The Whys, Whats and Wherefores of Spatial Development

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Why Spatial?

- Spatial skills and spatial learning are important
  - in human functioning in general
  - in the STEM disciplines in specific
- There are sex-linked and SES-linked differences in spatial intelligence--addressing these differences is important for social equity
- Spatial skills and spatial learning can be improved, thus increasing the STEM workforce and the population's ability to engage in STEM discourse

Spatial Skills and Learning Are Important

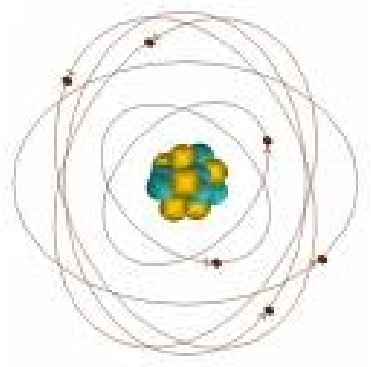
- In an evolutionary context, spatial adaptation is vital
- In modern everyday life, spatial thinking is used both in everyday tasks and in reasoning and communication

Typology of Spatial Skills

	Intrinsic (Within Object)	Extrinsic (Between Objects)
Static		
Dynamic		

The Third Dimension: Scale

- What is an object varies according to scale
  - Although objects that can be handled are likely privileged (action-to-abstraction theme)



Divides in the Study of Spatial Development

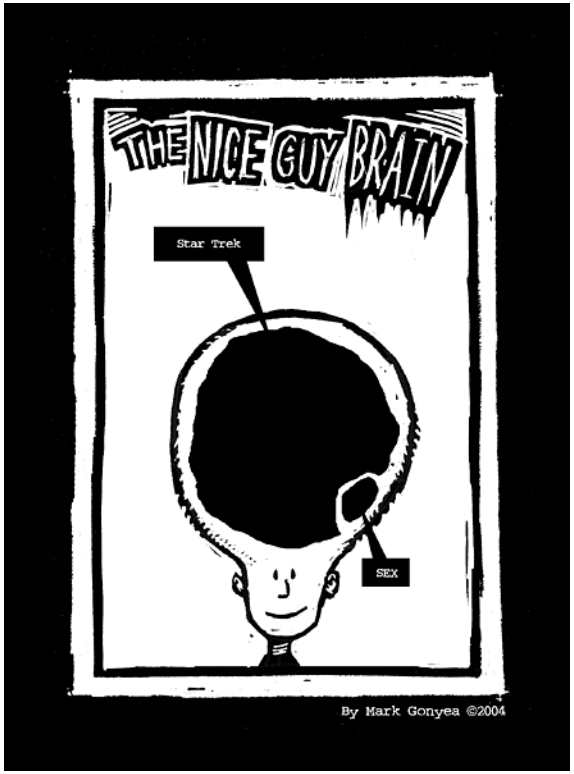
- Fundamental questions about nativism and empiricism have largely focused on normative development of navigation
- Research on individual differences and on application has largely focused on object-centered processing, especially mental rotation

Part 1: Three Theoretical Issues

- Modularity of mind
  - Adaptive pressure works to select specific mental abilities
- Nativism versus empiricism
  - These evolutionarily-selected modules are innately specified
- Language and thought
  - Human language integrates and enriches these modules

Massive Modularity?

- Innate modules have proliferated
  - Language acquisition
  - Face processing
  - Theory of mind
  - Cheater detection
  - Geometric module

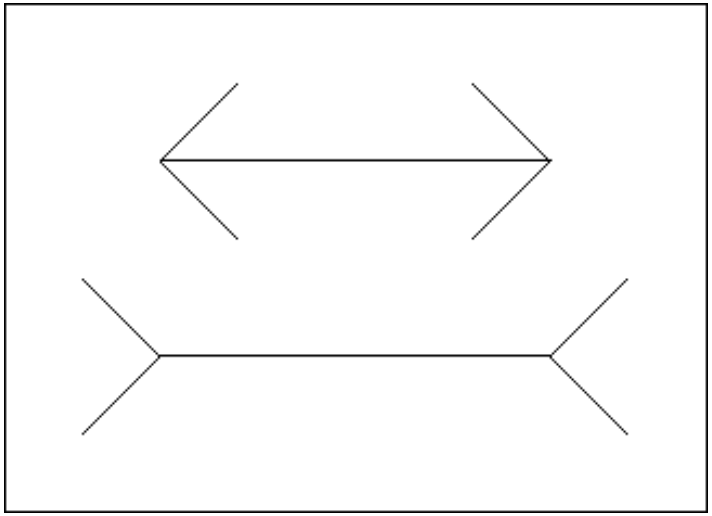


Core Knowledge Perspective

- Spelke & Kinzler (2007) →
  - Geometric relations
  - Object representation
  - Number
  - Actions
  - Social partners

What Do We Mean By Modularity?

- *Modular cognitive systems are domain specific, innately specified, hard wired, autonomous, and not assembled.*
  - Fodor (1983, p. 37)

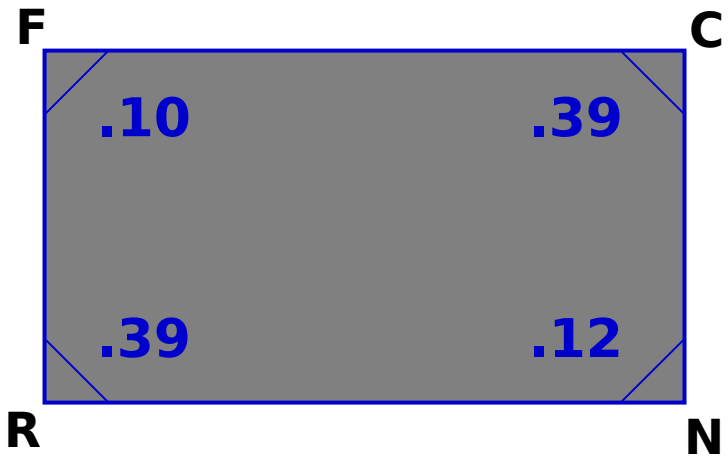


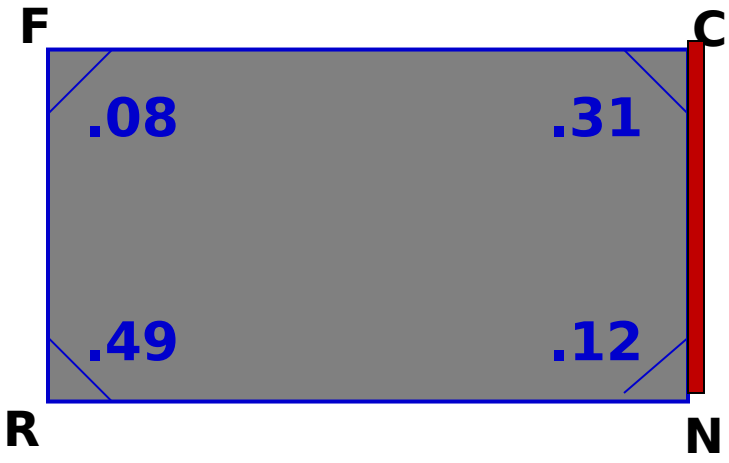
Case Study of the Geometric Module

- A representation of geometric information that guides reorientation following disorientation
- That does NOT use nongeometric information even when doing so would be advantageous

Hermer & Spelke (1996): Search Rates for Toddlers

White Room



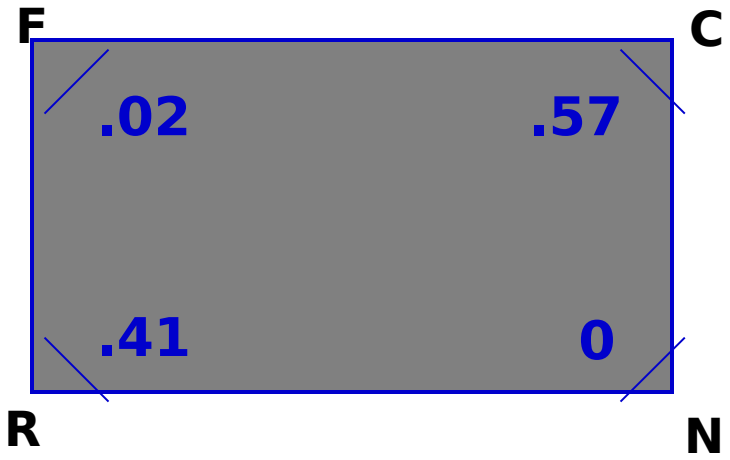


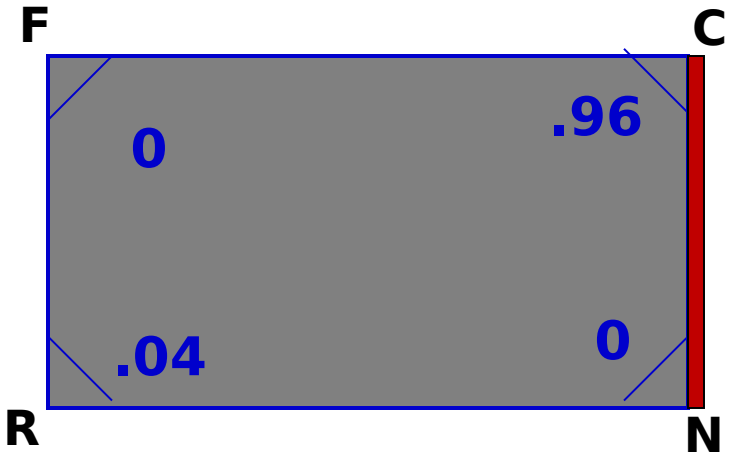
C = Correct
N = Near

R = Reversal
F = Far

Hermer & Spelke: Search Rates for Adults

White Room





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Language-as-Bridge Hypothesis

