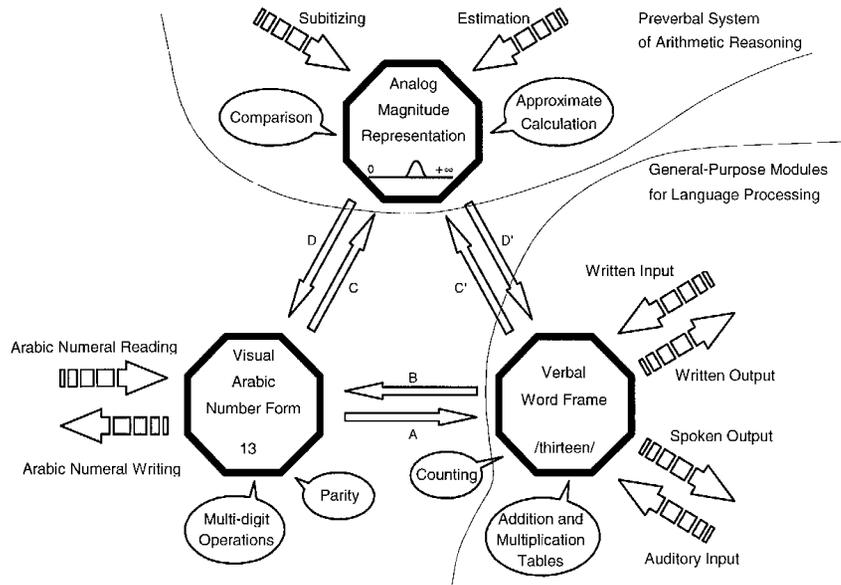
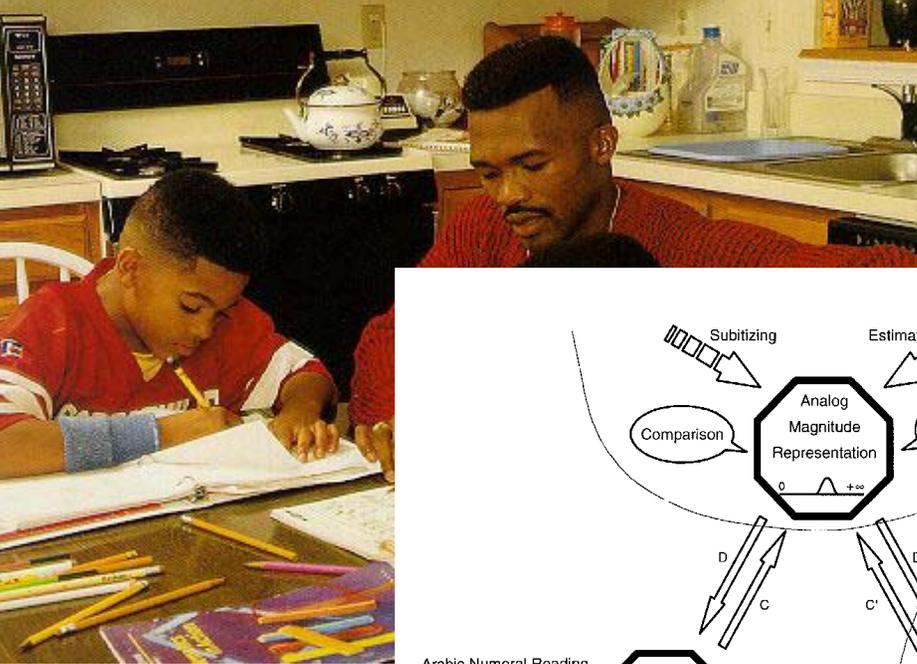


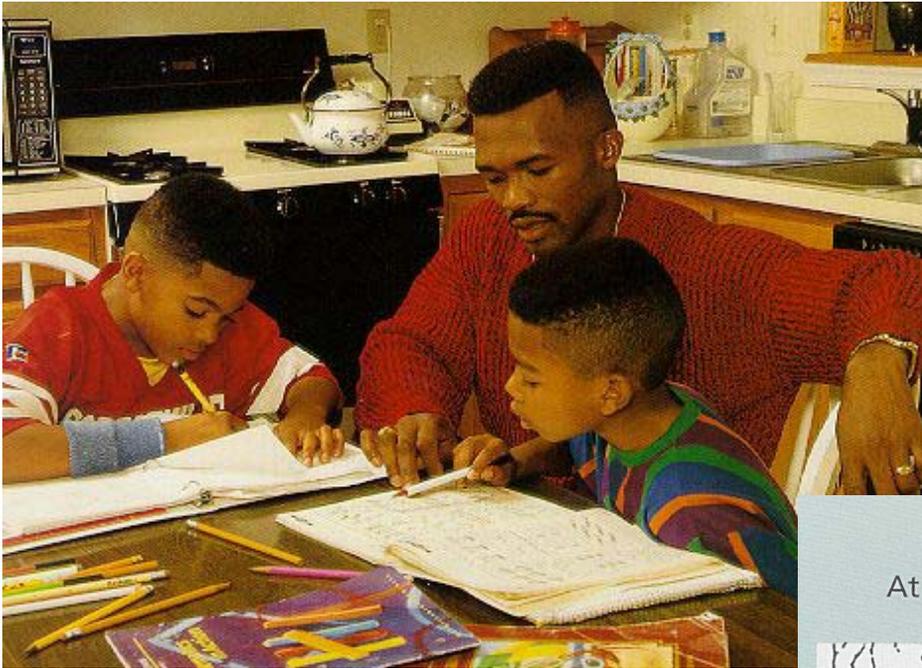
# Herbert Spencer Lecture

A rational approach to education:  
integrating behavioral, cognitive,  
and brain science



d 14 Years Old

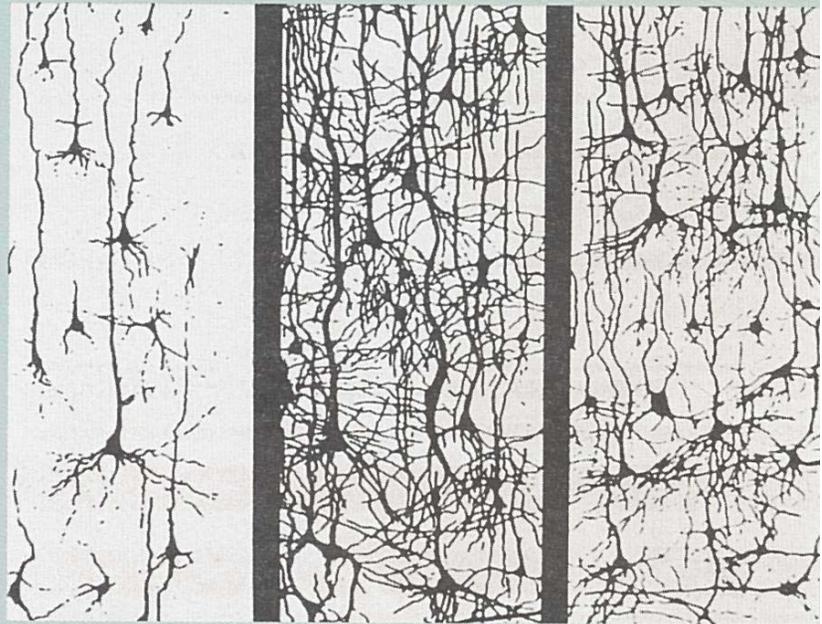




At Birth

6 Years Old

14 Years Old



# Brain Metabolism and Learning

Chugani, whose imaging studies revealed that children's brains learned fastest and easiest between the ages of four and ten, said these years are often wasted because of lack of input. (*R. Kotlulak, Inside the Brain, 1996, p. 46*)

Chugani's findings suggest that a child's peak learning years occur just as all those synapses are forming. (*D. Viadero, Education Week, September 18, 1996, pp. 31-33*)

Wayne State neurobiologist Harold Chugani points out that the school-age brain almost "glows" with energy consumption, burning a 225 percent of the adult levels of glucose. The brain learns fastest and easiest during the school years. (*E. Jensen, Teaching with the Brain in Mind, 1998, p.32*)

Thus, it is now believed by many (including this author) that the biological "window of opportunity" when learning is efficient and easily retained is perhaps not fully exploited by our educational system. (*H. Chugani, Preventive Medicine 27:184-88, 1998*)

