Neuroscience and Math. Education

METU
Summer 2016
Educational Neuroscience Study Group

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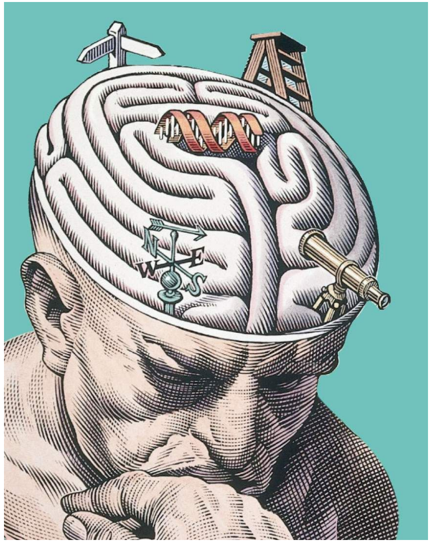
Main Question

Can **educational neuroscience** make a contribution to i**mproving society and the lives of individuals** by **improving math education**?



Main Readings for This Presentation

We prepared this presentation with synthesizing the knowledge provided in these offered articles.

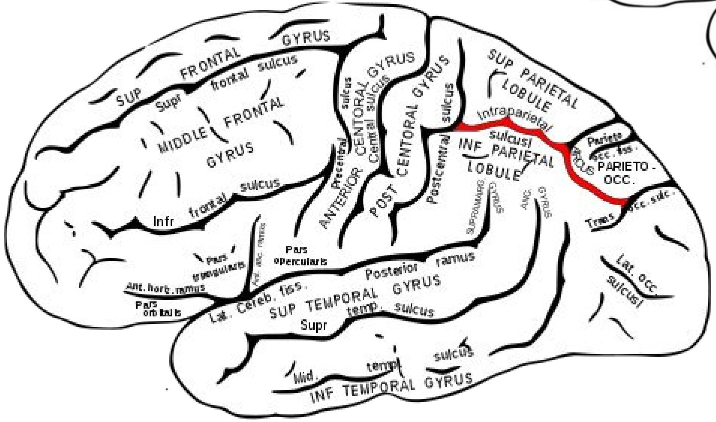
- Organisation for Economic Co-operation and Development [OECD] (2007). Understanding the brain: The birth of a learning science. London: OECD
- Butterworth, B., & Varma, S. (2013). Mathematical development. In D. Mareschal, B. Butterworth & A. Tolmie (Eds.), Educational Neuroscience (201-.236) Wiley-Blackwell. Oxford
- Lee, K., & Ng, S. F. (2011). Neuroscience and the Teaching of Mathematics. Educational Philosophy And Theory, 43(1), 81-86.

Topics studied in neuroscience

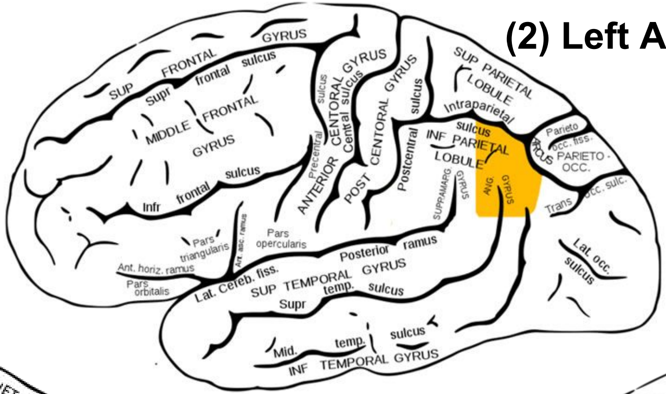
- Numeracy
- Comprehension of the concept of numbers
- Simple arithmetic operations
- Early operations in algebra
- Discalculia (A disorder that has a neurological basis similar to dyslexia, specific to mathematics)

