

**Tutoring Strikes Again:
DARPA's Digital Tutor
Effectiveness, Return on Investment,
and Implications Thereof**

**Advanced Distributed Learning iFEST
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The Digital Tutor

- **Initiated under DARPA's Defence Sciences Office "Training Superiority" Program**
- **Continued under "Education Dominance"**
- **Three Program Managers (Drs. Chatham, Cohn, & Casebeer)**

**Side Trip:
Tutorial Instruction
and ADL**

A Third Revolution in Learning?

- **(Phonetic) Writing (c. 3000 BC)**
Content of learning made available anytime, anywhere
- **Books (1000 or 1400 AD)**
Affordable content of learning made available anytime, anywhere
- **Technology (1950 AD)**
Affordable content and tutorial interactions of learning made available anytime, anywhere

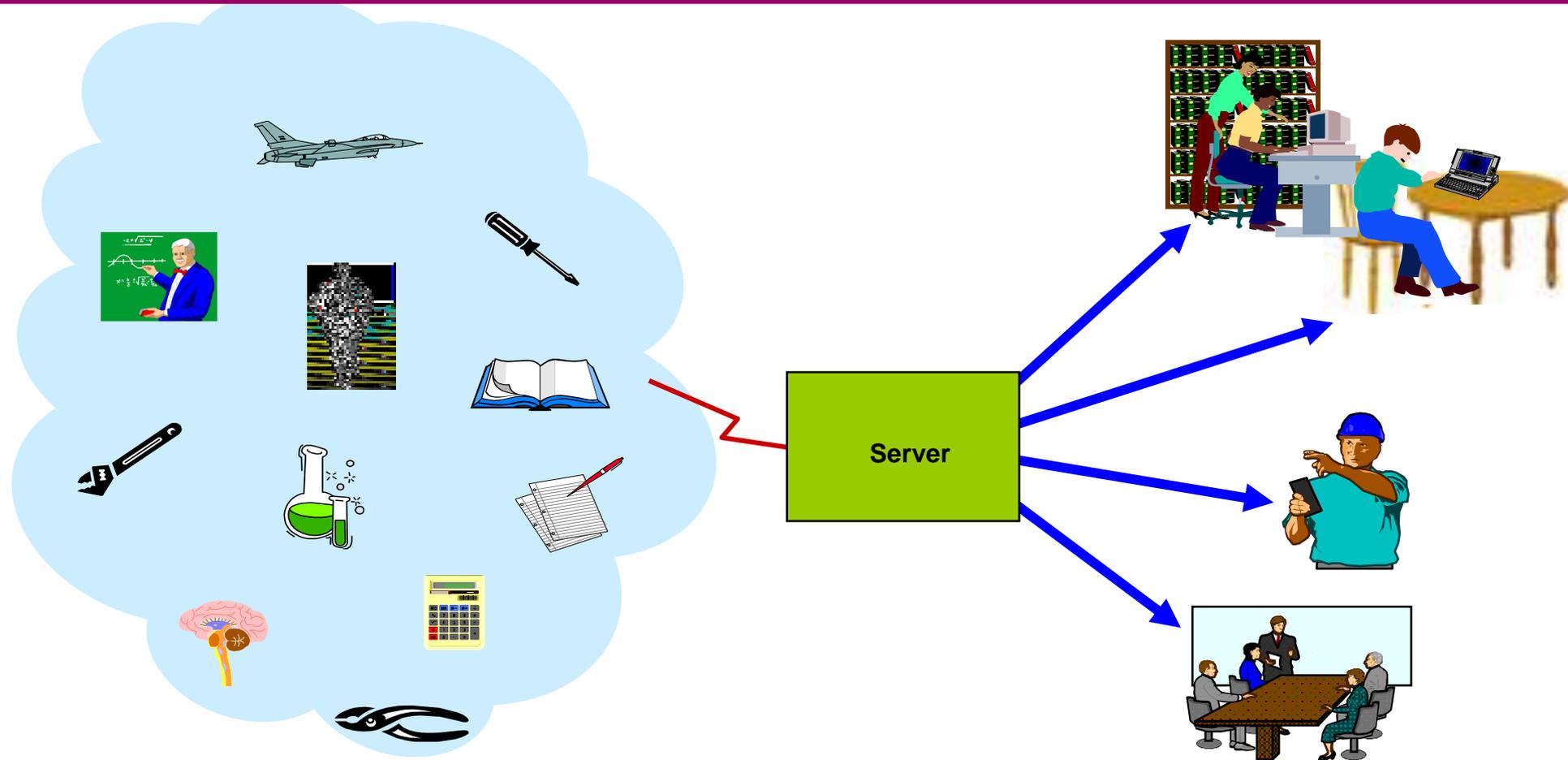
Some Trends and a Prediction

Intelligent Tutoring Systems
Moore's Law
Global Information Grid
Natural Language Interaction
Electronic Performance Aids
Distributed Learning Capabilities
Object Oriented Applications
Hand-Held or Worn Computers
Simulations and Games
Etc.



**Personal
Learning
Associates**

Hence, the ADL Vision



***Shareable
instructional objects
from across the World
Wide Web***

***Assembled in
real-time, on-
demand***

***To provide learning
and assistance
anytime, anywhere
via guided dialogues***

What Does ITS have to do with ADL?

- **Anywhere, Anytime Learning Integrated with Performance/Decision Aiding**
(Integrating the supply and demand side of learning)
- **Fewer Lessons, More Learning**
(Learning as conversation)
- **Fewer Tests -- More Assessment**
(Continuous, Unobtrusive)
- **Personal Learning Associates**
(In classrooms and out – anytime, anywhere)

**Instruction (and Performance/Decision Aiding)
as Individualized Tutorial Conversation**

The DARPA (Acuitus) Digital Tutor

But First, Another Side Trip: Effect Size

A descriptive (not inferential) statistic often used to estimate the magnitude of an effect (e.g., experimental treatment). It may be calculated as:

$$\text{Cohen's } d = \frac{\text{Mean Group 1} - \text{Mean of Group 2}}{\text{"Pooled" Standard Deviation}}$$

| | |
|---------------------|-------------------|
| d < 0.20 | Negligible |
| 0.20 to 0.39 | Small |
| 0.40 to 0.59 | Moderate |