- Adults may have a further system of representation that is uniquely human and that emerges over the course of development. This system may connect to many other systems of representation, regardless of their domain-specific content. Its operation may be governed by rules and principles allowing the arbitrary combination of information from distinct, domain-specific sources….The language faculty appears to have all the right properties to serve as this uniquely human combinatorial system of representation. --Hermer-Vazquez, Spelke & Katsnelson (1999, p. 34)

Support for Role of Language

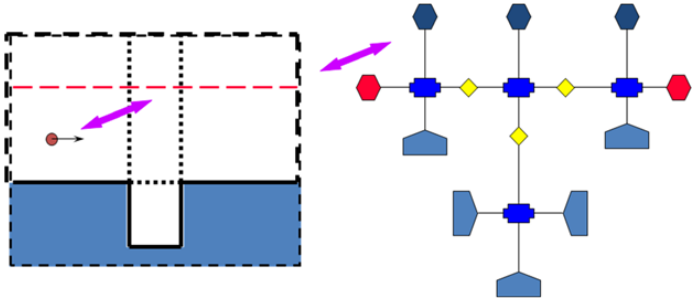
- Transition to feature use at 6 years is correlated with productive use of *left* and *right*
  - Hermer-Vazquez, Moffet & Munkholm (2001)
- Training *left* and *right* leads to feature use
  - Shusterman (2007)
- Adults who do linguistic shadowing task concurrently do not use features
  - Hermer-Vazquez, Spelke & Katsnelson (1999)

Adaptive Combination Models

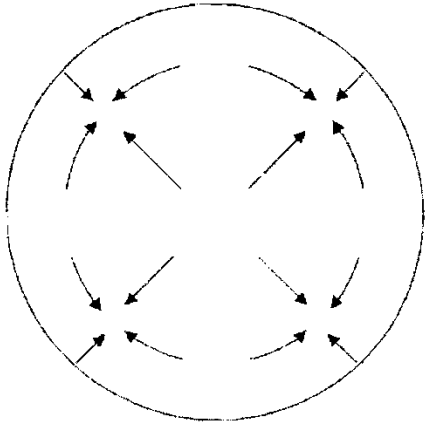
- Various sources of spatial information
  - Ego-referenced: response learning and path integration
  - Allo-referenced: cue learning, place learning
- Weighting depends on
  - Salience
  - Certainty and variability with which information is encoded
  - Validity
    - probabilities of finding objects given use of the information, derived from interaction with the environment
- Weighting *develops* both in real time and in developmental time

Qualitative and Quantitative Integration

- Categorical (or qualitative) and fine-grained (or quantitative or coordinate or metric) information in Bayesian combination



Forbus (1983)



Huttenlocher, Hedges & Duncan (1991)

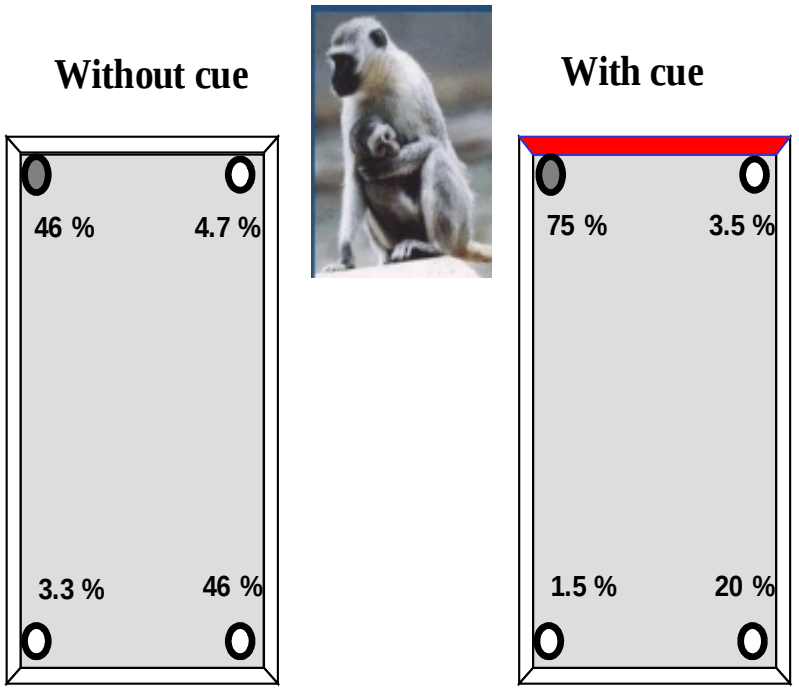
Holden, Curby, Newcombe & Shipley (2010)

Point 1: Language Does Not Play a Necessary Role

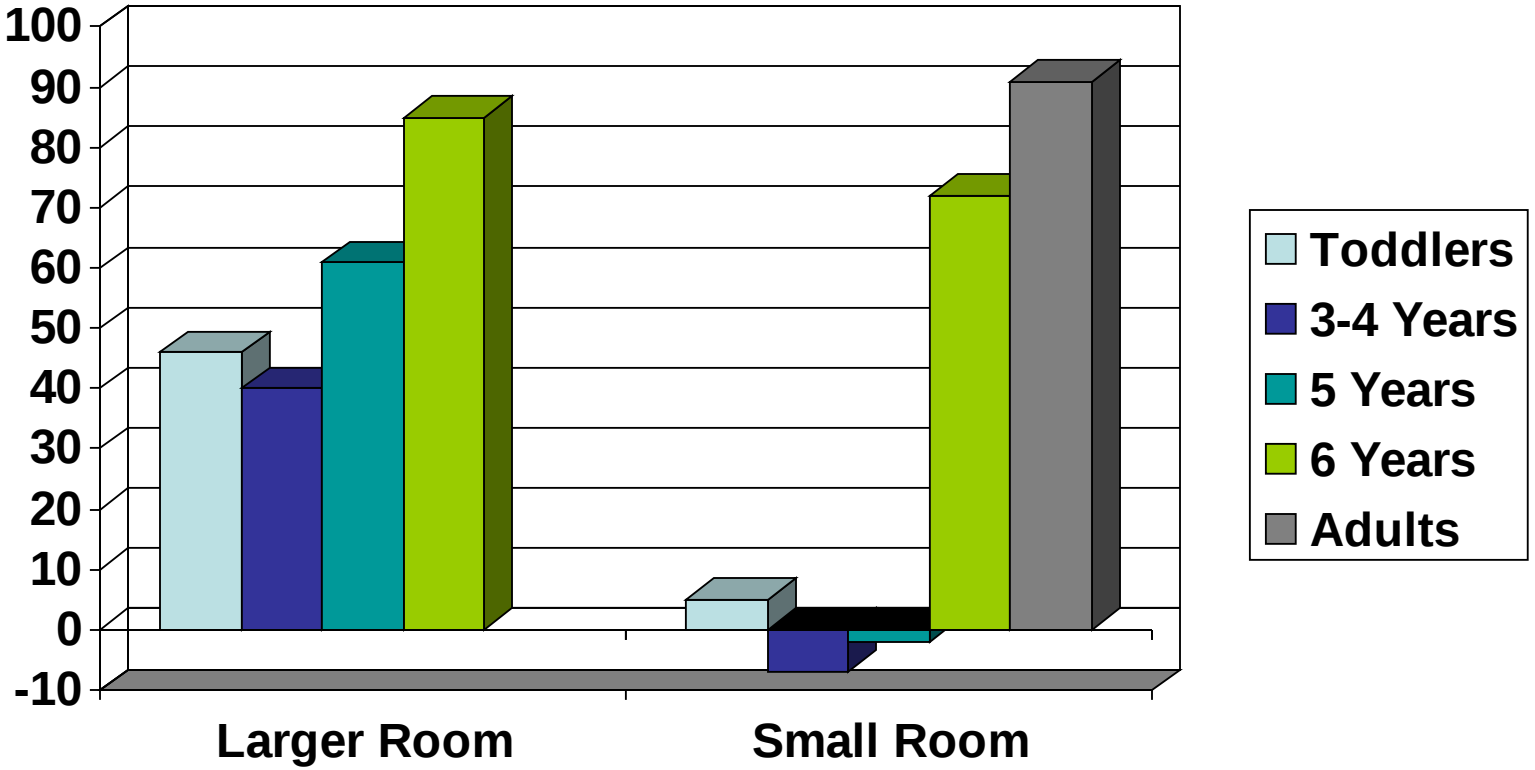
- Non-human (and non-linguistic) animals can use features
- Young children can use features in larger rooms
- Human adults' feature use is disrupted in spatial as well as verbal interference paradigms