Neural Roadmap for Mathematics

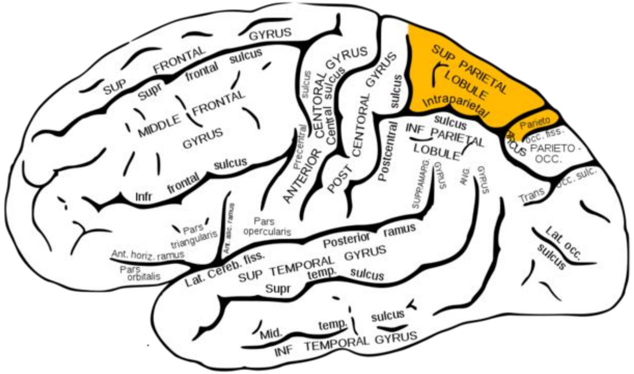
(1) Intra-parietal Sulcus



(2) Left Angular Gyrus



(3) Posterior Superior Parietal Lobule

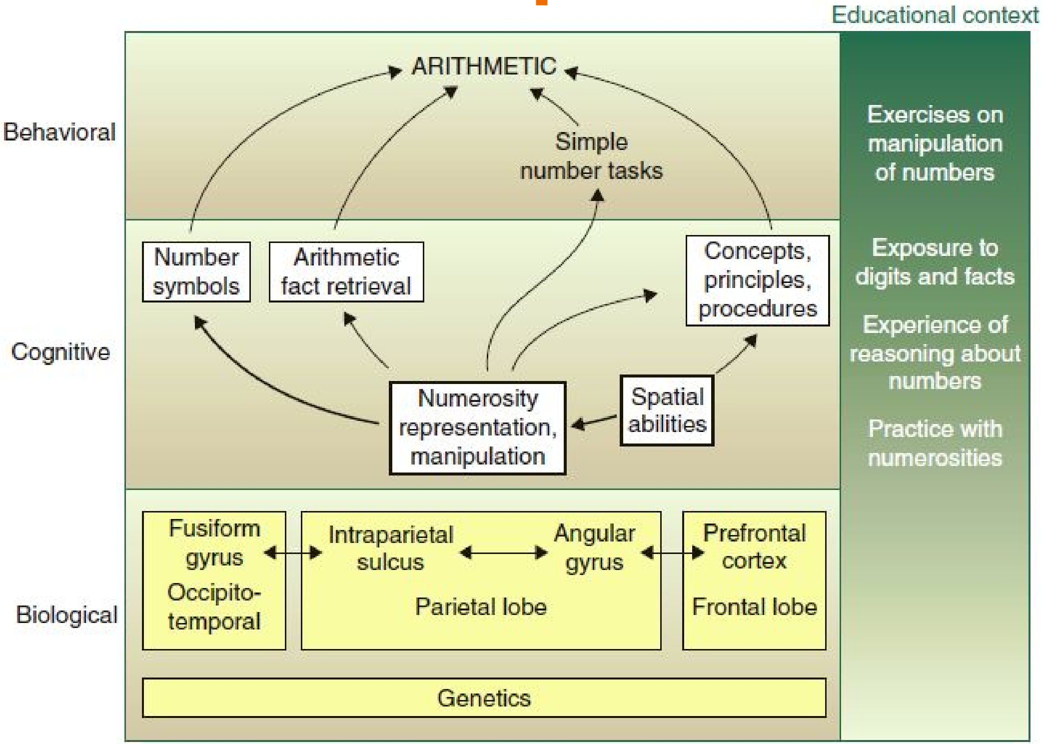


Neural Roadmap for Mathematics

- The function of the brain structures are called neural circuits which are conducive to processing number. developed throughout the experience, numeracy like literacy is not only dependent to nature.
- Mathematical abilities are distributed in different parts of the brain, not gathered in a specific part. A specific mathematical activity may require cooperation of these parts.

Implications for mathematics education: Different representations of mathematical knowledge may enhance the learning of mathematics.

Neural Roadmap for Mathematics



It shows causal relationship between biological, cognitive and behavioral levels (genetics). The green part belongs to education which is considered as environmental factor.

Ref: Butterworth, B., & Varma, S. (2013). Mathematical development. In D. Mareschal, B. Butterworth & A. Tolmie (Eds.), Educational Neuroscience (201-.236) Wiley-Blackwell. Oxford.

Two principles

- Mathematics is dissociable from other cognitive domains.

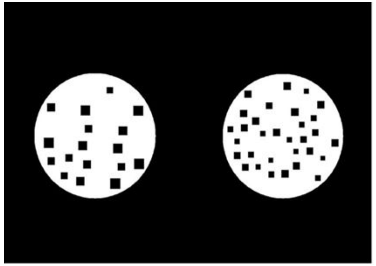
Implication for mathematics education: Using different representations and assessment techniques

- Abilities within the domain of mathematics can be dissociable from one another

Implications for mathematics education: The teachers' grouping of the students as low level or high level by considering performance of one or two skills are questionable. And the advances in the mathematics curriculum for each topic in each grade are questionable as well.

Two effects...