# Metabolic Brain Images

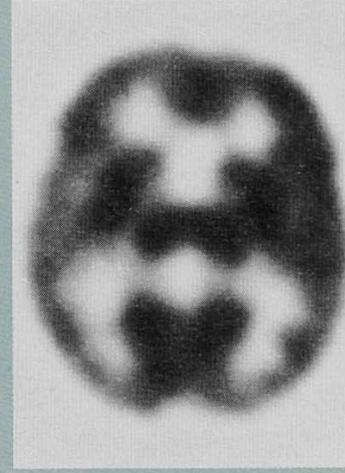
5 Days



2 Months



1 Year



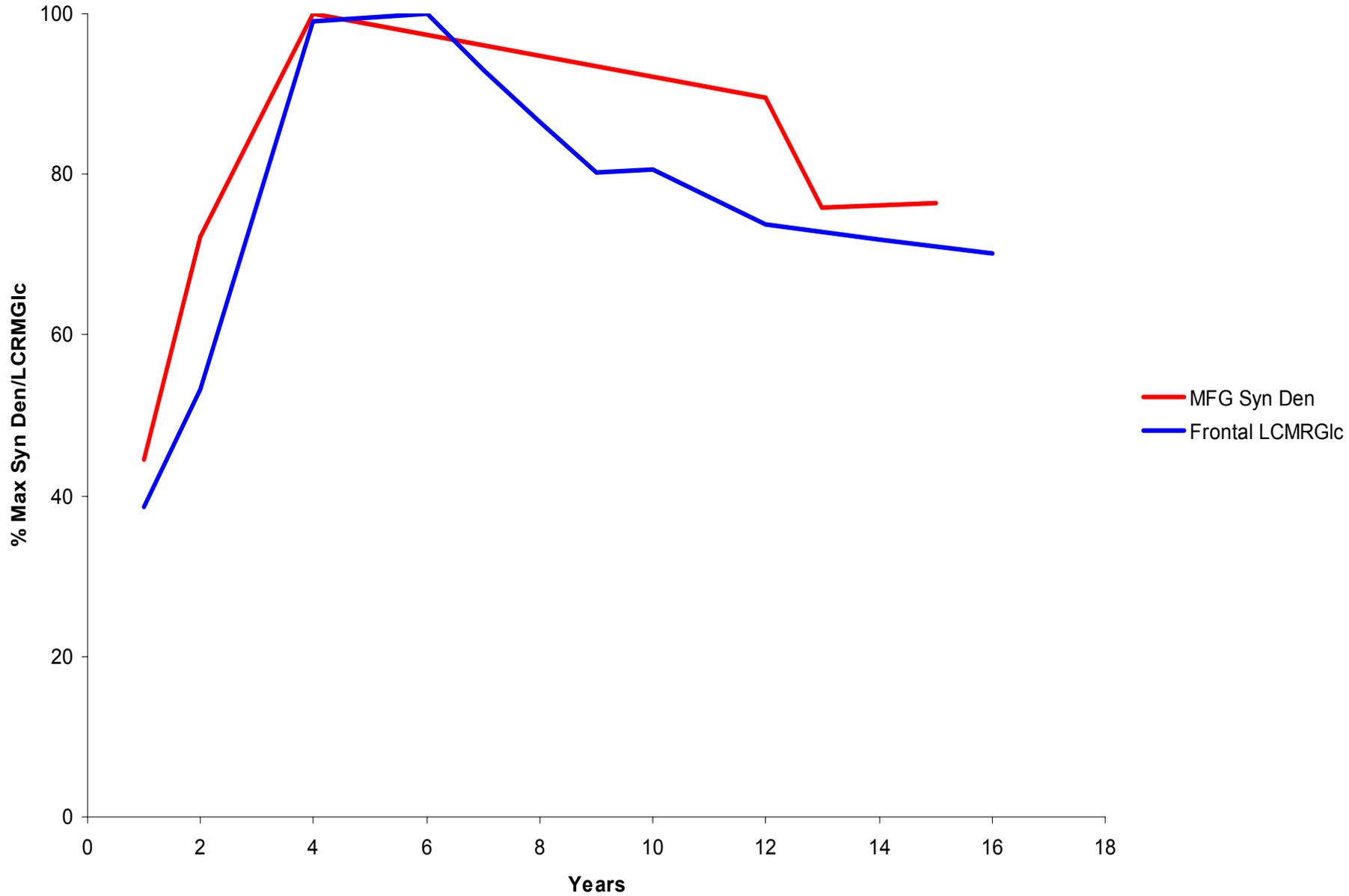
28 Years



*RAPID EARLY DEVELOPMENT: These PET scans suggest that the brain of a one year old more closely resembles an adult's brain than a newborn's.*

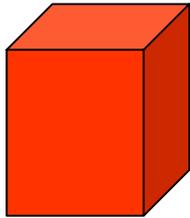
Source: H.T. Chugani

Huttenlocher/Chugani Data: Frontal Cortex

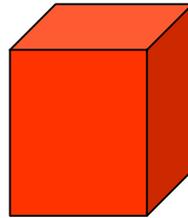


# Oddity with Trial Unique Objects

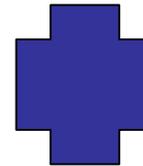
Trial 1



-



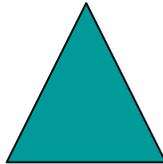
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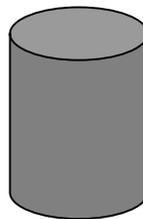
+