Non-Human Animals Can Use Features

- Monkeys use colored walls and large but not small features (a sensible choice given likely cue validity)
- Other species
  - Chickens
  - Pigeons
  - Fish
- See Cheng & Newcombe, *PBR* 2005, for review



Featural Cues Are Only Neglected in Tiny Rooms

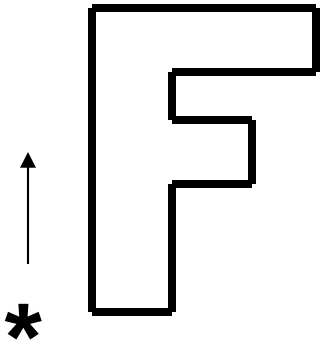


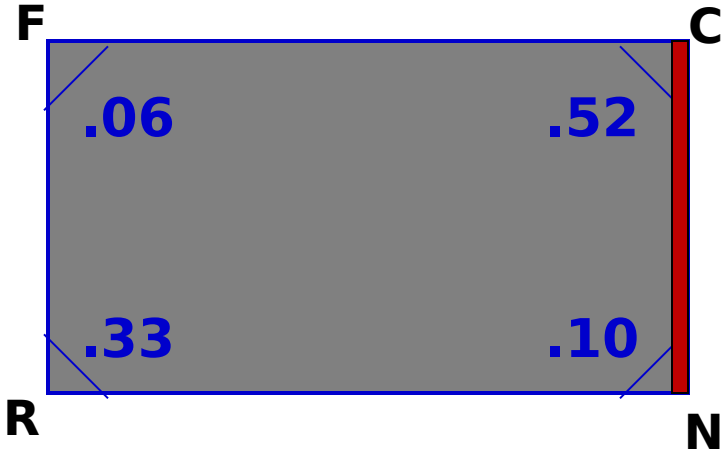
Cheng & Newcombe
(*Psychonomic Bulletin & Review*, 2005)

Note: Perfect Performance = 100

Spatial as Well as Verbal Shadowing Reduces Feature Use in Adults

Ratliff & Newcombe, *Cognitive Psychology*, 2007; also--Hupbach et al., *Spatial Cognition & Computation*, 2007





Usual results with white room and with colored wall but no concurrent task

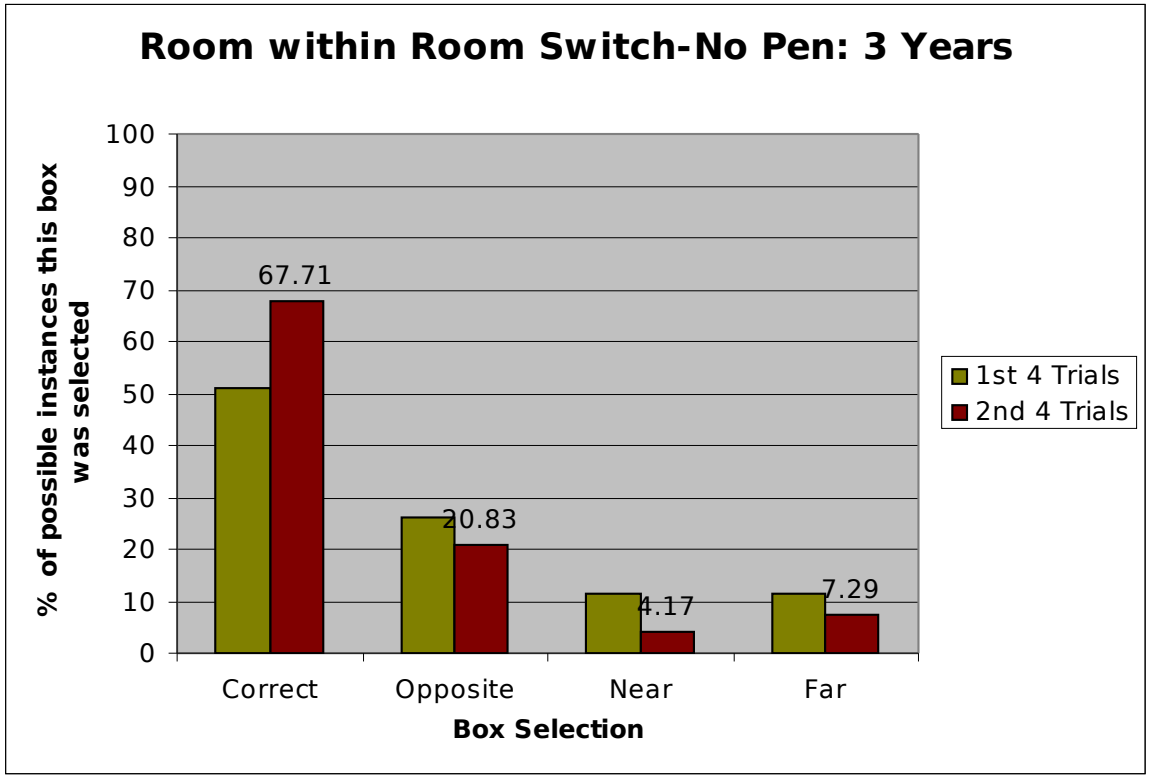
Point 2: Room Size Effect

- For children (as we saw)
- For chicks (Vallortigara's lab)
- For adults (in conflict paradigms)
  - Ratliff & Newcombe, *Psychological Science*, 2008

Point 3: Experience Matters

- Over the short term (brief training)
  - Children
  - Adults in conflict paradigm
- Over the long run (rearing)

Featural Cue Use is Easy to Get in Young Children



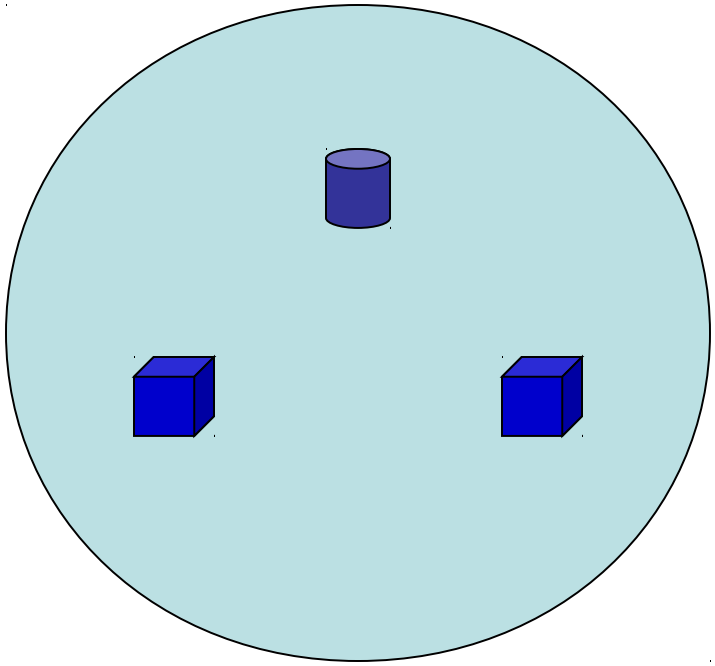
Learmonth, Newcombe, Sheridan & Jones (*Developmental Science*, 2008)
Similar finding: Twyman, Spetch & Friedman, (*Developmental Psychology*, 2007)

The Role of Early Experience

- More Rigid Development
  - Domestic chicks
  - Black-capped chickadees
- More Malleable Development
  - Fish
  - Mountain chickadees
  - Mice
- ***Humans are more like which of the above species?***

Point 4: Use of Features is NOT Merely Associative

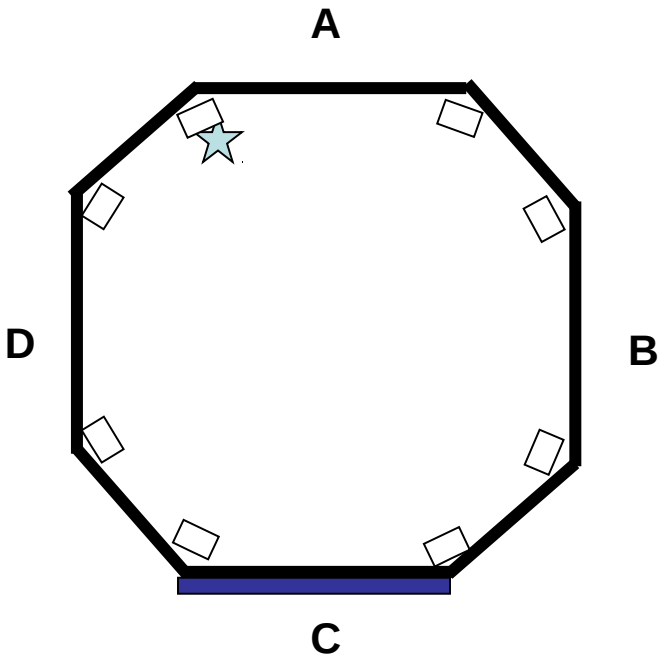
- Lee, Shusterman & Spelke (2006) argue that —
- *Search behavior following disorientation depends on two distinct processes: a modular reorientation process… and an associative process that directly links landmarks to locations* (p. 581)