| 0.60 to 0.79 | Large |
| d > 0.80 | Very Large |

Onward: Does This ITS Stuff Work?

VanLehn (2011):

- 27 Evaluations
 - Effect size of 0.59 overall
 - Effect size of 0.76 for step-based tutoring
 - Effect size of 0.40 for substep-based tutoring

Kulik/Fletcher (2012):

- 45 “Systems Evaluations”
 - Effect size of 0.60 overall
 - Effect size of 0.75 for 39 properly aligned studies

Context for the Digital Tutor (DT)

- A product of DARPA's Education Dominance program (DARWARS, Ambush!, Tactical Language and Cultural Training, ...)
- Focused on accelerating expertise
- Provides 16 weeks covering "A" school and some "C" school training for USN Information Systems Technology (IT) rating
- Approach is to capture procedures and practices of expert one-on-one tutors
 - Spiral curriculum focused on concepts
 - Hands-on work with IT systems

Basic Approach for the Digital Tutor

- **Borrows ideas from intelligent tutoring technology and constructivist notions, but aspires to be neither**
 - **Its strategy is eclectic and pragmatic**
 - **Its validation is job performance**
- **Its approach is to:**
 - **Capture procedures and practices of subject matter experts who are also expert one-on-one tutors**
 - **Emphasize active (situated, authentic) problem solving to develop higher order concepts**

Why Information Technology?

- **An operationally critical competency**
- **Current training in sore need of improvement (agreement across all echelons)**
- **An Incredibly Complex Task**

Five DT Assessments

- **April 2009 (5 weeks of Phase 1 IWAR)**
- **July-August 2009 – Phase 1 IWAR**
- **April 2010 – 4 weeks then available of the DT**
- **November 2010 – 8 weeks then available of the DT**
- **March-April 2012 – Phase 2 IWAR**

NB:

- **Main focus is on job performance**
- **Effect size measured by Cohen's d**

April 2009 (IDA 2010 Document D-4047)

Comparison Groups:

- 1 week of DT, 9 weeks of human tutoring (N = 15) \Leftrightarrow 16 weeks “A” School ILE (N = 20)

Measure: Navy-provided Written Knowledge Test (133 items)

Results:

| Question Type | Cohen's d | Significance |
|-----------------|-----------|--------------|
| Constructed | 2.5 | p < 0.01 |
| Diagrams | 1.9 | p < 0.01 |
| Multiple choice | 1.1 | p < 0.01 |
| Overall | 2.36 | p < 0.01 |