A. **Distance effect:** When comparing two numbers (i.e., judging which one is greater or lesser), the larger the difference in magnitude, the shorter the response time.



B. **Problem size effect:** When the number is larger, the slower and the less accurate the answer is.

Ref: Moeller, K., Klein, E., Nuerk, H.-C., & Cohen Kadosh, R. (2012). A unitary or multiple representations of numerical magnitude? – The case of structure in symbolic and non-symbolic quantities. *Frontiers in Psychology, 3*. doi:10.3389/fpsyg.2012.00191

Tabula rasa!

- Babies are not a “docile blank slate”. On the contrary, they have inborn abilities such as quantitative sense. They even “count” and “perform” mathematical operations.

- The infant brain has more brain cells (neurons) and more connections (synapses) than the adult brain, and this means that it is more “plastic,” that is, more responsive to experience, including formal and informal instruction, than later on. As a consequence, learning new material appears to be easier earlier than later.

Implication for education: This early knowledge base can be used to facilitate understanding of formal mathematical concepts. It was recommended to link symbolic mathematics with real-world understandings throughout the early learning process.

How to study with infants?

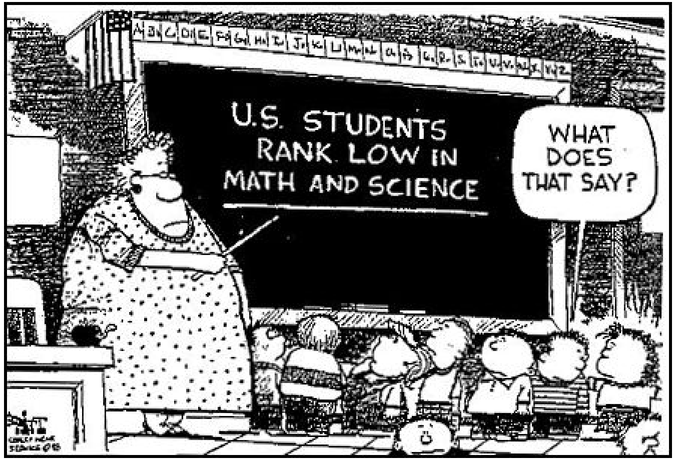
Many studies have used a dishabituation paradigm, which capitalizes on the fact that young infants will look longer at a stimulus if it differs from prior stimuli in a meaningful way.

https://www.youtube.com/watch?v=7uh8FkR_4OU

https://www.youtube.com/watch?v=dlilZh60qdA

This student is not successful in math!

- Mathematics for all students!
- Abilities within the domain of mathematics can be dissociable from one another. That means ability in a certain mathematical skill is not necessarily predictive of ability in another.



Implications for mathematics education: The teachers' grouping of the students as low level or high level by considering performance of one or two skills are questionable.

Ref: https://larrycuban.wordpress.com/category/testing/

Brain functions do not change!

- Children become more accurate when they grew older. Symbolic and non-symbolic distance effects can be seen among these age of children.
- The results of the studies demonstrate both continuities and discontinuities in the development of number.
- Young infants and primary- and middle school children show nonsymbolic distance effects that are comparable to those of adults, both behaviorally and neurally, suggesting a common representation of numerosity in IPS.
- The story for the symbolic distance effect is different: while both adults and children show this effect behaviorally, the neural correlates are different, with adults showing modulated activation in both the left and right IPS but 10-year-old children showing it in prefrontal cortex. Thus, the neuroscience data reveal a developmental discontinuity in how number symbols are processed.

Brain functions do not change!

- From middle grades to adulthood, the nonsymbolic and symbolic distance effect is still valid for adulthood.
- Over development, children transitioned from strategic processing to a mixture of symbol processing, automatic (verbal) memory retrieval, and magnitude processing. This qualitative shift, which was opaque given the behavioral data alone, highlights how neuroscience data can provide unique insights into mathematical development.

Embodying the Numbers?

- Mathematical symbols and expressions gain meaning through their grounding in the perceptual and motor systems of the body (Lakoff & Nunez, 2000).
- Geary et al. note that “The use of fingers during counting appears to be a working memory aid that allows the child to keep track of the addends physically, rather than mentally, during the process of counting.”

Implication for education: Many curricula have children first use manipulatives to help them construct and informal semantics for new mathematical concepts before introducing them to the relevant symbolic formalism.

Embodying the Numbers?