Rebuttal

- Problems with Lee et al.
  - Small moveable landmarks
  - Defining quite small area
- Alternative way to test the two step hypothesis
  - Use of colored wall in an octagon with alternating short and long sides to discriminate among 3 all white corners

The Octagonal Space



Starting with An All-White Octagon

- Questions
  - Can children use geometry in a more complex figure?
    - YES
  - Methodologically, have children been successfully disoriented?
    - YES

Data from Octagon with Colored Wall

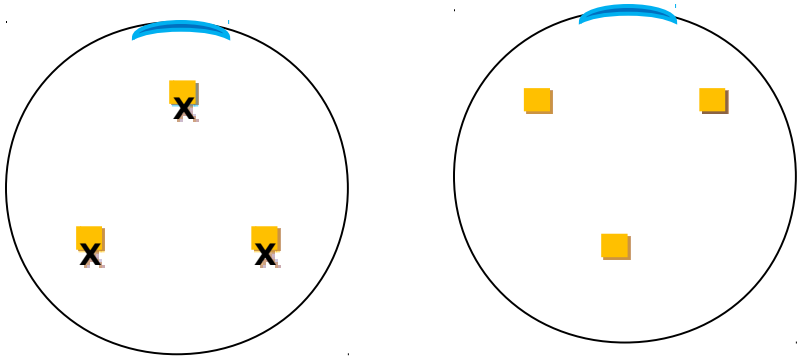
Newcombe et al., *Developmental Science*, 2010

- Correct choices at all-white corners reliably greater than average of other geometrically correct corners
  - 35% versus 14% at 3 years
  - 38% versus 10% at 5 years
- These data show that young children do in fact use features to reorient

Can Children Use Features ALONE?

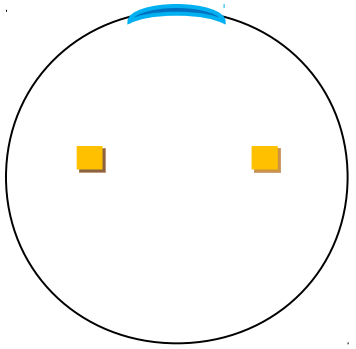
Newcombe et al., *Developmental Science*, 2010

Three Hiding Boxes



On these 2 conditions, children averaged 50%, reliably greater than chance (33%)

Two Hiding Boxes



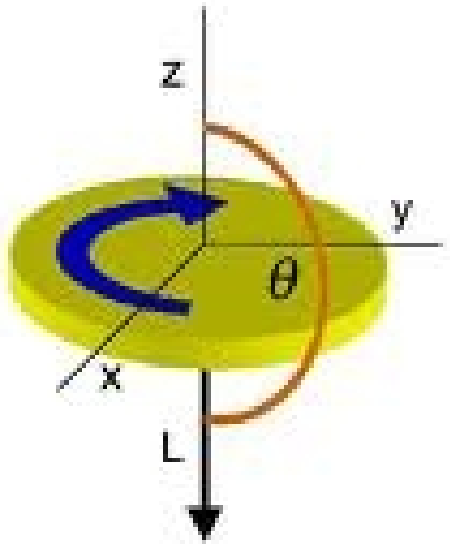
In this condition, children averaged 64%, reliably greater than chance (50%)

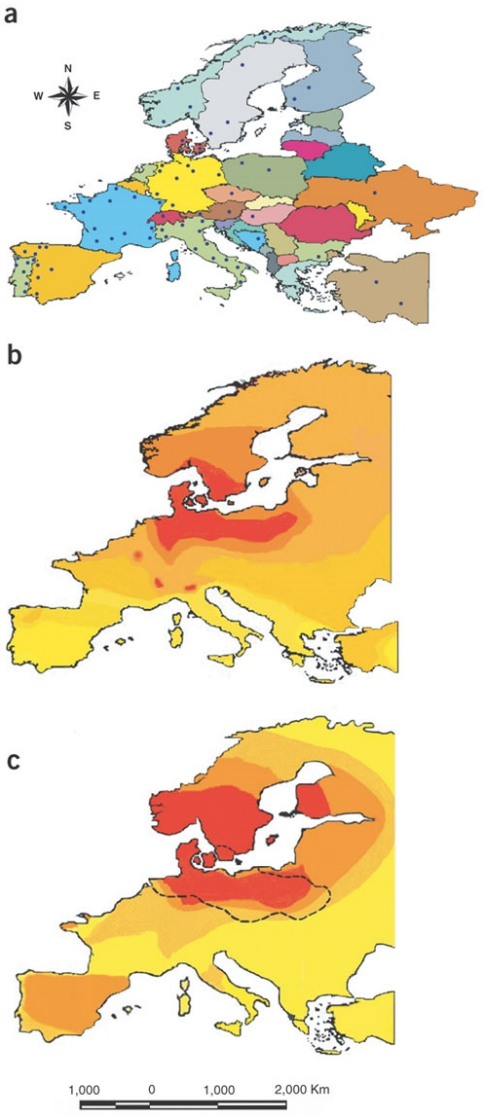
General Conclusions

- We can analyze spatial navigation and orientation as an evolved mental skill without postulating
  - Encapsulated modularity
  - Highly specific innate endowment
- These data (together with other work) suggest the virtues of a *neoconstructivist* approach to development

Part 2: Spatial Skills and Learning Are Important in STEM

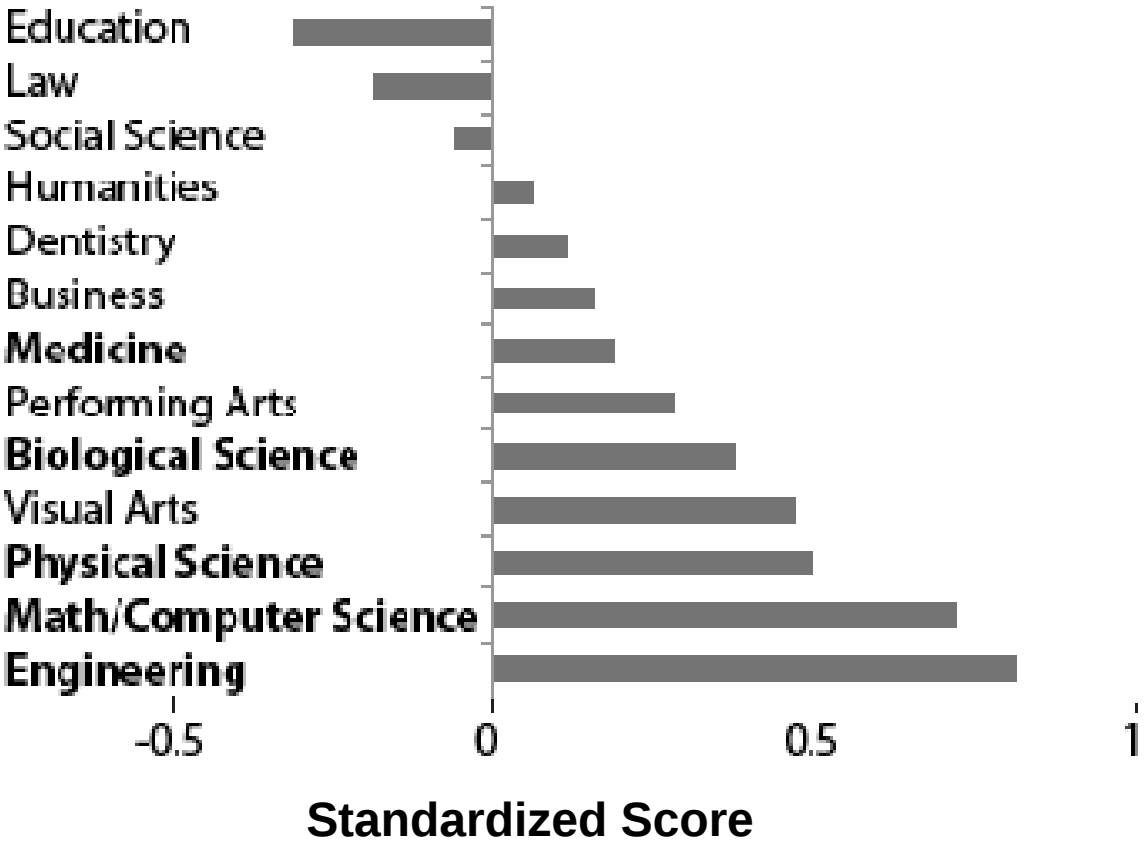
Spatial thinking seems pervasive in scientific discoveries and in STEM education





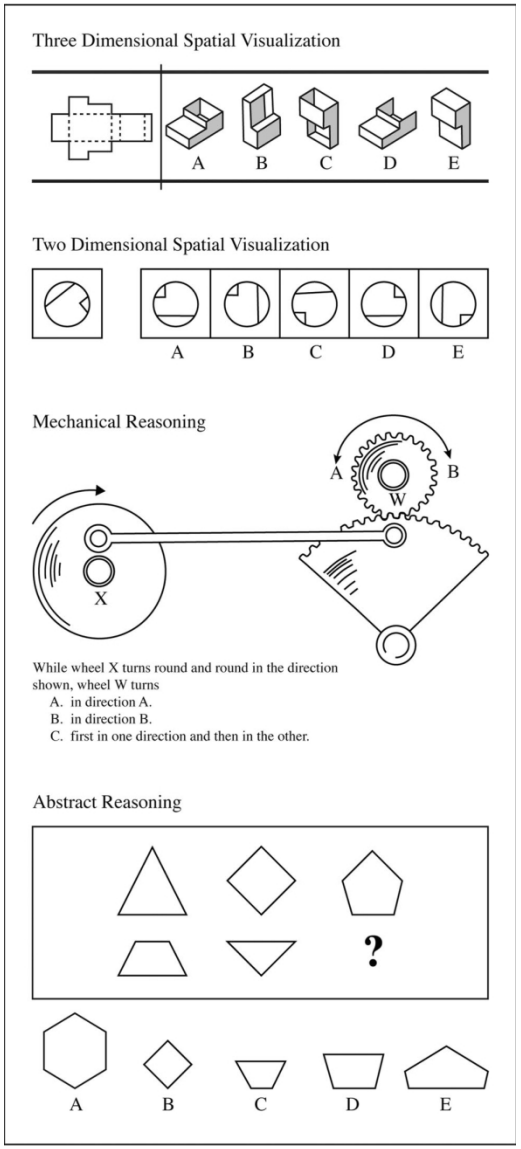
Predicting Occupations from High School Spatial Ability

Wai, Lubinski & Benbow (2009)



What Were The Spatial Tests?