Phase 1 IWAR

(IDA 2010 Document D-4047)

Comparison Groups:

- 1 week of DT plus 15 weeks of one-on-one (human) tutoring (N = 12) \Leftrightarrow Fleet ITs with 4-18 years Navy IT experience (N = 12, again)

Measures:

- 139-item Written Knowledge Test
- Practical Troubleshooting Exercises (2.5 days)
- System Building Exercise (6 hours)
- (Also Dockside and Deployed observations)

Phase 1 IWAR (IDA 2010 Document D-4047)

Results:

- **Written Knowledge Test**

DT \Leftrightarrow Fleet ITs (d = 1.02)^a

- **1-Week DT portion**

DT \Leftrightarrow Fleet ITs (d = 1.73)^a

- **Practical Troubleshooting Exercises**

DT \Leftrightarrow Fleet ITs (99 \Leftrightarrow 79 solved)^a

- **System Building Exercises:**

Fleet \Leftrightarrow DT (113 \Leftrightarrow 84 objectives met)^c

^a(p < 0.01) ^cnot significant

**Human Tutoring So Far.
Now, Can We Digitize it?**

April 2010

(IDA 2011 Document NS D4260)

Comparison:

- 4 weeks of then available DT (N = 20) \Leftrightarrow
 - 16 weeks of Integrated Learning Environment (ILE) CBT graduates (N = 31)
 - ILE and DT instructors (N = 10)

Measure:

152-item written knowledge test covering DT material

Results:

DT \Leftrightarrow ILE (d = 2.81)^a

DT \Leftrightarrow Instructors (d = 1.26)^a

Instructors \Leftrightarrow ILE (d = 1.25)^a

^a(p < 0.01)

November 2010

(IDA 2011 Document NS D4260)

Comparison:

- 8 weeks of the available DT (N = 20) \Leftrightarrow
 - 16 weeks of Integrated Learning Environment (ILE) CBT graduates (N = 18)
 - 19 weeks of IT of the Future (IToF) graduates (N = 20)
 - ILE instructors (N = 10)

Measures:

- 293-item written knowledge test covering DT material
- 4 hours practical trouble shooting exercises
- 2 hours packet tracing exercises
- Oral exams (about 30 minutes) of 7 DT and 6 IToF students

November 2010 Results (1)

- **Written Knowledge test**

DT ~ ILE (d = 4.68)^a

DT ~ IToF (d = 1.95)^a

DT ~ Instructors (d = 1.35)^a

IToF ~ ILE (d = 3.54)^a

IToF ~ Instructors (d = 0.10)^c

Instructors ~ ILE (d = 2.35)^a

- **Practical exercises**

DT ~ IToF (d = 1.90)^a

- **Packet Tracing Exercises**

DT ~ IToF (d = 0.74)^a (Un-Weighted)

^a(p < 0.01) ^cnot significant DT ~ IToF (d = 1.00)^a (Weighted)

November 2010 Results (2)

- **Individual Review Board Comment:**

“It seemed comparatively unambiguous that the Digital Tutor students understood IT in a way that the other students did not. ... The confidence of the digital tutor students and their clear knowledge was very considerable. This was further displayed when they provided correct answers or explanations quickly which resulted in further deeper dives for level of comprehension. All 3 panel members were impressed.”

Phase 2 IWAR -- March-April 2012

Comparison Groups:

- 16 weeks of the completed DT (N = 12) \Leftrightarrow
 - 35 weeks of IT Training Continuum (ITTC) graduates (N = 12)
 - Experienced Fleet ITs (N = 12)

Measures:

- 272-item written knowledge test covering DT material
- 16 hours practical trouble shooting exercises
- 3 hours security exercises
- 6 hours system build exercise
- 20-30 minute individual interviews

Phase 2 IWAR Results (1)

Written Knowledge test:

DT \Leftrightarrow Fleet (d = 3.63)^a

DT \Leftrightarrow ITTC (d = 2.63)^a

ITTC \Leftrightarrow Fleet (d = 1.00)^a

Practical exercises:

DT \Leftrightarrow Fleet (d = 0.83)^a

DT \Leftrightarrow ITTC (d = 1.02)^a

ITTC \Leftrightarrow Fleet (d = -0.19)^c

^a(p < 0.01) ^cnot significant

Phase 2 IWAR Results (2)