15 sec Intertrial Interval

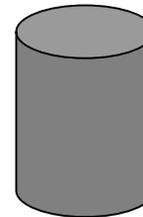
Trial 2



+

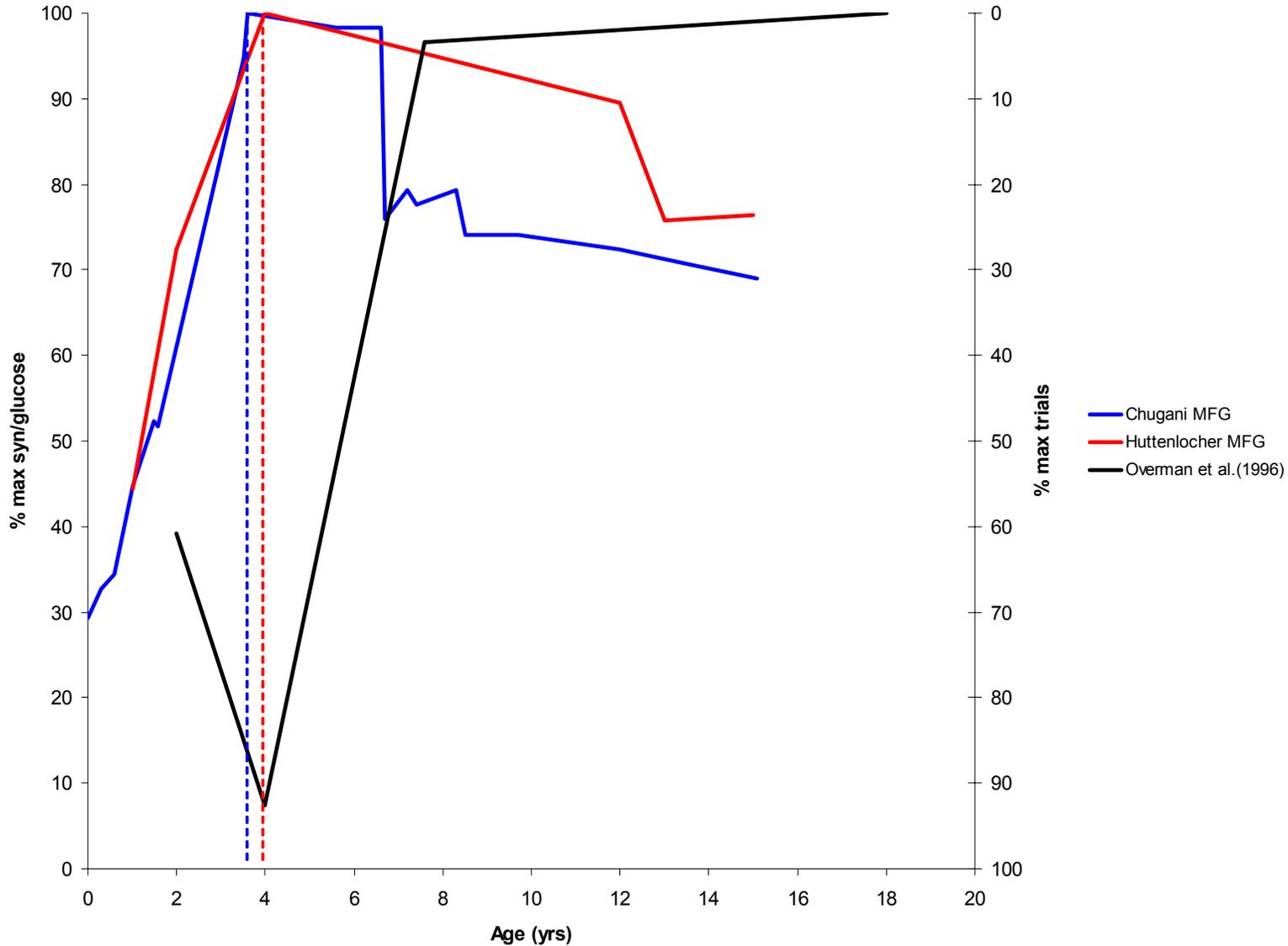


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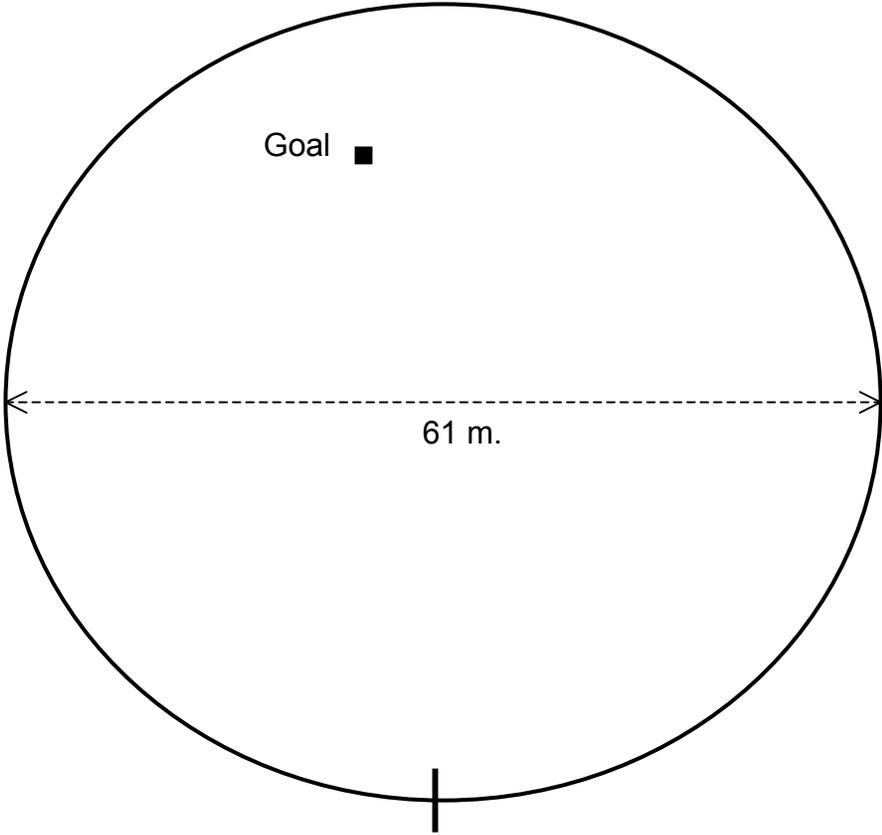
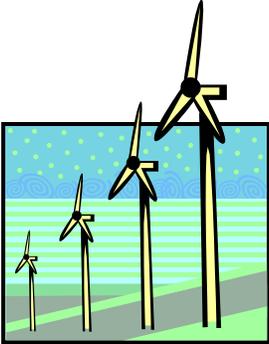


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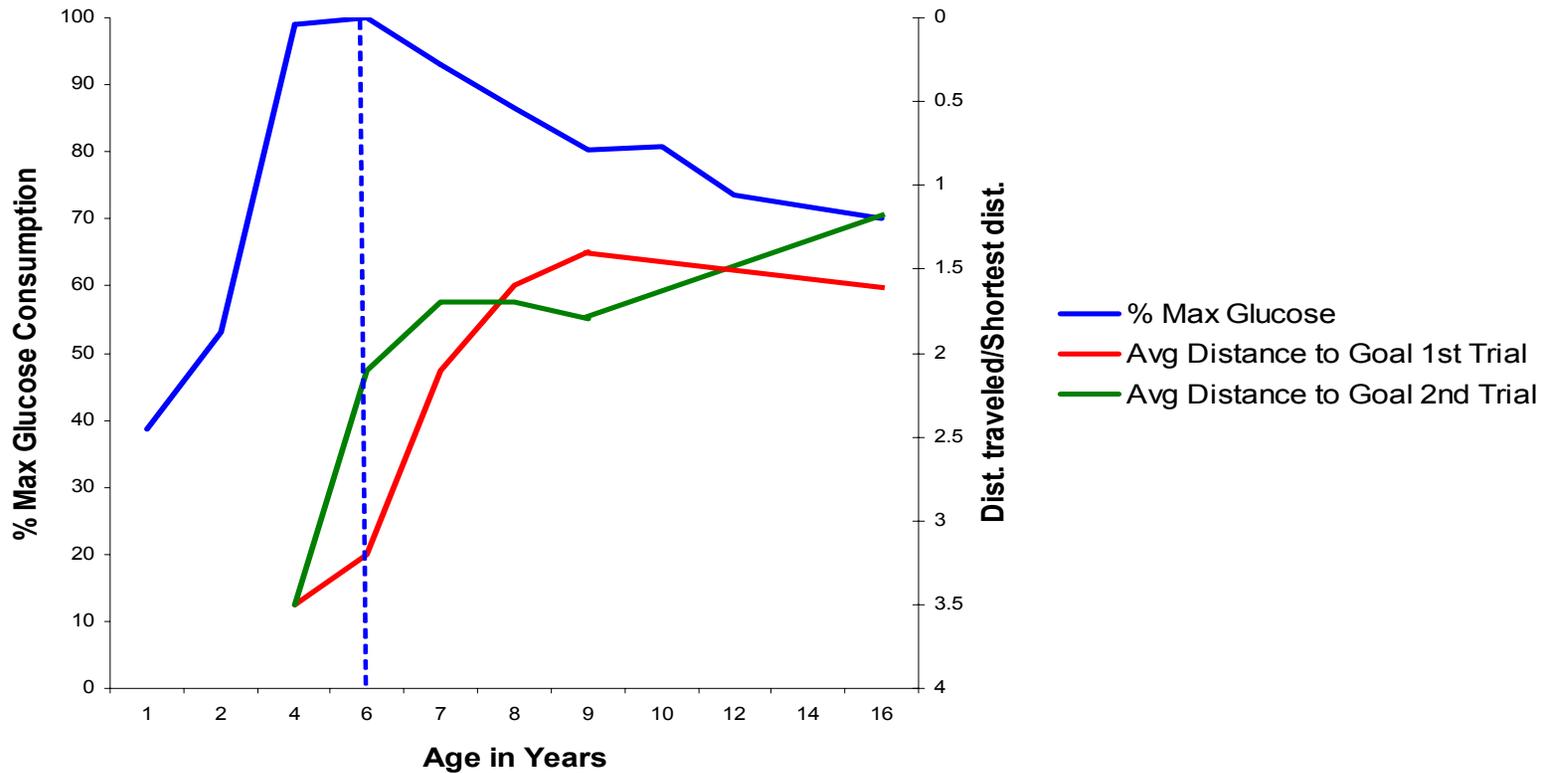
# Learning A Non-Verbal Oddity Task