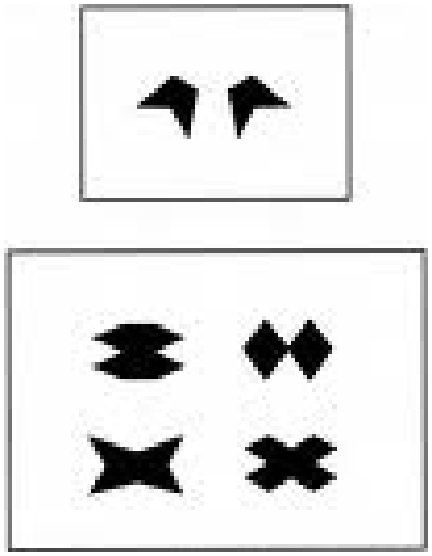
- Four tests were used
- All of them focused on objects
- Three of them required mental transformation or animation
- None involved spatial relations in the larger world

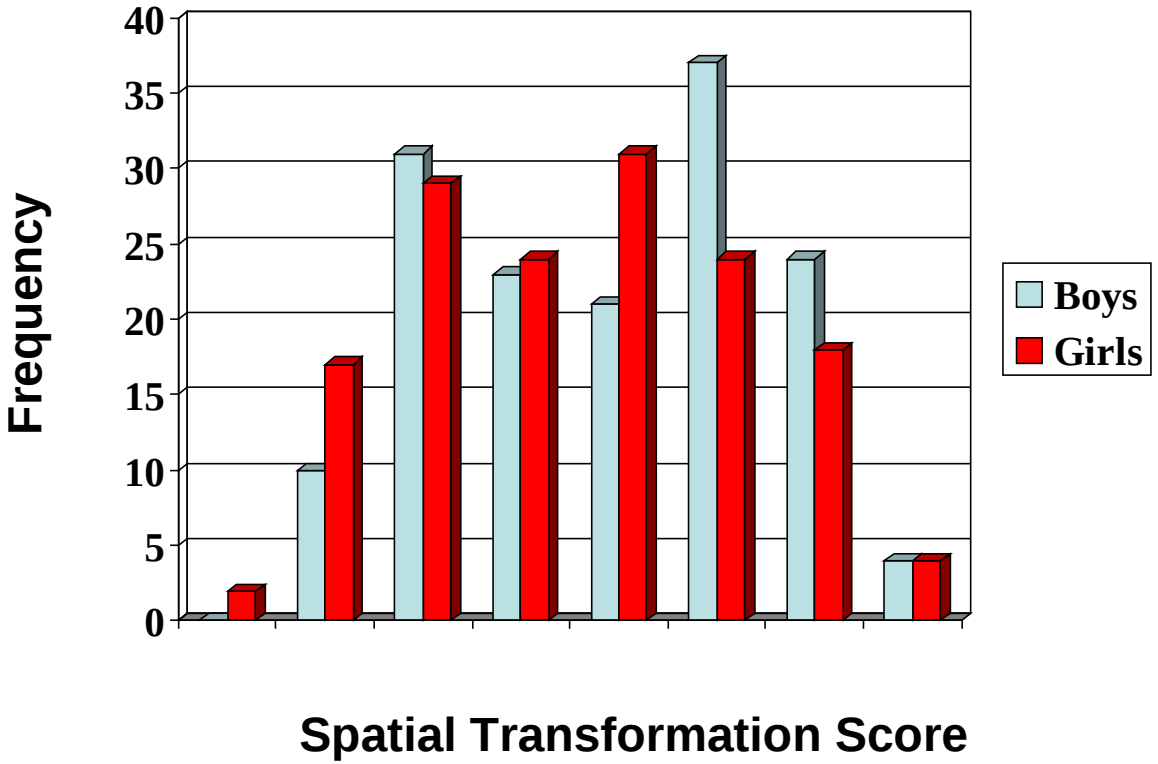


Gender Differences Begin Early

Levine, Huttenlocher, Taylor & Langrock (1999)

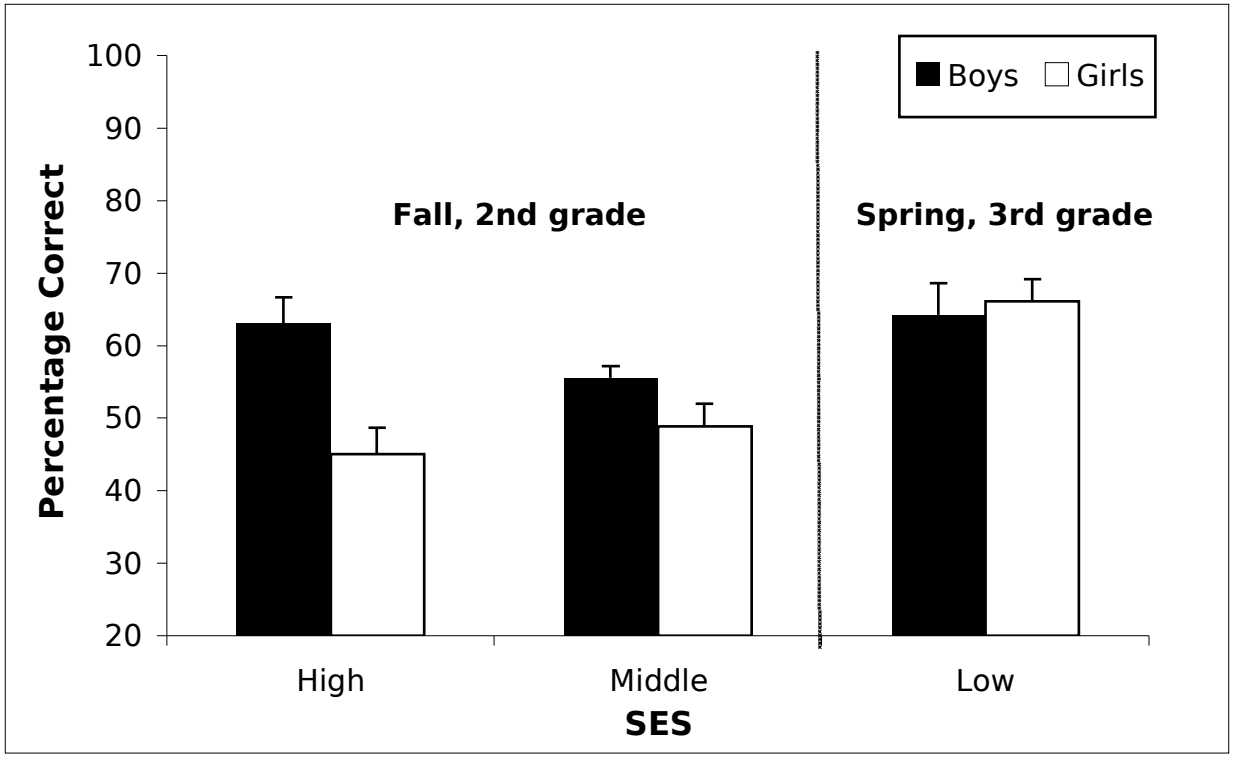
Test Item





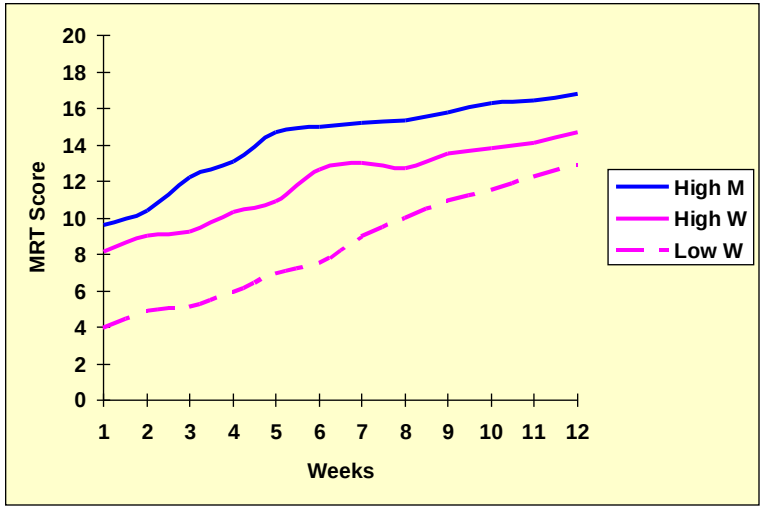
Social Class Differences Begin Early Too