- Fayol, Barrouilet, and Marinthe (1998) found that individual differences in motor ability predict individual differences in mathematical achievement.
- Noel (2005) tested five-year-olds for finger agnosia and left-right test were good predictors of numerical skills one year later, but not good predictors of readings skills, which proves their specificity to mathematics.
    - Tests are just picking up the development of the parietal cortex, not the functional role of fingers.

Left-right test: https://faculty.washington.edu/chudler/java/hands1.html

Discussion Topics

- Arithmetic abilities are needed in every aspect of daily life but simple arithmetic abilities are sufficient for these types of tasks like counting, multiplication, subtraction. We can distinguish mathematical concepts into two categories: numerical magnitude simple operations and higher mathematical abilities such as differentials, integral. Higher mathematical concepts enhance daily life in a different way. For example, doing necessary calculation and producing a vehicle is the result of advanced mathematics. Mainly simple arithmetics and advance mathematics use symbols. But in the simple arithmetic operations, we use spatial magnitudes, distances etc. Thus they refer to concrete properties. On the other hand, advances mathematics use symbols in the abstract level. **According to educational neuroscience, parietal cortex is responsible for magnitude related mathematical operations. What about the higher one? I think all high level operations are executed in many areas in the brain that communicate with each other.**

Study Designs

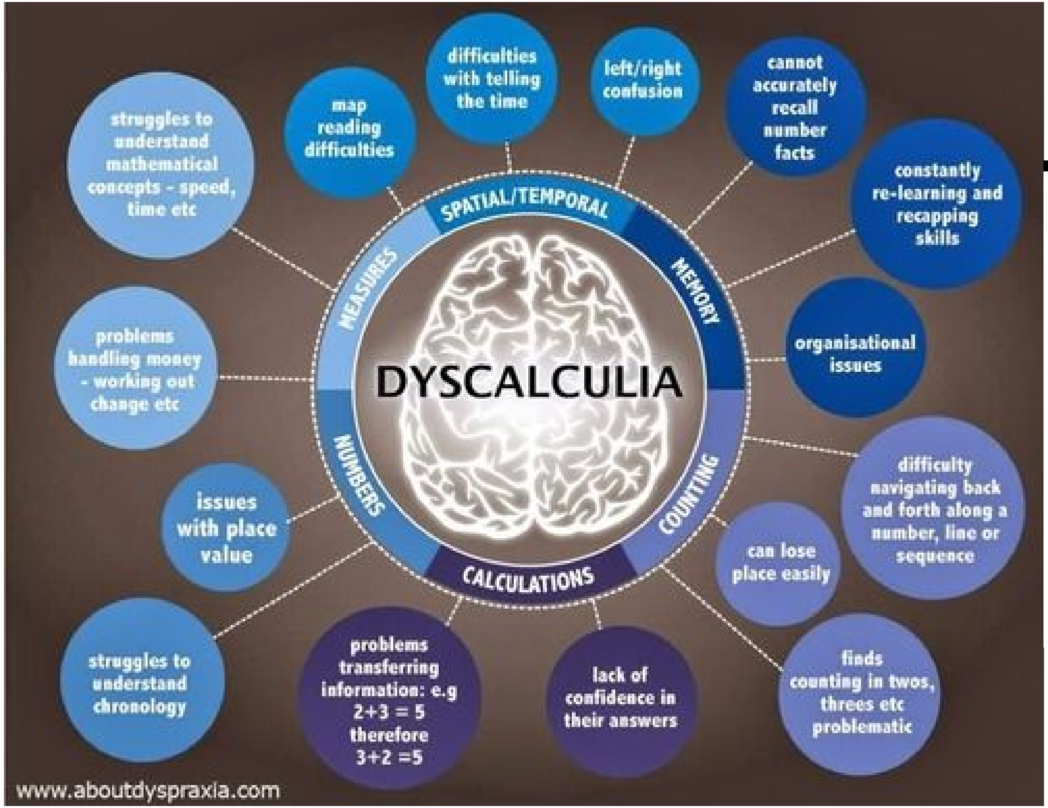
- Cross-sectional design to investigate whether individual differences in number representation are associated with individual differences in mathematical achievement.
  - Holloway and Ansari (2009): symbolic vs nonsymbolic distance effects and achievement scores in 6, 7 and 8-year-old children.
    - The size of a child's symbolic distance effect predicted her arithmetic fluency in contrast to nonsymbolic distance effect.
    - The fidelity of the mapping between number symbols and magnitude representations - but not necessarily the fidelity of the magnitude representations themselves - is related to mathematics achievement.

