Models of Cognition in Distributed Learning Environments

MOVES Annual Research & Education Summit
Naval Postgraduate School
Monterey, CA
13 July 2010

J. D. Fletcher
Institute for Defense Analyses
fletcher@ida.org
### Models of Cognition in Distributed Learning Environments

1. **REPORT DATE**
   13 JUL 2010

2. **REPORT TYPE**

3. **DATES COVERED**
   00-00-2010 to 00-00-2010

4. **TITLE AND SUBTITLE**
   Models of Cognition in Distributed Learning Environments

5. **AUTHOR(S)**

6. **PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
   Institute for Defense Analyses, 4850 Mark Center Dr, Alexandria, VA, 22311

7. **SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

8. **PERFORMING ORGANIZATION REPORT NUMBER**

9. **DISTRIBUTION/AVAILABILITY STATEMENT**
   Approved for public release; distribution unlimited

10. **ABSTRACT**
   10th Annual MOVES Research and Education Summit 2010, 13-15 July.

11. **SUBJECT TERMS**

12. **SECURITY CLASSIFICATION OF:**
   - a. REPORT: unclassified
   - b. ABSTRACT: unclassified
   - c. THIS PAGE: unclassified

13. **LIMITATION OF ABSTRACT**
   Same as Report (SAR)

14. **NUMBER OF PAGES**
   39

15. **NAME OF RESPONSIBLE PERSON**
In Conclusion …

• Cognitive models are an instructional imperative ... and no longer an economic impossibility.

• Cognitive models have been used in technology-based instruction from the beginning.

• Cognitive models are needed for simulation used to train. Open questions remain.
Two Cultures, Divided by a Common Language

Simulationists
- Collectives/Units
- Exercises
- Full Fidelity
- Big Simulation

Trainers
- Individuals/Teams
- Programs of Instruction
- Selective Fidelity
- Small Simulation

These are complementary not competing cultures.
How Trainers Think: Learning Objectives

Learning Content
- Meta-Cognition
- Adaptive Procedures
- Concepts
- Simple Procedures
- Facts

Learning Objectives
- Remember
- Understand
- Apply
- Analyze
- Evaluate
- Create

(Framework courtesy of Anderson & Krathwohl, 2001)
“The principal consequence of ... individual differences is that every general law of teaching has to be applied with consideration of the particular person, ... responses ... to any stimulus ... will vary with individual capacities, interests, and previous experience.”

(E. L. Thorndike, 1906, Principles of Teaching)
Q&A: Why Bother with Cognitive Models?

Q: Why do we use cognitive models in instruction?
A: To tailor instruction to learners.

Q: Why do we want to tailor instruction to learners?
A: Because it is very efficient.

Q: Why do we want efficient training?
A: Because it contributes to productivity and effectiveness in operations – more can be done with fewer people and fewer resources.
“Whilst part of what we perceive comes through our senses from the object before us, another part (and it may be the larger part) always comes out of our mind.”

(William James, 1890 -- General Law of Perception in *Principles of Psychology*)
Cognitive Models in Education & Training

- **Learning Content**
  - Meta-Cognition
  - Adaptive Procedures
  - Concepts
  - Simple Procedures
  - Facts

- **Learning Objectives**
  - Remember
  - Understand
  - Apply
  - Analyze
  - Evaluate
  - Create

**Learning environments.** Simulations that are ‘situated’ and ‘authentic’ -- used to compress practical experience. Focus on learner productivity – rarely measured.

**Explicit and implicit cognitive models.** Instruction we’ve known how to create since the 1960s. Focus on instructional productivity – often measured.

(Framework courtesy of Anderson & Krathwohl, 2001)
About Training
Cognitive models are an instructional imperative ... and no longer an economic impossibility.
The Tutorial Imperative

Adapted From: Bloom, B.S. The Two Sigma Problem: The Search for Methods of Group Instruction as Effective as One-to-One Tutoring. Educational Researcher. 13, 4-16 (1984)
Why Is Tutoring So Effective?

- Individualization of
  - Sequence,
  - Content,
  - Style,
  - Difficulty,
  - and Pace.

- Intensified interactivity.
Enter the Computer:
A Third Revolution in Learning?

• Writing
  Content of learning made available anytime, anywhere

• Books
  Affordable content of learning made available anytime, anywhere

• Technology
  Affordable content and interactions of learning made available anytime, anywhere
A DARPA Challenge

16 weeks of simulation-based, “intelligent” training to produce graduates who are superior to technicians with 7 years of IT experience in the Fleet.
Cognitive models have been used in technology-based instruction from the beginning.
An Intrinsic Cognitive Model: Keller’s PSI

Keller’s Personalized System of Instruction (PSI)

Modularized Instruction

Pre-Test ➔ Diagnose & Assess ➔ Study Guide ➔ Post-test
In the multiplication $3 \times 4 = 12$, the number 12 is called a ______.

A. Factor [Branch to remedial X1]
B. Quotient [Branch to remedial X2]
C. Product [Reinforce, go to next]
D. Power [Branch to remedial X3]
In the multiplication $3 \times 4 = 12$, the number 12 is called a ______.