Levine, Vasilyeva, Lourenco, Newcombe & Huttenlocher (2005)



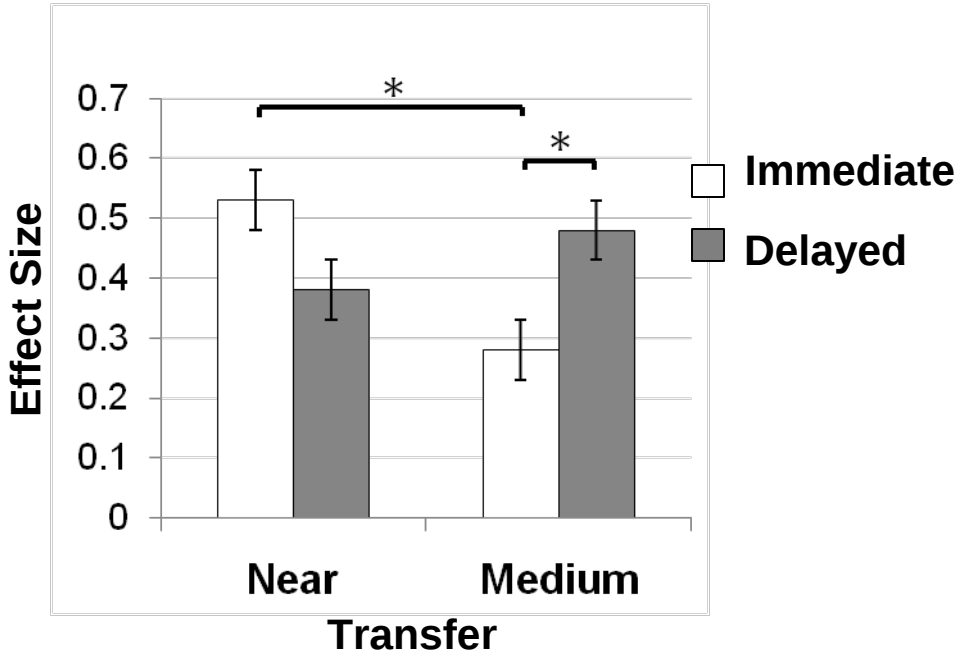
Spatial Skills Can Be Improved

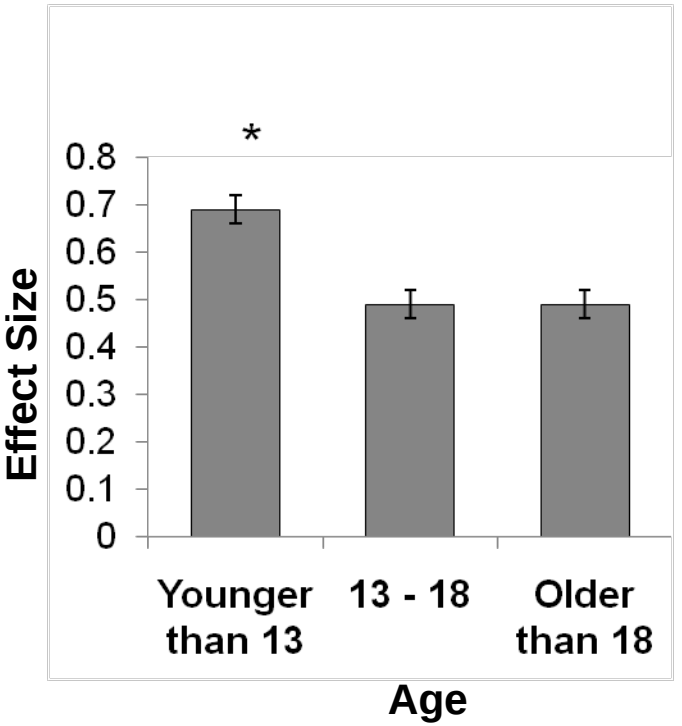
- Initial meta-analysis of training studies
  - Baenninger & Newcombe (1989)
- Two recent studies showed that improvement is *durable* and *transferable*
  - Terlecki, Newcombe & Little (2008)
  - Wright, Thompson, Ganis, Newcombe & Kosslyn (2008)



Spatial Skills Can Be Improved

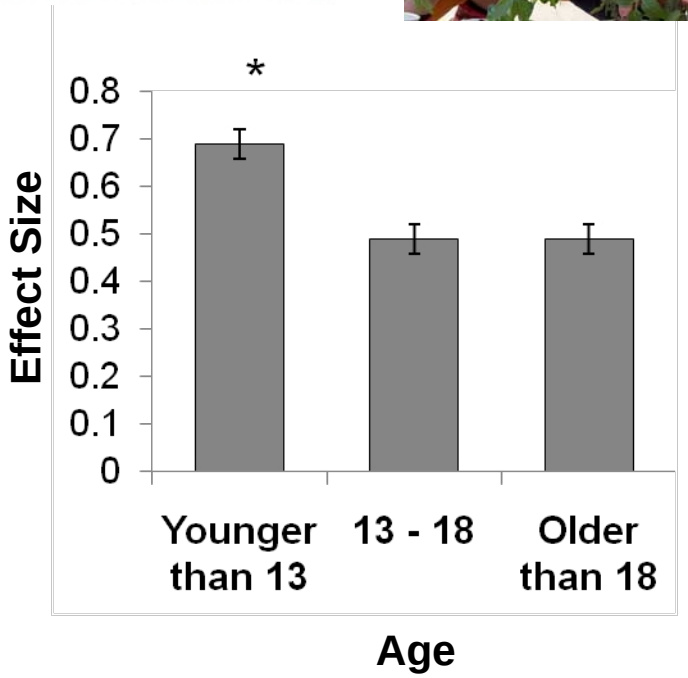
- New meta-analysis supports *large training effects*
  - Uttal, Meadow, Liu, Warren, Lewis & Newcombe (under review)
  - as well as *durability* and *transfer*
  - larger effects for *children*





Importance of Early Childhood

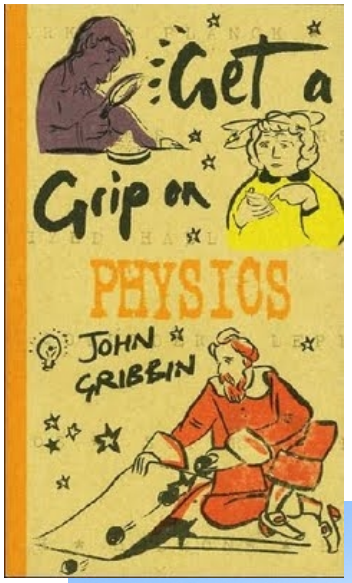
- Period of greatest plasticity
- Early skills set the stage for later learning—establish a trajectory
- Gender and SES differences begin early and should be addressed early —given the cumulative nature of learning

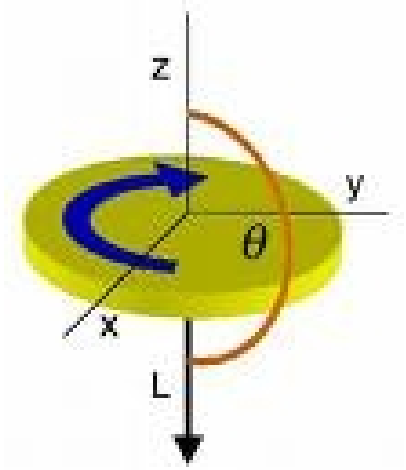


Focus on Early Education

- Teachers and parents need to know what spatial thinking is, and that it's important
- Teachers and parents need to avoid spatial anxiety
- How should we best enhance spatial learning in children?
  - Importance of action, including gesture
  - Importance of spatial language
  - Usefulness of analogy
  - Playful methods
    - Puzzle play, paper folding, block play