# Open Field Navigation Task

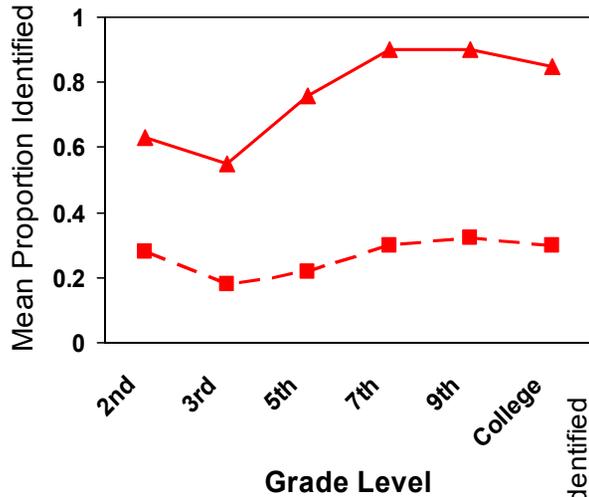


# Learning an Open Field Navigation Task

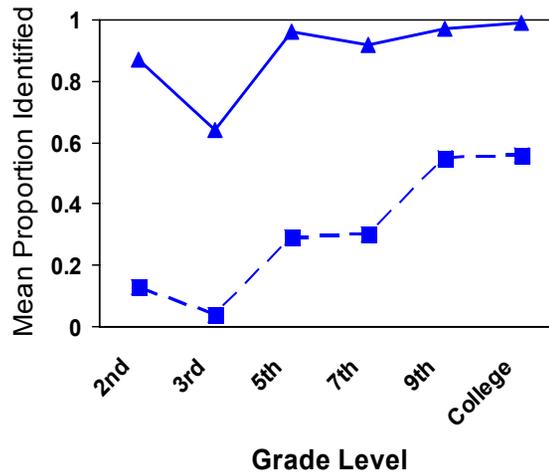


# Development of Expert/Novice Knowledge (Means & Voss 1985)

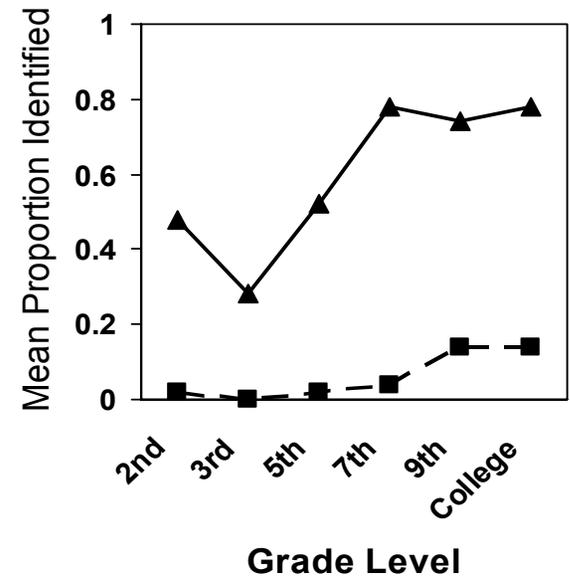
## Basic Actions



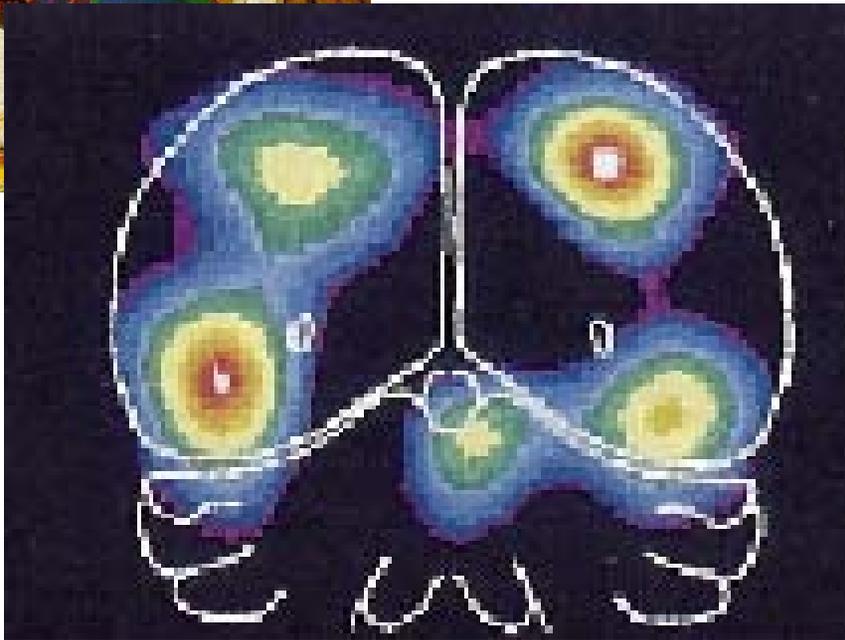
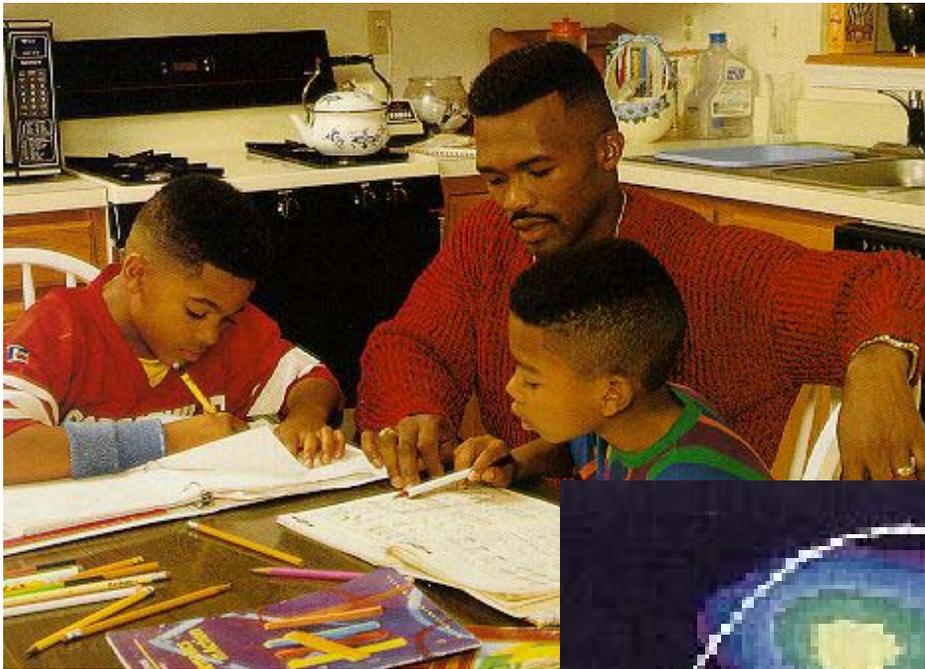
## Subgoal Breadth



