Cognitive Task Analysis 1

Announcements

- Change of plan for next Tuesday
  - Go to PSLC Poster Session
  - Outside of 6115 in the new Gates building
  - Return to class by 5:30 to discuss
- Are the posted slides complete? On a PC?
- Today’s plan
  - Review assignment 1
  - Questions on assignment 2?
  - Intro to Cognitive Task Analysis
  - Example of Aptitude-Treatment Interaction?

Cognitive Task Analysis

- Techniques to specify cognitive structures & processes associated with task performance
  - Structured interviews of experts
  - Think alouds of experts & novices performing tasks
  - Computer simulations of human reasoning

Definitions of Cognitive Task Analysis

- Clark reading
  - Clark’s or Chipman’s?
  - We will use Chipman’s broader definition
- Others
  - The general term used to describe a set of methods and techniques that specify the cognitive structures and processes associated with task performance. The focal point is the underlying cognitive processes, rather than observable behaviors. (Clark & Estes, 1996)
  - Another defining characteristic of CTA is an attempt to describe the differences between novices and experts in the development of knowledge about tasks
Kinds of Cognitive Task Analysis

- 2 Kinds of Approaches
  - Empirical: Based on observation, data, exp.
  - Analytical: Based on theory, modeling.

- 2 Kinds of Goals
  - Descriptive: How students actually solve problems. What Ss need to learn.
  - Prescriptive: How students should solve problems. What Ss need to know.

- 4 Combinations ...

Example: Think Alouds in Statistics Tutor Development

- Task: Exploratory Data Analysis
  - Given problem description and data set
  - Inspect data to generate summaries & conclusions
  - Evaluate the level of support for conclusions

- Example Problem
  In men’s golf, professional players compete in either the regular tour (if they're under 51 years old) or in the senior tour (if they are 51 or older). Your friend wants to know if there is a difference in the amount of prize money won by the players in the 2 tours. This friend has recorded the prize money of the top 30 players in each tour. The variable money contains the money won by each of the players last year. The variable tour indicates which tour the player competed in, 1=regular, 2=senior. The variable rank indicates player rank, 1=top in the tour.

Task Analysis of Major Goals in Statistical Analysis

- This is an “analytic prescriptive” form of CTA

- Break down task:
  - 7 major goals
  - Each goal involves multiple steps or subgoals to perform
  - Write if-then rules (productions) that describe how each subgoals is achieved

Where does Clark fit?
Sample Transcript

<table>
<thead>
<tr>
<th>#</th>
<th>Participants words &amp; actions</th>
<th>Annotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oh, okay.</td>
<td>Goal 1</td>
</tr>
<tr>
<td>2</td>
<td>So we need to, he wants to know whether there is a difference in the amount of prize money, the amount of money won by players in the two tours.</td>
<td>Goal 2</td>
</tr>
<tr>
<td>3</td>
<td>So, I think this is the prize money, uh, money contains the prize money won by each of these players.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Tour indicates which tour the player competes in.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Well, you don't really need rank, in order to solve this, right?</td>
<td>Goal 4</td>
</tr>
<tr>
<td>6</td>
<td>Cause like, well, I don't know.</td>
<td>Goal 5</td>
</tr>
<tr>
<td>7</td>
<td>Um... I'm gonna do a boxplot... ...</td>
<td>Goal 6</td>
</tr>
<tr>
<td>8</td>
<td>[Subject uses statistics package to make a boxplot] oh, cool (laugh)- I did it.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>All right, uh, so just looking at the average.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>It looks like the people in the senior tour get less money.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Um, and there's a lot less variation in the amount of money that, like all the prizes.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>A couple little outliers in each which means like, I don't know, like some people won, like a lot of money at a time...</td>
<td></td>
</tr>
</tbody>
</table>

Comparing Think Aloud Results with Task Analysis

- Percentages to the right of each step represent the percentage of students in the think-aloud study who showed explicit evidence of engaging in that step.
- Step 3 is totally absent!
  - A tutor can help students to do & remember to do step 3

Using if-then rules to model differences between novices & experts

- Novices make errors either because
  - Lack of knowledge -- modeled as a missing rule
  - Incorrect knowledge -- modeled as a “buggy” rule
- Missing rule (to set goal 3):
  Characterize problem
  If goal is to do an exploratory data analysis & relevant variables have been identified then set a subgoal to identify variable types
- Buggy rule (skipping from goal 2 to 4):
  Select any data representation
  If goal is to do an exploratory data analysis & relevant variables have been identified then set a subgoal to conduct an analysis by picking any data representation
Clark’s CTA Families

- Differ strategies for knowledge elicitation (empirical)
  - Observation and interviews
  - Process tracing
  - Conceptual techniques
    - Formal, with fixed protocols for interaction with participants
- Formal models (theoretical)
  - Simulations of task performance or “cognitive models”

Knowledge representations schemes

- Clark’s
  - Concept maps
  - Flow charts
  - Semantic nets
- Other’s
  - Goal trees
  - If-then rules written in English
  - Cognitive modeling, like ACT-R

Clark’s steps

- Collect preliminary knowledge
- Identify knowledge representations
- Apply focused knowledge elicitation methods
- Analyze and verify data acquired
- Format results for intended application

My Steps In Task Analysis

- What are instructional objectives?
  - Standards, existing tests, signature tasks
- Has someone done the work for you? Don’t reinvent the wheel. Do a literature review!
  - “8 weeks of analysis saves an hour in the library”
- Specify space of tasks
- Do either or both:
  - Theoretical task analysis: Create a model that is sufficient to deal with space of tasks
  - Empirical task analysis: Do think aloud, difficulty factors assessment, expert interviews...
Some examples ...