Learning from Action-to-Abstraction

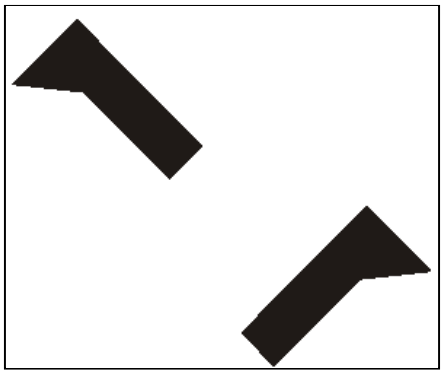


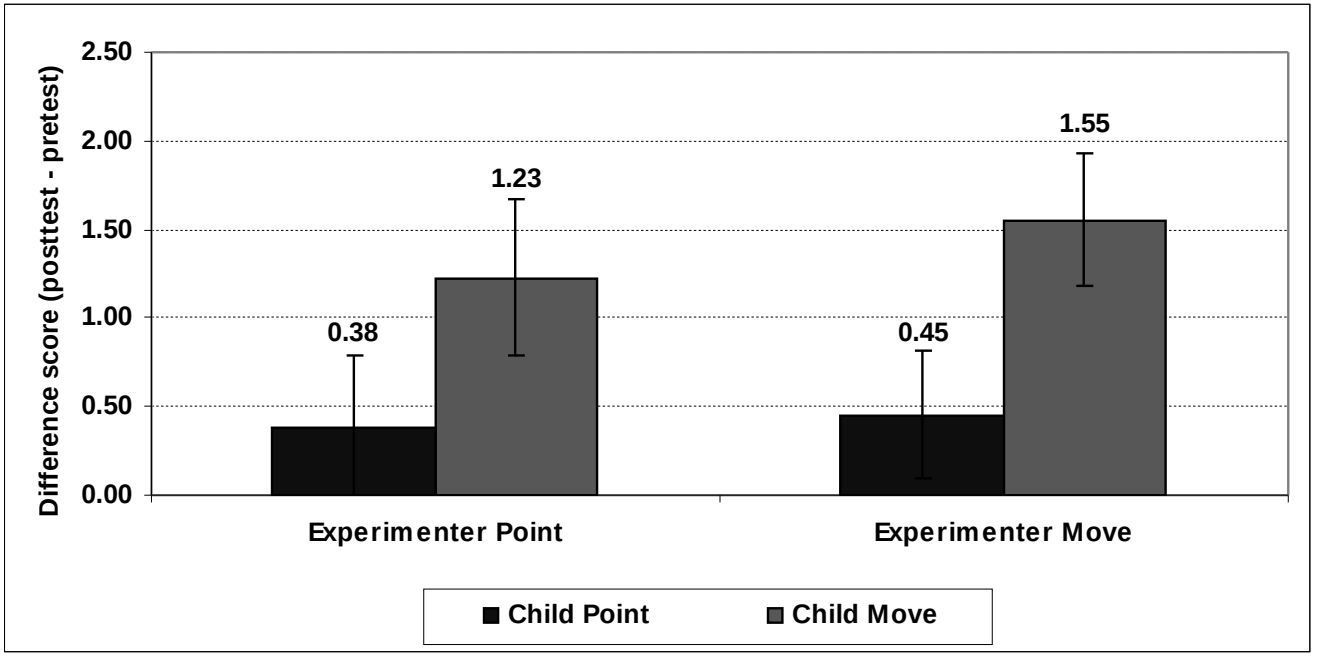


- Embodied cognition
  - But action sometimes hurts and sometimes helps
- Gesture
  - e.g., in discussions on geological field trips
- Sketching
  - e.g., in engineering design

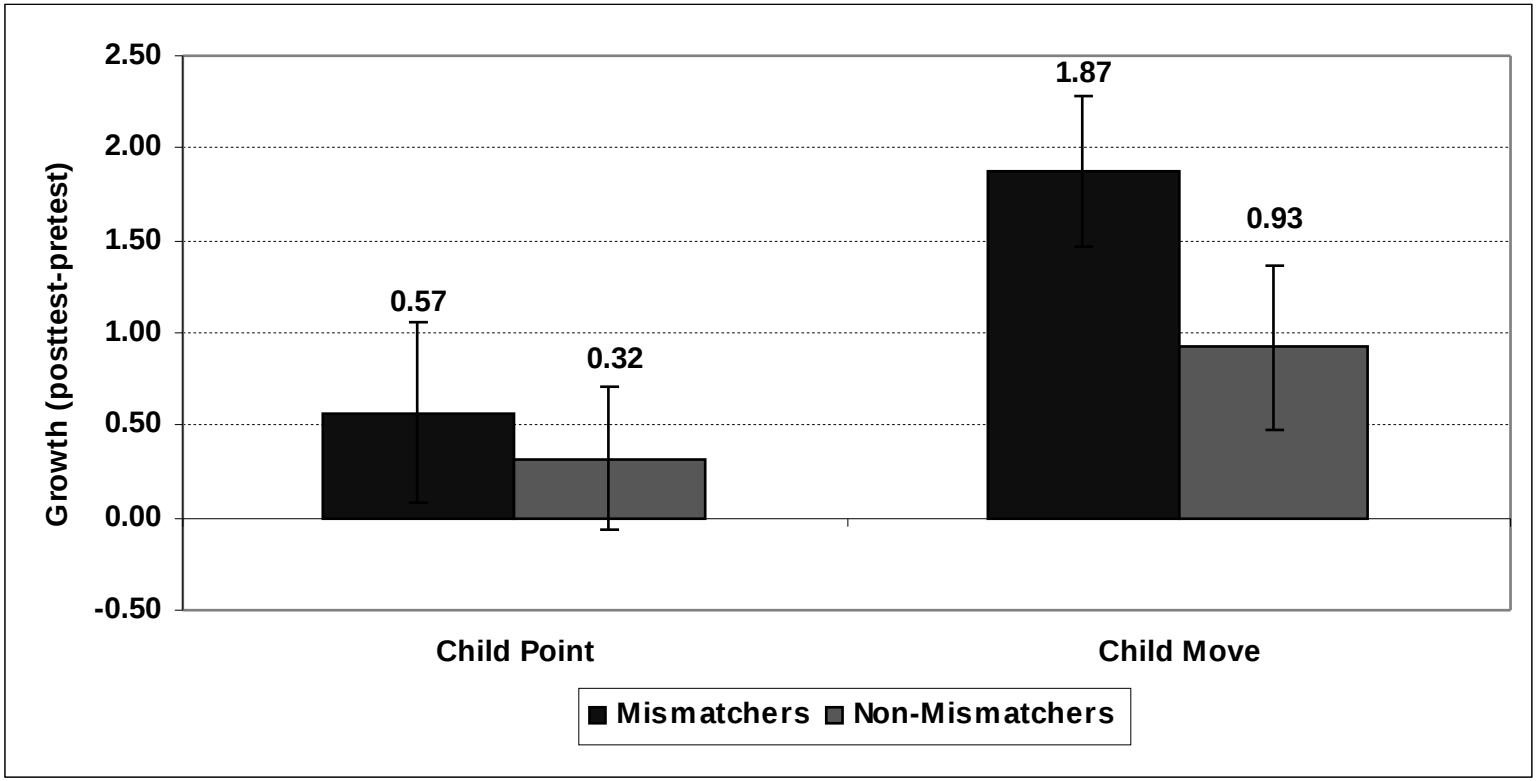
Gesture Helps Children Start Solving Rotation Problems