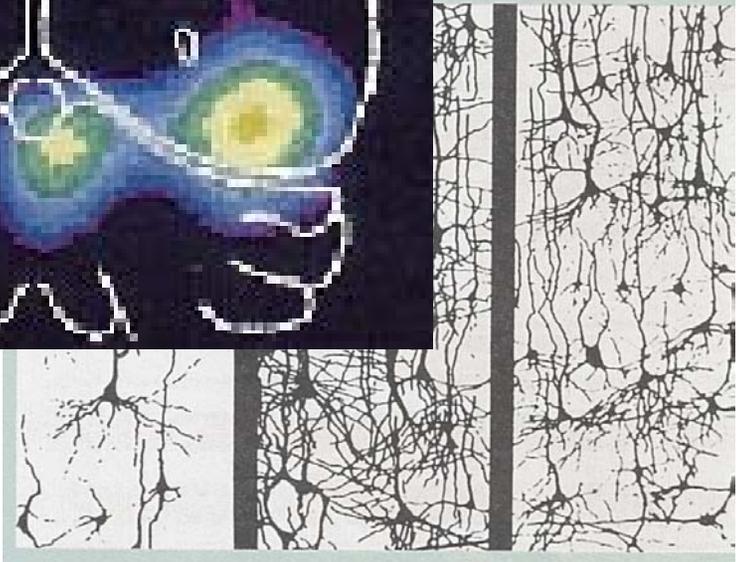
## High Level Goals



Expert ————  
Novice - - - - -

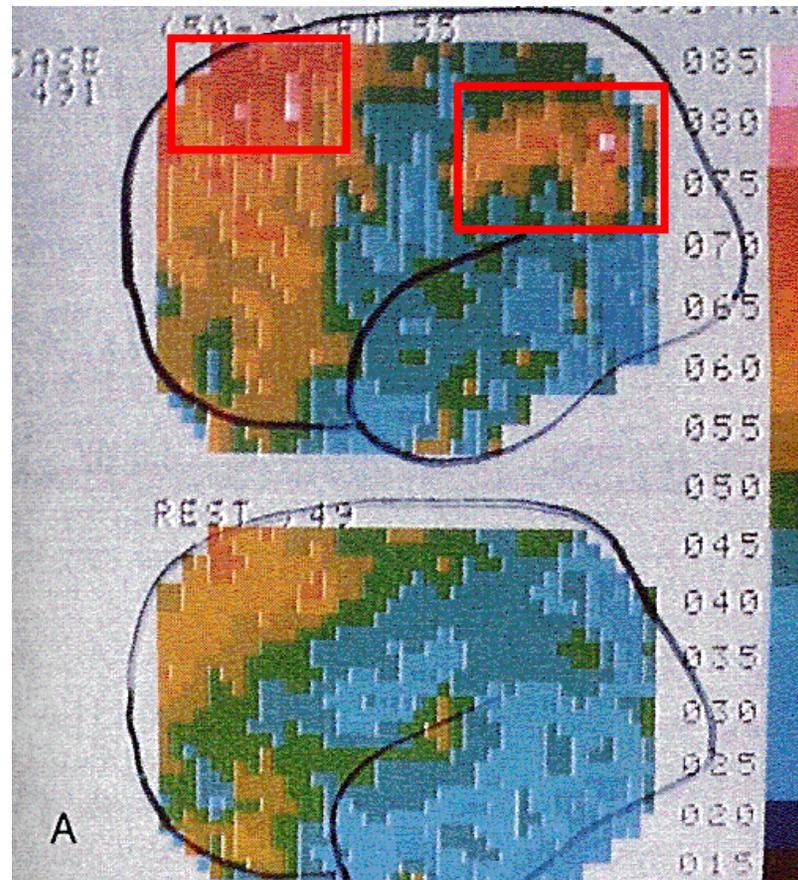


d 14 Years Old

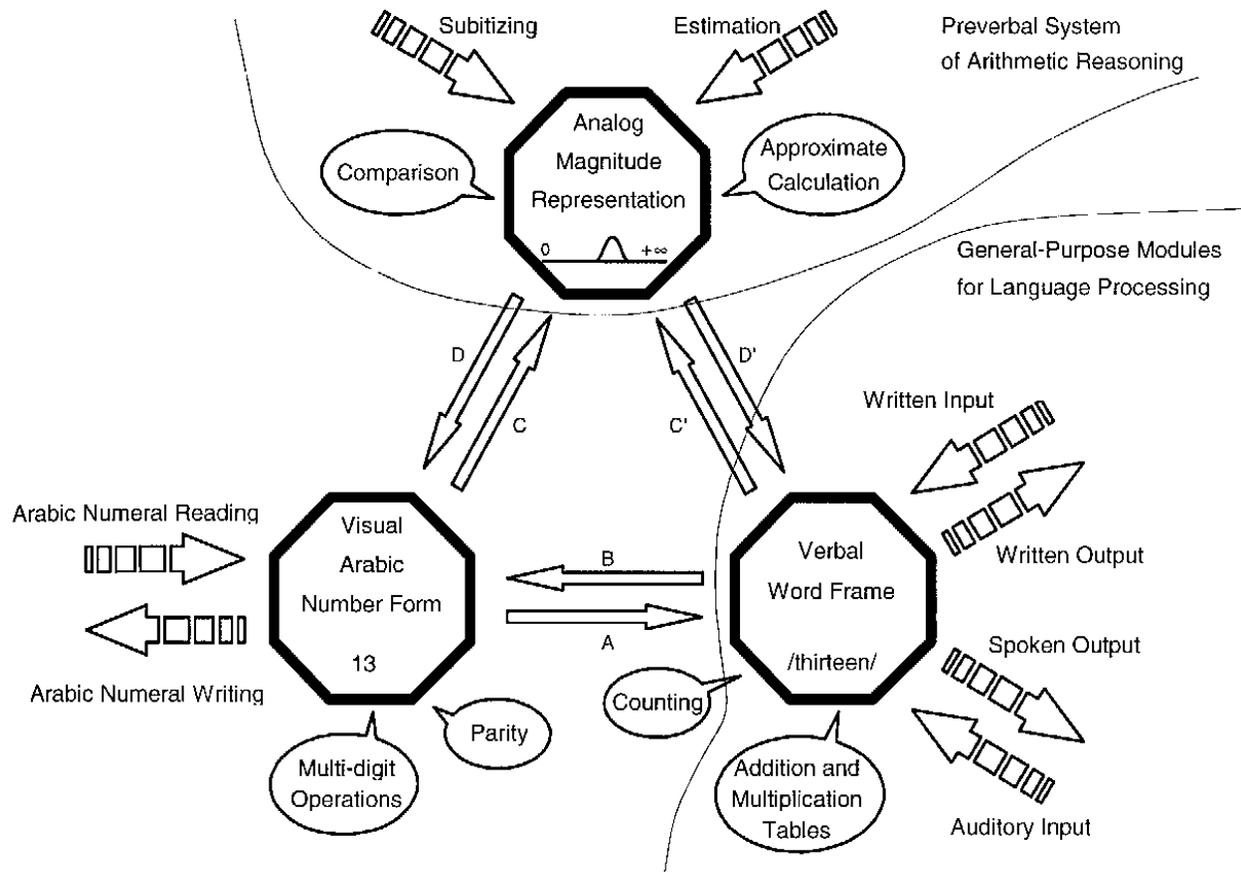


# Imaging Number Processing: An early study

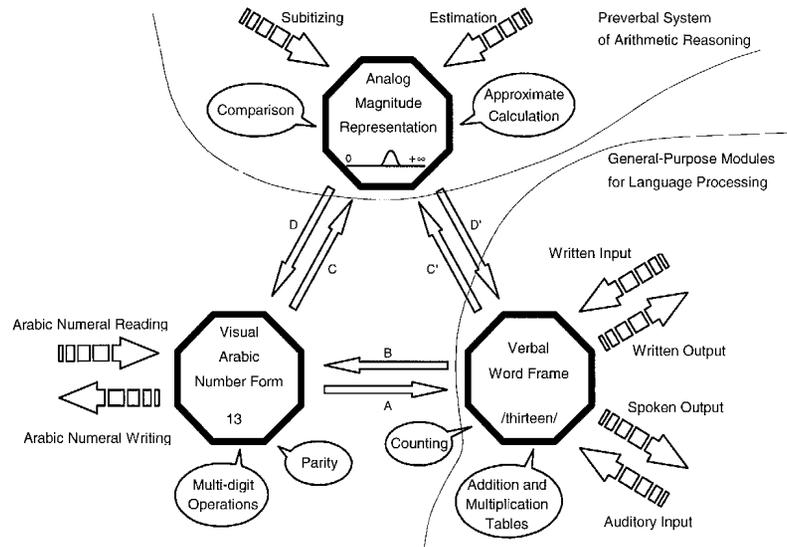
Counting  
backward  
from 50 by 3s



# Triple Code Model of Number Processing



# What kinds of evidence support the model?



Evidence derives from four kinds of studies:

- Numerical competence of normal and gifted adults
- Development of numerical competence in children
- Animal studies of sensitivity to numerical parameters
- Neuropsychological studies of brain-lesioned patients

# Examples of Supporting Evidence

- **Adult performance on single-digit operations (2 + 3, 4 x 7)**
  - Response time to solve such problem shows the *problem size effect* and *tie effect*
  - Calculation time correlates with the product of the operands or square of their sum except for ties ( 2 + 2, 4 x 4) which show constant RT
  - These patterns are explained by duration and difficulty of memory retrieval from a stored lexicon.
- **Children's performance on single-digit addition**
  - RT for younger children is proportional to the sum
  - RT for older children is proportional to the smaller addend
  - Younger children use the *count-all* strategy, while older children use the *count-on from larger addend* strategy.
- **Pigeons and rats can be taught to discriminate two “numerousities”**
  - Discrimination is easier when the distance between the two numerosities is larger
  - Animals, like humans, manifest a “distance effect” when making numerical comparisons.
  - Thus, animals, like humans, use an analogue representation in making numerical comparisons.

