance

- If \( P \) = probability of success during instruction then:

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

Derivation:
- 15 instructional dimensions
- 3 options per dimension
- 2 stages of learning
- \( => 3^{15^2} \) options