A. Factor [Branch to remedial X1]
B. Quotient [Branch to remedial X2]
C. Product [Reinforce, go to next]
D. Power [Branch to remedial X3]
## Selecting an Item/Problem to Present Next: Some Models of Memory

<table>
<thead>
<tr>
<th>State on Trial n</th>
<th>State on Trial n+1 When Presented</th>
<th>P(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>S</td>
</tr>
<tr>
<td>L</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>S</td>
<td>c</td>
<td>1-c</td>
</tr>
<tr>
<td>U</td>
<td>a</td>
<td>b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>State on Trial n</th>
<th>State on Trial n+1 When Not Presented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
</tr>
<tr>
<td>L</td>
<td>1</td>
</tr>
<tr>
<td>S</td>
<td>c</td>
</tr>
<tr>
<td>U</td>
<td>a</td>
</tr>
</tbody>
</table>
Allocating Time Among Students: Fun with Regression Equations

Linear:
\[ E(O_i) = b_0 + b_1 P_i + b_2 T_i \]

Linear with interaction:
\[ E(O_i) = b_0 + b_1 P_i + b_2 T_i + b_3 P_i T_i \]

Cobb-Douglas:
\[ E(\ln O_i) = b_0 + b_1 \ln P_i + b_2 \ln T_i \]

Exponential:
\[ E(\ln O_i) = b_0 + b_1 \ln P_i + b_2 \ln T_i + b_3 (\ln T_i)^2 + b_4 (\ln T_i)^3 \]

(O = outcome; P = pretreatment measure; T = time)
Use of Technology-Based Instruction (adaptive and distributable) can reduce costs of instruction by about 1/3, and

Either increase learning by about 1/3
(教育)

Or reduce time to learn by about 1/3
(培训)

N.B.: The real payoff is increased effectiveness and productivity
Simulation in the Small: Simulation Meets Cognitive Modeling (and Vice Versa)
Student: What is the base emitter voltage of the voltage limiting transistor?

SOPHIE: The base emitter voltage of Q5 is -.037 volts.

Student: What about for the current limiting transistor?

SOPHIE: The base emitter voltage of Q8 is .349 volts.

Student: What should it be?

SOPHIE: In a working circuit, the base emitter voltage of Q8 is .593 volts.

Student: Replace Q8.

SOPHIE: I am going to ask you some questions about how Q8 is faulted. Are any junctions shorted?

(From Brown, Burton, & DeKleer, 1982)
### Some Early ICAI/ITS Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Domain</th>
<th>Author(s)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCHOLAR</td>
<td>South American geography</td>
<td>Carbonell, 1970</td>
<td></td>
</tr>
<tr>
<td>WHY</td>
<td>Causes of rainfall</td>
<td>Stevens, et al., 1982</td>
<td></td>
</tr>
<tr>
<td>INTEGRATE</td>
<td>Symbolic integration</td>
<td>Kimball, 1982</td>
<td></td>
</tr>
<tr>
<td>SOPHIE</td>
<td>Electronic troubleshooting</td>
<td>Brown, et al., 1982</td>
<td></td>
</tr>
<tr>
<td>WEST</td>
<td>Arithmetic expressions</td>
<td>Burton &amp; Brown, 1979</td>
<td></td>
</tr>
<tr>
<td>BUGGY</td>
<td>Subtraction</td>
<td>Brown &amp; Burton, 1978</td>
<td></td>
</tr>
<tr>
<td>WUSOR</td>
<td>Logical relations</td>
<td>Goldstein, 1982</td>
<td></td>
</tr>
<tr>
<td>EXCHECK</td>
<td>Logic and set theory</td>
<td>Suppes, 1982</td>
<td></td>
</tr>
<tr>
<td>BIP</td>
<td>BASIC programming</td>
<td>Barr, et al., 1976</td>
<td></td>
</tr>
<tr>
<td>SPADE</td>
<td>LOGO programming</td>
<td>Miller, 1982</td>
<td></td>
</tr>
<tr>
<td>ALGEBRA</td>
<td>Algebra word problems</td>
<td>Lantz, et al., 1983</td>
<td></td>
</tr>
<tr>
<td>LMS</td>
<td>Algebraic procedures</td>
<td>Sleeman, 1982</td>
<td></td>
</tr>
<tr>
<td>QUADRATIC</td>
<td>Quadratic equations</td>
<td>O’Sheo, 1982</td>
<td></td>
</tr>
<tr>
<td>GUIDON</td>
<td>Infectious diseases</td>
<td>Clancey, 1982</td>
<td></td>
</tr>
<tr>
<td>MENO</td>
<td>PASCAL programming</td>
<td>Soloway, et al., 1983</td>
<td></td>
</tr>
<tr>
<td>STEAMER</td>
<td>Steam propulsion (USN)</td>
<td>Williams, et al., 1981</td>
<td></td>
</tr>
</tbody>
</table>
A Rotary Dial with Detents

Flash Object
86 program statements

ReAct Object
1 program statement

AECEM_ON
AECEM_Stndby
ESM
AntServo
OFF

AECEM_Stndby
Simulation in the Large: Preparing for Incredibly Complex Tasks
Figure 1. The Sanders teacher (flight trainer).
“Top Gun” Example

Air-to-Air Loss/Exchange Ratio

12:1
10:1
8:1
6:1
4:1
2:1

USN
Top Gun
School Formed
No
Air-to-Air
Combat

1965-1968
USN 2.5:1
USAF 2.5:1

1969
USN 12:1

1970-1973
USAF 2.5:1
## What Was Different?