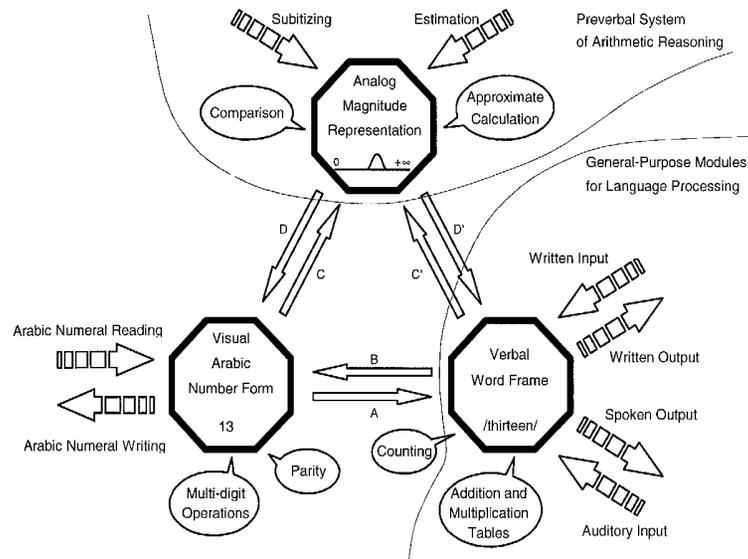
# Neuropsychological Inference

## Task

## Patient Profile

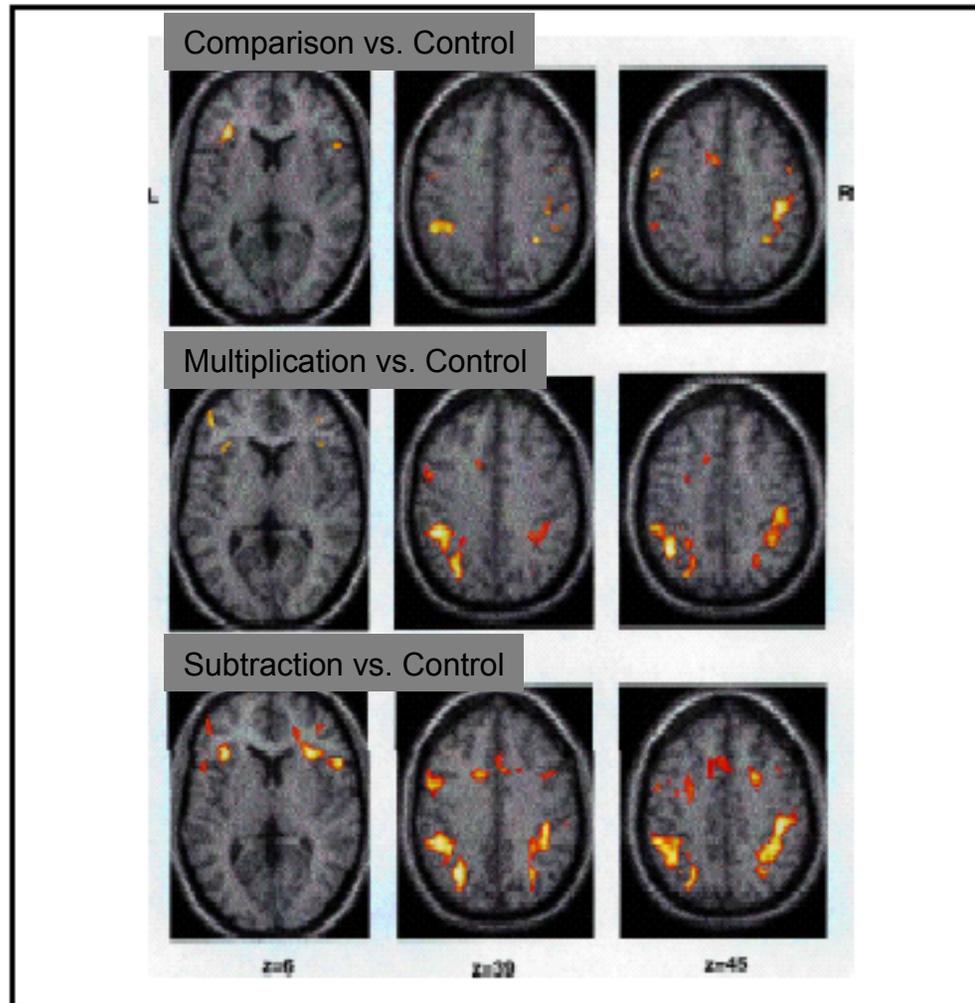
- Reading number words aloud ➤ impaired
- Writing number words to dictation ➤ Impaired
- Responding to verbally to questions of numerical knowledge ➤ impaired
- Comparing orally presented and spelled out number words ➤ impaired
  
- Comparing Arabic numerals ➤ spared
- Making proximity judgments of Arabic numerals ➤ spared
- Reading a thermometer ➤ spared
  
- Solving subtraction problems ➤ spared
- Solving multiplication problems ➤ impaired

# Experimental Design for Brain Mapping Study of Number Processing

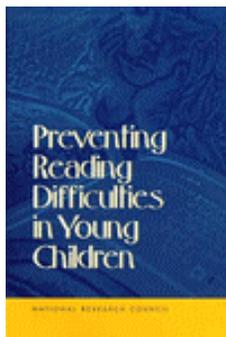


Task	Stresses
Mentally name letters	Control condition
Mentally name target digit	Visual & verbal systems/representations
Compare target digit with standard, mentally say "larger", "smaller"	Magnitude system/representation.
Multiply target digit by 3, mentally name	Verbal system/representation
Subtract target digit from 11, mentally name	Magnitude representation (relative to multiplication)

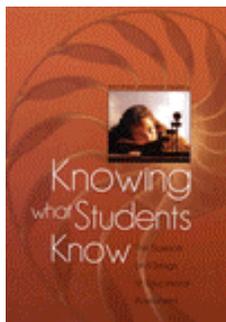
# Number Tasks: Activated Brain Areas



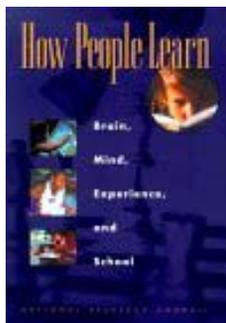
- No brain science mentioned or cited.



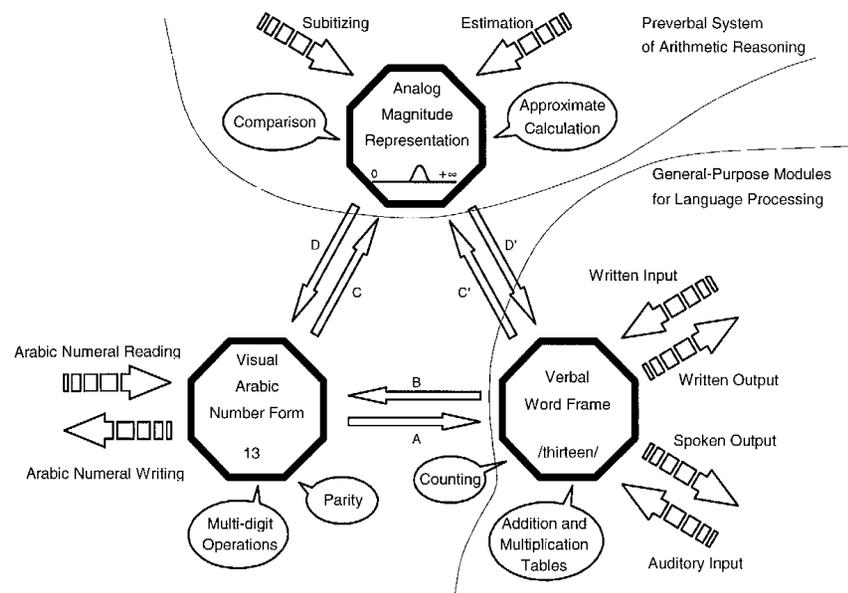
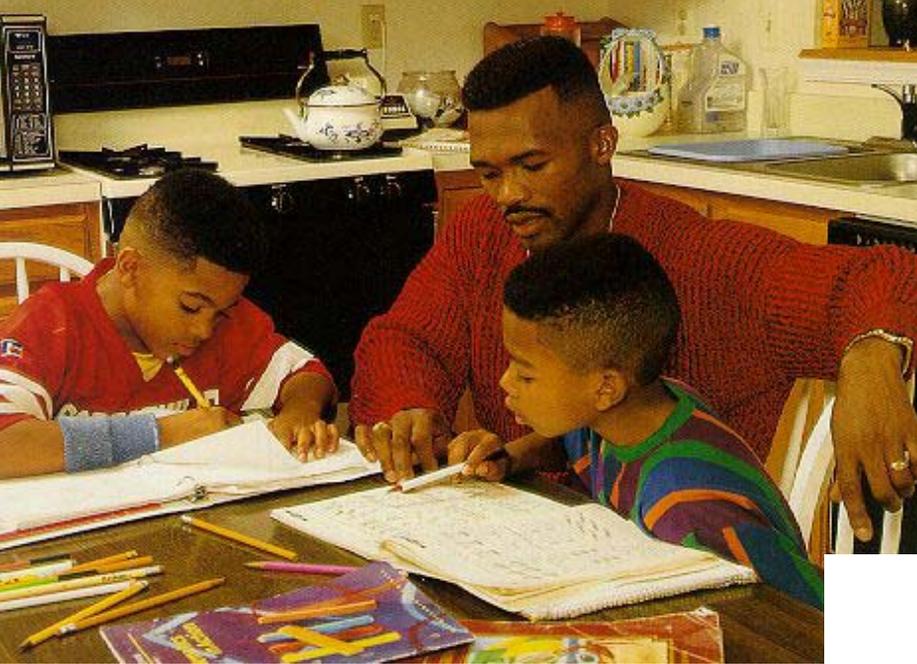
- Cites two neuroscientific studies (Shaywitz, 1996, Shaywitz et al. 1998), but finding anomalous brain systems says little about change, remediation, response to treatment.