Susan Goldin-Meadow and Susan Levine



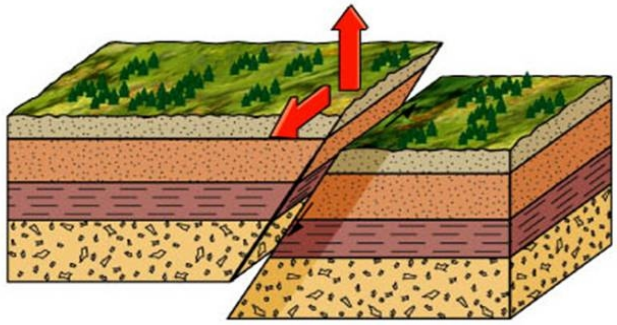


Especially True for Children Ready to Learn



Learning from External Symbol Systems

- Language
- Maps, Diagrams and Graphs



C Oblique-slip fault

Play Contexts

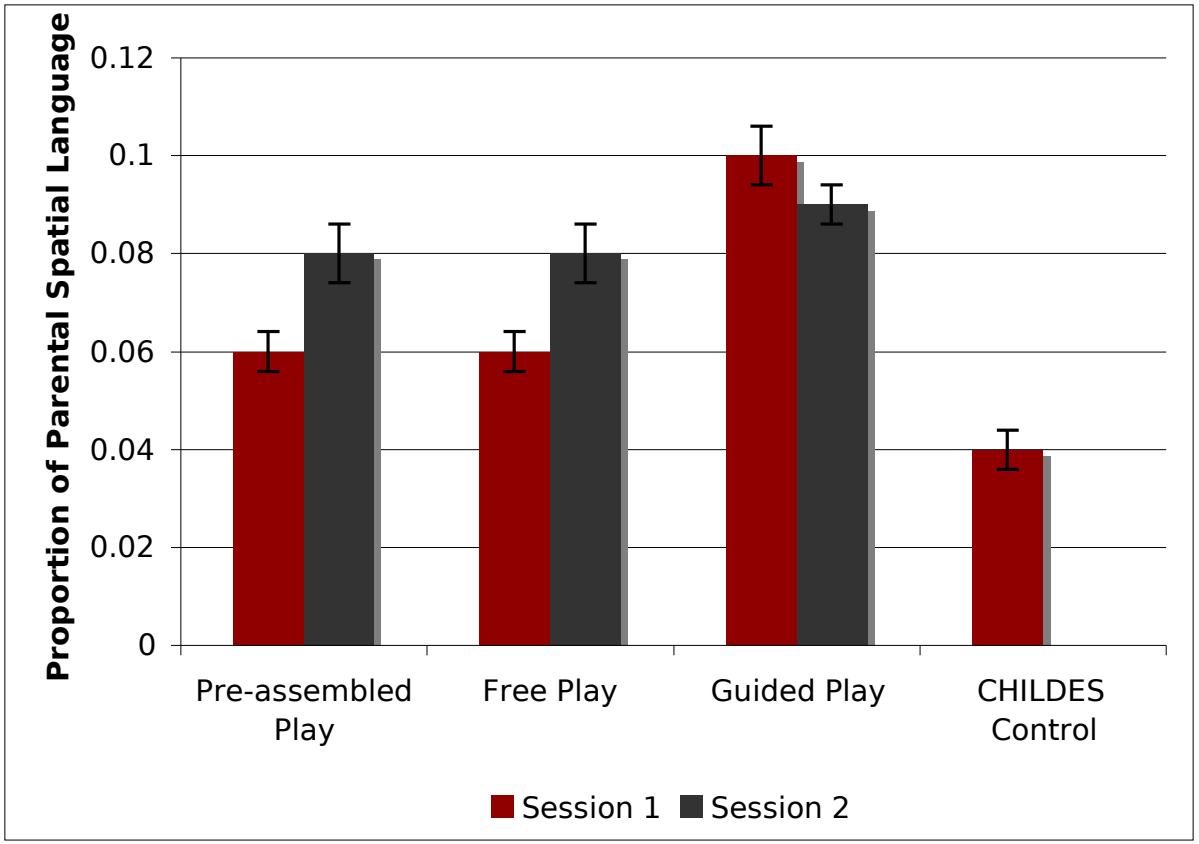
Pre-assembled Play

Free Play

Guided Play

Parental Spatial Language in Four Contexts

Ferrara, Hirsh-Pasek & Newcombe

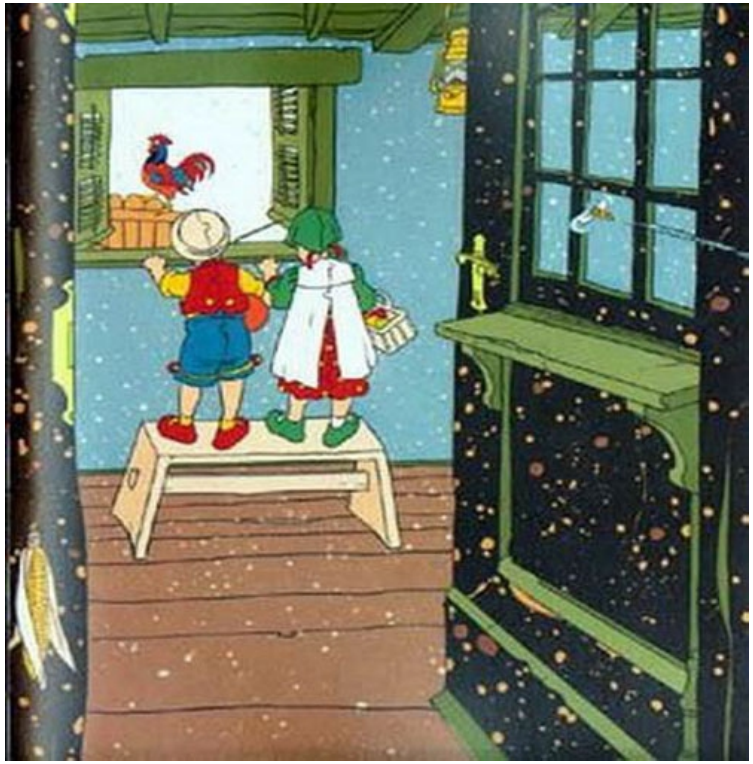


Spatial Books and Poems

OUT, ABOUT, AND ALL AROUND
(A VERY SPATIAL DAY)
Julie Dillemuth

My day begins getting UP out of bed
Daddy puts ON my clothes, OVER my head.
Then DOWN DOWN DOWN DOWN all of the stairs
TO the kitchen for breakfast - bananas and pears!

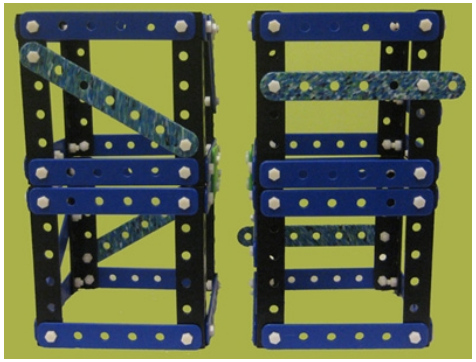
ZOOM

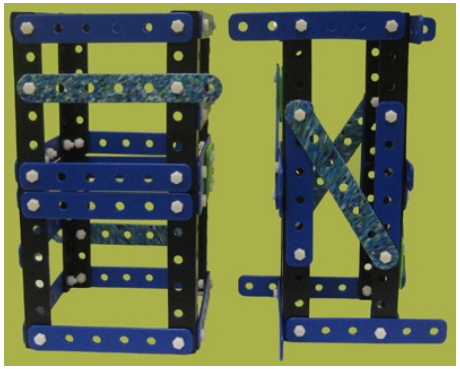


Spatial Analogy Is a Key Learning Mechanism

Gentner, Levine & Dhillon

- Analogy is widely used in spatial learning
- One pair (but not the other) helps young children learn the brace principle from a museum exhibit in just a few minutes

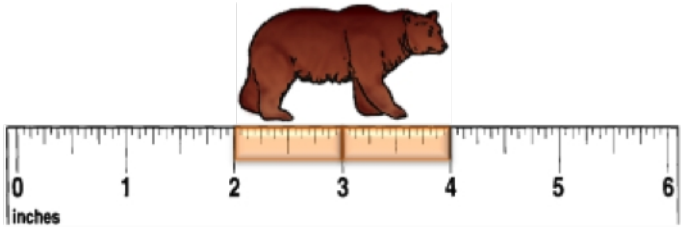




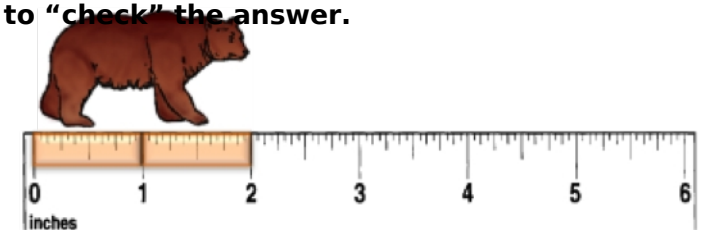
Structured Intervention Helps Children Learn to Measure

Kristin Ratliff & Susan Levine

1. Measure the object so that it is not aligned with the beginning of the ruler. Place opaque unit pieces below the object to measure how long it is.



2. Move the object back to the beginning of the ruler and use the unit pieces to "check" the answer.

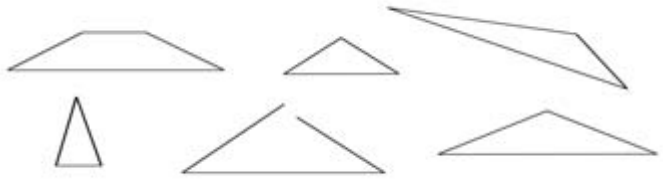


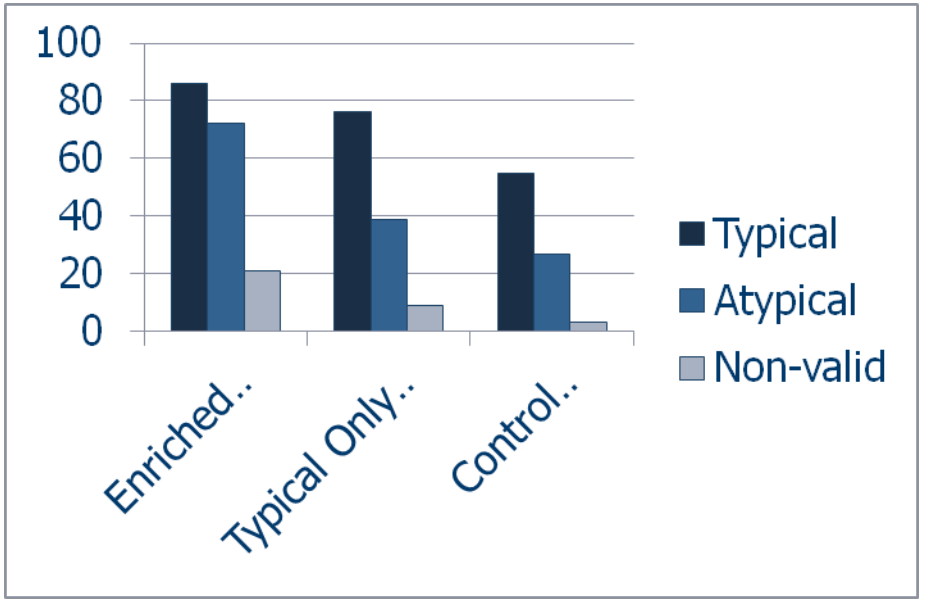
Teaching Geometric Shapes

Fisher, Hirsh-Pasek & Newcombe

- Which of these figures is

  a valid triangle?
- Children often see only typical shapes
- Showing a range of shapes helps
  - Especially in a guided play context





Questions?