<table>
<thead>
<tr>
<th>Before Top Gun</th>
<th>With Top Gun</th>
</tr>
</thead>
<tbody>
<tr>
<td>No instrumentation</td>
<td>Instrumentation</td>
</tr>
<tr>
<td>Untrained OpFor</td>
<td>Trained OpFor</td>
</tr>
<tr>
<td>Umpires</td>
<td>Force on Force</td>
</tr>
<tr>
<td>Classroom Tactics</td>
<td>Practice in the Sky</td>
</tr>
<tr>
<td>Tests</td>
<td>“Situated” Assessment</td>
</tr>
</tbody>
</table>
From REALTRAIN to MILES (Multiple Integrated Laser Engagement Simulation) to Simulation Networks to Irregular Warfare Training
Simulation for Irregular Warfare
What Value Do Cognitive Models Bring to Simulation in the Large?
Training for an Incredibly Complex Task:
An IMAT Display
## Incredibly Complex Tasks

<table>
<thead>
<tr>
<th>Abstract</th>
<th>Physical phenomena or causation are not readily visible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multivariate</td>
<td>Many variables underlie outcomes.</td>
</tr>
<tr>
<td>Interactive</td>
<td>Changes in one variable may affect several others.</td>
</tr>
<tr>
<td></td>
<td>Processes are co-dependent.</td>
</tr>
<tr>
<td>Continuous</td>
<td>Physical phenomena and their effects are described</td>
</tr>
<tr>
<td></td>
<td>as values along continua, rather than as discrete</td>
</tr>
<tr>
<td></td>
<td>properties.</td>
</tr>
<tr>
<td>Non-Linear</td>
<td>Relations among variables are not simple straight-line</td>
</tr>
<tr>
<td></td>
<td>functions.</td>
</tr>
<tr>
<td>Dynamic</td>
<td>The process of variation is of interest, rather than</td>
</tr>
<tr>
<td></td>
<td>end-state</td>
</tr>
<tr>
<td>Simultaneous</td>
<td>Systemic variation is coincident rather than serial.</td>
</tr>
<tr>
<td>Conditional</td>
<td>Outcomes are highly dependent on boundary conditions</td>
</tr>
<tr>
<td></td>
<td>and context.</td>
</tr>
<tr>
<td>Uncertain</td>
<td>Exact values of underlying variables are not known</td>
</tr>
<tr>
<td></td>
<td>precisely – they may be estimates, interpolations,</td>
</tr>
<tr>
<td></td>
<td>approximations</td>
</tr>
<tr>
<td>Ambiguous</td>
<td>The same outcome may arise from different combinations</td>
</tr>
<tr>
<td></td>
<td>of inputs.</td>
</tr>
</tbody>
</table>
Cognitive readiness is the mental preparation (including skills, knowledge, abilities, motivations, and personal dispositions) an individual needs to establish and sustain competent performance in the complex and unpredictable environment of modern military operations.
Some Open Questions

- Do we need cognitive models in simulation in the large?

- What might be their value of cognitive models? (Design, development, implementation (AARs), assessment)

- From METLs to MECs – how do we prepare people for the unexpected – cognitive readiness?

- Cognitive models for teams?

- What are the psychometric characteristics of simulations (reliable, valid, precise)?
Some Cognitive Models

- Atomic Components of Thought (ACT) & Atomic Components of Thought - Rational (ACT-R)
- Adaptive Resonance Theory (ART)
- Architecture for Procedure Execution (APEX)
- Business Redesign Agent-Based Holistic Modeling System (Brahms)
- Cognition and Affect Project (CogAff)
- Cognition as a Network Of Tasks (COGNET)
- Cognitive Complexity Theory (CCT)
- Cognitive Objects within a Graphical EnviroNmentT (COGENT)
- Concurrent Activation-Based Production System (CAPS)
- Construction-Integration Theory (C-I Theory)
- Distributed Cognition (DCOG)
- Executive Process/Interactive Control (EPIC)
- Human Operator Simulator (HOS)
- Man-machine Integrated Design and Analysis System (MIDAS)
- Micro Systems Analysis Of Integrated Network Of Tasks (Micro Saint)
- Operator Model Architecture (OMAR)
- PSI
- Situation Awareness Model for Pilot-in-the-Loop Evaluation (SAMPLE)
- State, Operator, And Result (SOAR)
In Conclusion ...

• Cognitive models are an instructional imperative ... and no longer an economic impossibility.

• Cognitive models have been used in technology-based instruction from the beginning.

• Cognitive models are needed for simulation used to train. Open questions remain.