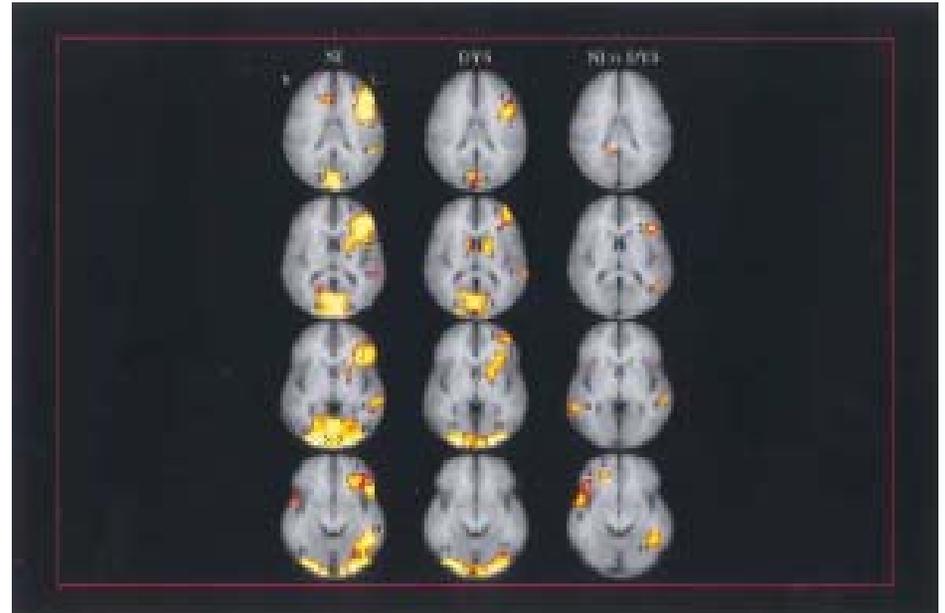
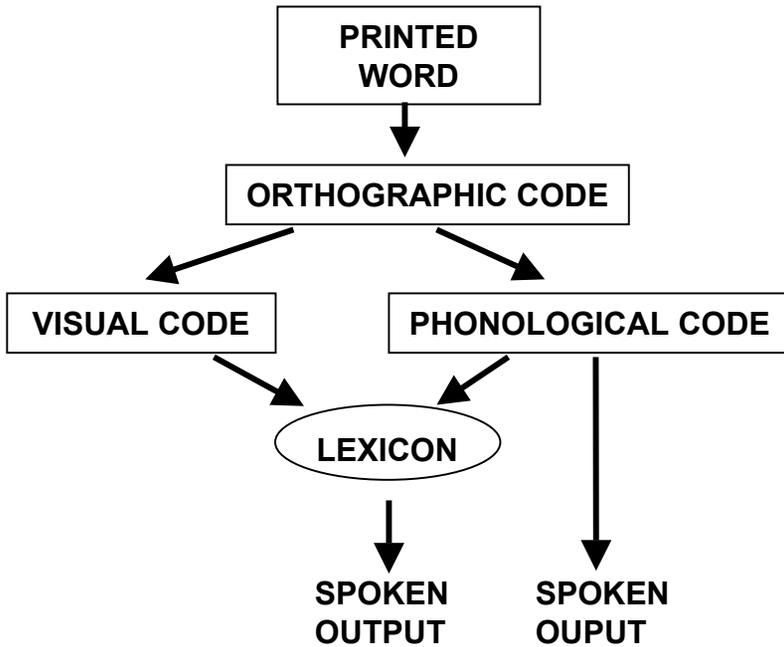
- A six-page appendix, “Cognition and Brain Science, dismisses “brain-based” claims about lateralization, enriched environments, and critical periods, but acknowledges promise of some neuroscientific research on dyslexia (e.g. Shaywitz, Tallal, Merzenich)



- One ten-page chapter concludes:
  - our current understanding of how learning is encoded by structural changes in the brain provides no practical benefit to educators
  - brain scientists should think critically about how their research is presented to educators

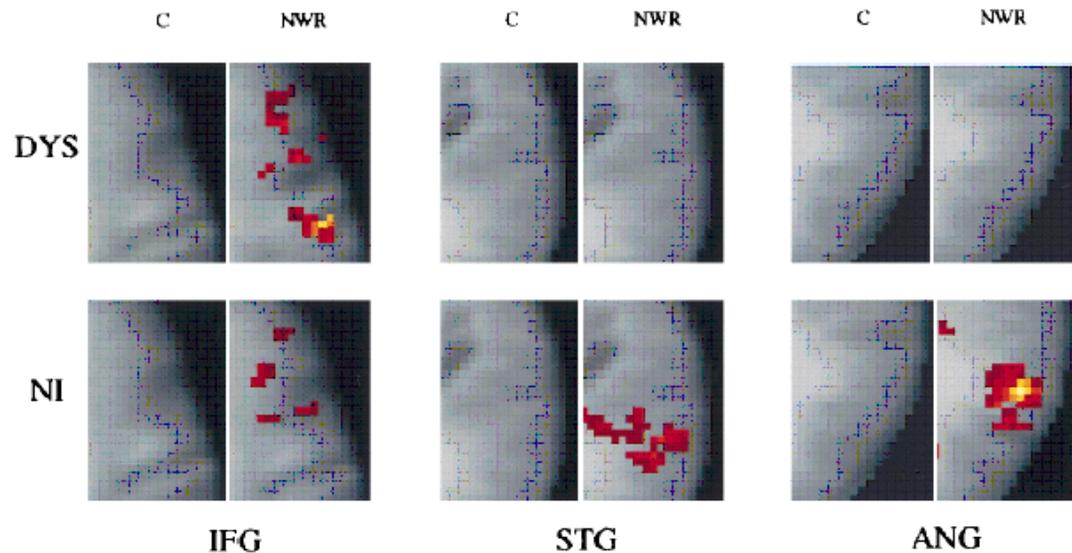


## Children



## Adults

Phonological Task Hierarchy
Line orientation (/> vs. \<)
Letter case (Bb vs. bB)
Single letter rhyme (T vs. V)
Non-word rhyme (leat vs. jete)
Semantic category (rice vs. corn)



# Evidence of Training Studies

- Numeracy
  - Numeracy requires integrating three representations of number
  - Learning problems arise from inadequate integration of these representations
  - Training studies show learning problems remediable when representations and their integration are taught explicitly (Resnick, Case & Griffin)
  
- Early Reading
  - Word recognition requires integrating linguistic representations
  - Dyslexia can arise from inadequate integration of orthographic/phonological representations
  - Training studies show explicit integrative instruction is beneficial (Bradley & Bryant 1983, NRP, NRC)

# Linking Number Words to Magnitudes

Learning first formal arithmetic

# Kindergartner's Performance on Number Knowledge Test (% Correct)

<b>Item</b>	<b>High SES</b>	<b>Low SES</b>
Here's a candy. Here are 2 more How many do you have?	100	92
Which pile has more? (Show two piles of chips.)	100	93
How many triangles are there? (Show mixed array of triangles/circle.)	85	79
If you had 4 candies and received 3 more, how many would you have?	72	14
What comes two numbers after 7?	64	28
Which number is bigger/smaller? (Show two Arabic digits.)	96	18

# Mean Scores (s.d) on Number Knowledge Test Pre- and Post Number Worlds Instruction

<b>Group</b>	<b>Pre-K</b>	<b>Post-K</b>	<b>Post-Gr. 1</b>
<b>Treatment 1</b>	<b>6.3(2.5)</b>	<b>11.2(2.7)</b>	<b>16.5(3.0)</b>
<b>Treatment 2</b>	<b>5.7(2.5)</b>	<b>12.1(1.9)</b>	<b>17.4(2.0)</b>
<b>Control 1</b>	<b>7.2(2.4)</b>	<b>8.9(2.4)</b>	<b>12.5(2.8)</b>
<b>Control 2</b>	<b>7.2(2.0)</b>	<b>9.3(2.8)</b>	<b>14.3(2.9)</b>
<b>Norm 1</b>	<b>9.8(3.2)</b>	<b>11.4(2.8)</b>	<b>16.9(4.0)</b>
<b>Norm 2</b>	<b>10.6(1.7)</b>	<b>13.5(2.9)</b>	<b>18.8(2.9)</b>

**Expected Score: K = 9 - 11; Grade 1 = 16 -18**

# Linking Number Words with Visual Arabic Numerals

Learning Arabic algorithms for  
multi-digit computation

# Linking Calculation with Counting

## Arithmetic Bugs

Smaller from larger:

$$\begin{array}{r} 930 \\ - 653 \\ \hline 433 \end{array}$$

Borrow from zero:

$$\begin{array}{r} 602 \\ - 437 \\ \hline 265 \end{array}$$

Borrow across zero:

$$\begin{array}{r} 602 \\ - 327 \\ \hline 225 \end{array}$$

Brown & VanLehn

Problem: 300 - 139

The child:

1. Displays larger number in blocks
2. Writes problem in column aligned format
3. Trades 1 hundred block for 10 tens.
4. Notates the trade.
5. Trades 1 ten block for 10 units blocks
6. Notates the trade.
7. In each denomination removes the number of blocks specified in the bottom number.
8. In each column notates the number remaining.

