Cognitive Principles in Tutor & e-Learning Design

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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

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

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**KLI**: Instructional principles derived from experiments

Instructional events
- Explanation, practice, text, rule, example, teacher-student discussion
- Assessment events
  - Question, feedback, step in ITS
- Exam, belief survey

Learning events

Knowledge Components

KEY
- Ovals = observable
- Rectangles = inferred
- Arrows = causal links

Overview

• Cognitive Tutor Principles
• Multimedia Principles
  – Theoretical & Experimental evidence
• Building on prior knowledge
  – Need empirical methods to apply
• Summary and Future Challenge

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

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


Intelligent Novice Condition Learns More

Coding Concepts
- Expert Tutor vs. Intelligent Novice Tutor
- Number of attempts at a step by opportunities to apply a production rule

Retention Transfer
- Expert Tutor vs. Intelligent Novice Tutor
- Learning Curves: Difference Between Conditions Emerges Early

y = 2.684x^{-1.1043} 
R^2 = 0.7452

y = 2.3309x^{0.2595} 
R^2 = 0.9452
Overview

- Cognitive Tutor Principles
- **Multimedia Principles**
  - Theoretical & Experimental evidence
- Instructional Bridging Principles
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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

- Narration ➔ Auditory WM
- OnScreen Text ➔ Visual WM
- Animation ➔ Visual WM
- Build Referential Connections ➔ Long Term Memory

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Media Element Principles of E-Learning

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

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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
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)

<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>
</tr>
<tr>
<td>Modality</td>
<td>80</td>
<td>1.17</td>
<td>4 of 4</td>
</tr>
<tr>
<td>Redundancy</td>
<td>79</td>
<td>1.24</td>
<td>2 of 2</td>
</tr>
<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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  - **Building on prior knowledge**
    - Need empirical methods to apply
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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?

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

Algebra Student Results:
Story Problems are Easier!

<table>
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<tr>
<th>Problem</th>
<th>Percent Correct</th>
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<tbody>
<tr>
<td>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?</td>
<td></td>
</tr>
<tr>
<td>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?</td>
<td></td>
</tr>
<tr>
<td>Equation:</td>
<td>( x \times 6 + 66 = 81.90 )</td>
</tr>
</tbody>
</table>

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 abstract rep aids induction & refinement of deep features
Other evidence for bridging from concrete to abstract


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>Situation</th>
<th>Decimal place value</th>
<th>Decimal arithmetic</th>
<th>Factors &amp; Multiples</th>
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<tr>
<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>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?</td>
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%correct 61%
Add: 8.72 + 25
The common factors of 64 & 40 are: 8, 4

%correct 65%
Add: 8.72 + 25
The common factors of 64 & 40 are: 8, 4
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 ...
• Principles should be supported by both:
  – Cognitive theory
  – Experimental studies
• Need Cognitive Task Analysis to apply principles
  – Domain general principles are not enough
  – Need to study details of how students think & learn in the domain you are teaching

Future Challenge
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)
  - 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.

The challenge

Need an *instructional theory* that transcends this complexity

Must *integrate domain* theories

Will require *vast data* that online *in vivo* experiments can provide