- ... and how CTA translates into better instruction

Unpacking & repacking expertise: Chick sexing

- Experts don’t know, what they know
  - 98% accurate after years of on-the-job training

- Interviews led to design of “pictures in which critical features of various types were indicated”

- After just minutes of instruction, novices brought to 84% accuracy!


Algebra Cognitive Tutor: Example Activity

Cognitive Tutors: Combining Cognitive Psychology & Intelligent tutoring systems

Research base

Cognitive Psychology

Artificial Intelligence

Curriculum Content

Math Instructors

Math Educators

NCTM Standards
Cognitive Tutor Technology

Use cognitive model to individualize instruction

- **Cognitive Model:** A system that can solve problems in the various ways students can

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

- **Model Tracing:** Follows student through their individual approach to a problem -> context-sensitive instruction

**Hint message:** “Distribute a across the parentheses.”

**Bug message:** “You need to multiply c by a also.”

- **Known?** = 85% chance

**Known?** = 45%

**Cognitive Tutors:** Combining Cognitive Psychology & Intelligent tutoring systems

Cognitive Task Analysis

Improves Instruction

Studies: Traditional instruction vs. CTA-based

- Med school catheter insertion (Velmahos et al., 2004)
  - Sig greater pre to post gain
  - Better with patients on all four measures used
  - Example: Sig fewer needle insertion attempts!

- Other examples
  - Radar system troubleshooting (Schaafstal et al., 2000)
  - Spreadsheet use (Merrill, 2002)

- Meta-analysis, 7 studies: 1.7 effect size!
  (Lee, 2004)
Isn’t knowledge analysis done for long-standing academic domains?

- Hasn't all this been worked out?
- Surely by now we understand the content of, say, Algebra?

**Difficulty Factors Assessment:**
Discovering What is Hard for Students to Learn

*Which problem type is most difficult for 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!

<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>


**Typical textbook strategy**

8. After buying donuts at Wholey Donuts, Laura multiplies the number of donuts she bought by their price of $0.37 per donut. Then she adds the $0.22 charge for the box they came in and gets $2.81. How many donuts did she buy? 

\[
\frac{0.37x + 0.22}{-0.22} = 2.81 - \frac{0.37}{0.37}
\]

\[
\frac{37x}{37} = \frac{2.59}{0.37}
\]

\[
x = 1
\]
Informal Strategies

The foreign language of algebra:
Difficulties with syntax & semantics

Expert Blind Spot:
Expertise can impair judgment of student difficulties

What’s behind expert blind spot?

- Self-reflection on current cognition, biased memory of past learning
- Aware of verbally-mediated reasoning
  - False inference: More words => more thinking
- Not aware of implicit processing & learning
  - Fluent algebra language processing requires extensive implicit learning
  - Our minds are continually engaged in pattern induction, analogy, chunking, strengthening ...

Example: Using Cognitive Task Analysis to design better algebra instruction

- **Inductive support strategy**
  - Help students generalize abstract math from their own intuitive concrete solutions
  - Similar to “progressive formalization” or “concreteness-fading” (Golstone & Son, 05)

- **Test idea with an *in vivo experiment***
  - Experiment *within a real course* where we *test a single principle* (change one thing)

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### Parametric Study: Textbook vs. Cognitively-Based Design

![Graph showing pre to post improvement scores for Textbook and Inductive Support](Image)

**Table:**

<table>
<thead>
<tr>
<th>Textbook (Symbolize first)</th>
<th>Inductive Support (Solve &amp; then symbolize)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre to Post Improvement Score</td>
<td>Pre to Post Improvement Score</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
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<td>3</td>
<td>3</td>
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<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

**Example Problems:**

1. \(35 + 42h = d\)
2. \(35 + 42 \times 3 = 161\)
3. \(35 + 42 \times 4.5 = 224\)
4. \(35 + 42h = 140\)

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**Extra Notes:**

- Plumbing Co. charges $42 per hour plus $35 for the service call
- 1. write an expression ...
- 2. How much for a 3 hour call?
- 3. What will bill be for 4.5 hours?
- 4. Find hours when bill is $140

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Example of Real Aptitude-Treatment Interaction

Following up discussion board
And illustrating some CTA!

Think alouds of students ...

Example rule from cognitive model

IF charge is 5 units away from path vertex
AND puck trajectory did not bend enough (wrt Angle g)
THEN move charge 1 unit closer to path

Figure 1. An example of simple interactions with Electric Field Hockey.

Aptitude-Treatment Interaction


Figure 10. Score versus mSAT by goal condition.

2nd “ATI” example

Figure 5: Linear regression shows a significant interaction between efficiency scores and pretest.