L. Resnick

# The Problem of Pre-existing Representations

Learning fractions

# Understanding Fractions

TABLE 10.2  
Examples of How Children in the Cohen, Gelman, and Massey Study  
Read and Explained their ordering of  $1\frac{1}{3}$  and  $1\frac{1}{4}$

Grade and Subject No.	How Fractions Were Read	Responses To Order Question	
		Order Choice	Explanation of Choice
Kindergarten	1. One, one three; One, one four	$1\frac{1}{4}$	four is more than three
	2. One plus three; One plus four	$1\frac{1}{4}$	$4 + 1 = 5$ and $1 + 3 = 4$
	3. One minus one plus three; One minus four	$1\frac{1}{4}$	cause there's a four
	4. One plus a one plus three; One plus four	$1\frac{1}{4}$	cuz four on the bottom and three on the bottom
Grade 1	1. One and a third; One and a quarter	$1\frac{1}{3}$	like 'regular' $\frac{1}{3}$ & $\frac{1}{4}$ —it's still bigger with the one since they both have it
	2. One hundred and thirteen; One hundred and fourteen	$1\frac{1}{4}$	three is less than four; same thing in the 100's
	3. Eleven three; Eleven four	$1\frac{1}{4}$	it has one number higher underneath
	4. One third; One fourth	$1\frac{1}{4}$ $1\frac{1}{4}$	three comes before four; lower when you count
Grade 2	1. Three and a half; Four and a half	$1\frac{1}{4}$ $1\frac{1}{4}$	three comes before four
	2. One third; One fourth	$1\frac{1}{3}$	$\frac{1}{4}$ has a smaller piece than a $\frac{1}{3}$
	3. Three and a half; Four and a half	$1\frac{1}{4}$	four is bigger than three
	4. Three-one-one; One-one-four	$1\frac{1}{4}$	that has four and this has three

# Understanding Fractions

**TABLE 10.1**  
**Percent Children In Follow-Up Fraction Study Who Correctly Read  $1\frac{1}{3}$  and  $1\frac{1}{4}$ ; Correctly Choose  $1\frac{1}{3}$  as more than  $1\frac{1}{4}$ ; and Do Not Explain Their Ordering Choices by Comparing Whole Numbers**

<i>Grade</i>	<i>Percent Correct Readings</i>	<i>Percent Correct More Choices</i>	<i>Percent Who Do Not Give Whole Number Explanations</i>
K	0	0	20
I	30	20	20
II	20	20	10

# The Promise of Pre-existing Representations

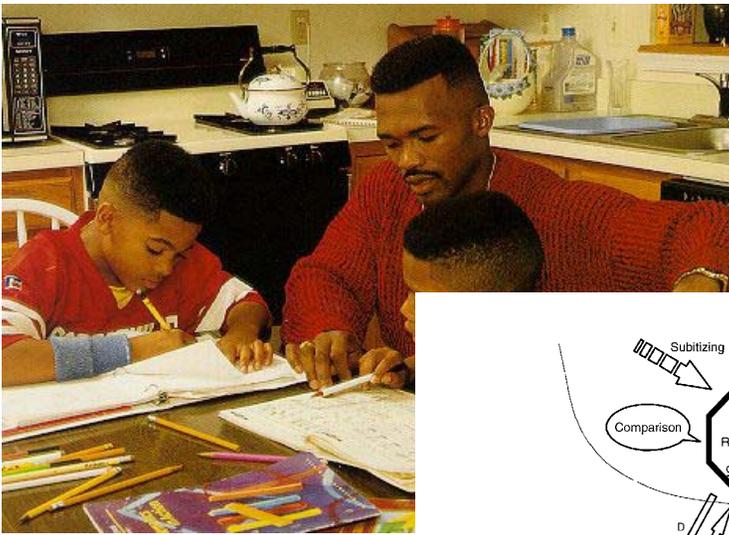
Teachers' misrepresentations and  
teaching algebra

# From Arithmetic to Algebra

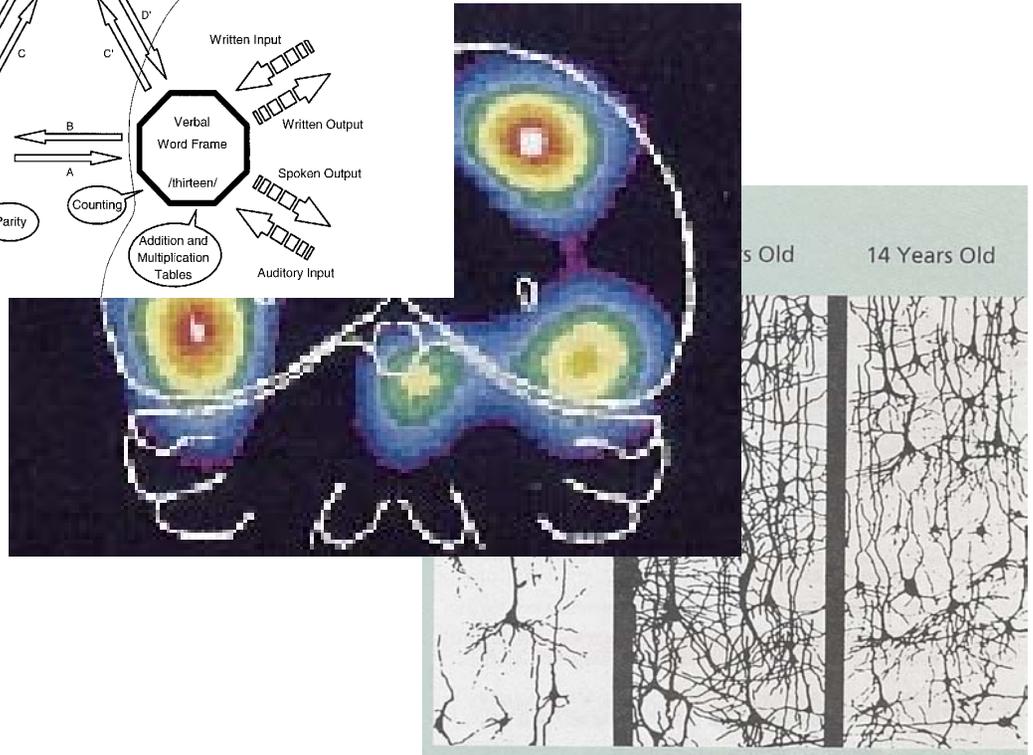
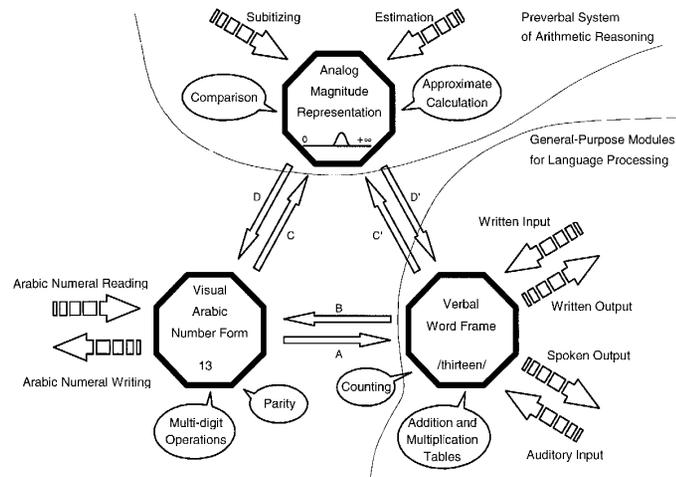
Problem Type
When Ted got home from work, he took the \$81.90 he earned that day and subtracted the \$66 received in tips. Then he divided the remaining money by the 6 hours he worked and found his hourly wage. How much per hour does Ted earn?
Starting with 81.9, if I subtract 66 and then divide by 6, I get a number. What is it?
Solve: $(81.90 - 66)/6 = y$ .
When Ted got home from work, he multiplied his hourly wage by the 6 hours he worked that day. Then he added the \$66 he made in tips and found he earned \$81.90. How much per hour does Ted make?
Starting with some number, if I multiply it by 6 and then add 66, I get 81.9. What number did I start with?
Solve: $y \times 6 + 66 = 81.90$

Teacher Rank	Student Performance
4	1
1	2
2	5
6	3
5	4
3	6

Rank correlation: **-.09**



*Cognitive science provides an empirically based technology for determining people's existing knowledge, for specifying the form of likely future knowledge states, and for choosing the types of problems that lead from present to future knowledge. - D. Klahr & R. Siegler*



*The challenge for the future is to understand at a deeper level the actual mental operations assigned to the various areas of [brain] activation. Before this goal can be achieved, the experimental strategies used in PET studies must be refined so that more detailed components of the process can be isolated.- M. Posner & M. Raichle*