Security Exercises:

DT \Leftrightarrow Fleet (d = -1.30)^c

DT \Leftrightarrow ITTC (d = -0.03)^c

ITTC \Leftrightarrow Fleet (d = -1.26)^c

System Building Exercises:

DT \Leftrightarrow Fleet (d = 0.77)^a

DT \Leftrightarrow ITTC (d = 1.41)^a

ITTC \Leftrightarrow Fleet (d = -0.63)^b

Individual Reviews:

DT \Leftrightarrow Fleet (d = 1.20)^a

DT \Leftrightarrow ITTC (d = 0.90)^b

^a(p < 0.01) ^b(p < 0.05) ^cnot significant

So What?

ROI from Accelerated Learning

- Student costs & schoolhouse infrastructure costs are the same for “A” school & DT training.
- Cost per “A” School graduate is \$12,876.
- DT graduates will have technical expertise equivalent to a Fleet IT with 7 years of experience.
- Percent of 7 year IT technical capabilities possessed by “A” school graduates: Yr(1) 10%, Yr(2) 20%, Yr(3) 40%, Yr(4) 50%, Yr(5) 65%, Yr(6) 80%; Yr(7) 95%.
- Average annual composite/burdened cost per Navy enlisted billet for 7 years of service: Yr(1-2) \$45,790, Yr(3-4) \$51,417, Yr(5-7) \$64,246.
- A 12 year time horizon.
- All “A” school training will be replaced by DT training after year 4 “overnight.”
- DT development costs of \$50 million and DT start-up costs of \$3 million.

| Training Option | Year | | | | | | | | | | | |
|-------------------------------|-------------------|-------------------|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-----------------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| “A” School | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 | A OJT/7 |
| “A” School plus Digital Tutor | A OJT/7 DTD | A OJT/7 DTD | A OJT/7 DTD | A OJT/7 DTD | -- OJT/7 DTI | -- OJT/6 DTO | -- OJT/5 DTO | -- OJT/4 DTO | -- OJT/3 DTO | -- OJT/2 DTO | -- OJT/1 DTO | -- -- DTO |

12-Year Difference in NPV

| Costs for "A" School | | Costs for Digital Tutor | |
|---|-----------------|--|-----------------|
| Cost for "A" School Graduate | 12,876 | Cost for "A" School Graduate | 12,876 |
| Cost for 24,000 "A" School Graduates (Yrs 1-12) | 309,024,000 | Costs for 8,000 "A" School Graduates (Yrs 1-4) | 103,008,000 |
| Cost per student for 7 yrs of OJT | 172,949 | Cost per student for 7 yrs of OJT | 172,949 |
| Total OJT cost for 24,000 "A" School Graduates | 4,150,783,200 | Total OJT cost for 8,000 "A" School Graduates | 1,383,594,400 |
| | | DT Dev. & Start-Up | 53,000,000 |
| | | Total Cost for 16,000 DT | 206,016,000 |
| Total Cost | \$4,459,807,200 | Total Cost | \$2,789,361,200 |
| Total Net Present Value | \$3,835,490,179 | Total Net Present Value | \$2,515,704,812 |

Net Present Value Difference: \$3,835 M - \$2,516 M = \$1,319 M

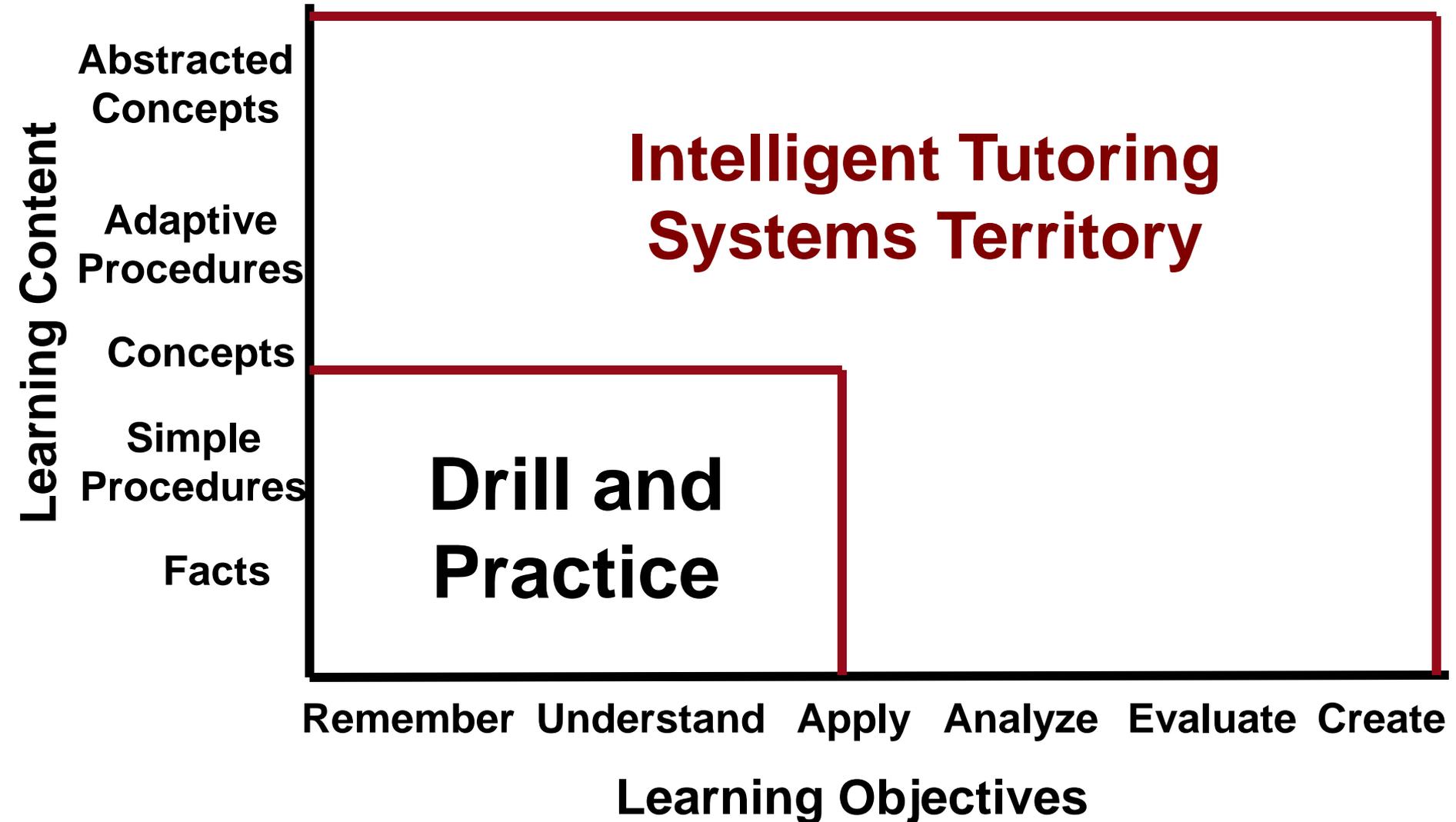
How it works: Digital Tutor Instructional Techniques

- **Spiral curriculum with “authentic experience”**
- **Appropriate conceptual levels**
- **Cloning tutorial and domain expertise**
- **Parsimonious hints**
- **Early intervention in errors**
- **Early success**
- **Mixed initiative dialogue**

Some Reflections on the Tutor

- **The primacy of Front End Analysis and Cognitive Task Analysis**
- **Serious choice of tutors**
- **The individualization imperative (from Yerkes-Dodson inverted “U” to deliberate practice)**
- **Importance of economic analyses**
- **Intrinsic motivation**
- **Deep learning for retention and transfer**

Instructional Strategy & Objectives



(Framework courtesy of Anderson & Krathwohl, 2001)

Some (of many) Remaining Issues

- **Was the Digital Tutor that good or were the alternatives that bad?**
- **What is curriculum alignment for training versus education?**
- **How transferable is the Digital Tutor approach?**
- **How can we reduce the costs to produce other Digital Tutors?**

Some Implications of All This

- **The fiscal folly of inadequate residential training**
- **Training is an investment not a TTHS expense**
- **Choose to increase amount (and depth) learned over reducing time to learn**
- **We can greatly accelerate the acquisition of expertise – and should – the Digital Tutor is not the only example (e.g., Sherlock, IMAT)**
- **We can similarly accelerate acquisition of basic skills – (e.g., Atkinson's reading studies)**
- **ROI in training is relatively insensitive to development costs at scale**

There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things.

- Niccolò Machiavelli

**Questions? Comments?
Objections? Complaints?**

Thank you!