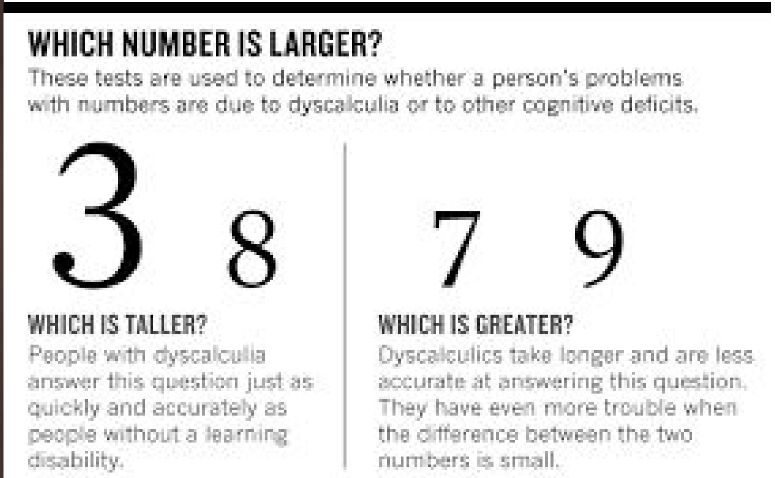
Study Designs

- Longitudinal design to sharpen cross-sectional findings. De Smedth, Verschaffel, and Ghesquiere (2009) measured the symbolic distance effect of children in first grade, and their mathematical achievement in second grade.
  - The size of a child's symbolic distance effect in first grade predicted mathematical achievement in second grade, even after controlling for fluid intelligence, processing speed, and age.
  - The longitudinal nature of this design is stronger evidence that a connection between number symbols and magnitude representations is important for mathematical achievement.

Acalculia means dyscalculia!

- Developmental dyscalculia is usually and rather broadly defined as a low mathematical achievement in the presence of otherwise normal intelligence and access to educational resources. Current prevalence estimates are between 3% and 6% (Reigosa-Crespo et al., 2011; Shalev, 2007), which is roughly one child in every classroom
- Recent research has revealed that dyscalculia is a congenital condition, often inherited, that can persist into adulthood.
- Acalculia is an acquired defect (caused by neurological trauma) but developmental dyscalculia is a developmental defect.


DYSCALCULIA
SPATIAL/TEMPORAL
MEMORY
COUNTING
CALCULATIONS
NUMBERS
MEASURES
difficulties with telling the time
left/right confusion
cannot accurately recall number facts
constantly re-learning and recapping skills
organisational issues
difficulty navigating back and forth along a number, line or sequence
can lose place easily
finds counting in twos, threes etc problematic
lack of confidence in their answers
problems transferring information: e.g 2+3 = 5 therefore 3+2 =5
struggles to understand chronology
issues with place value
problems handling money - working out change etc
struggles to understand mathematical concepts - speed, time etc
map reading difficulties
www.aboutdyspraxia.com


WHICH NUMBER IS LARGER?
These tests are used to determine whether a person's problems with numbers are due to dyscalculia or to other cognitive deficits.
3 8
7 9
WHICH IS TALLER?
People with dyscalculia answer this question just as quickly and accurately as people without a learning disability.
WHICH IS GREATER?
Dyscalculics take longer and are less accurate at answering this question. They have even more trouble when the difference between the two numbers is small.

Deficit in Discalculia

- In Rousselle and Noël (2007)'s study, The dyscalculic group was slower than the control group for symbolic comparison after controlling for age and overall processing speed. By contrast, the two groups were comparable for nonsymbolic comparison.
    - Inclusion criteria?
- An fMRI study a neuropathology underlying discalculia: Kucian et al. (2006)
    - Discalculic group displayed less activation in a bilateral frontoparietal network including MFG (Middle Frontal Gyrus), IFG (Inferior Frontal Gyrus), IPS (Intraparietal sulcus) for the largest group differences were observed on an approximate addition task.
    - Numerosity representations themselves be defective not just the mapping from symbol to the representations.

Deficit in Discalculia

Study	Dyscalculia Group	Age-matched Control Group	Task	Data Type
Price et al. (2007)	No effect	Neural distance effect in right IPS	Non-symbolic comparison task	fMRI
Kucian et al. (2006)	Less activation	Bilateral frontoparietal network	Non-symbolic comparison task	fMRI
Rousselle and Noël (2007)	Slower	Faster	Symbolic & Non-symbolic comparison tasks	Behavioral

The Mathematical Brain?

- Neuro-constructivism: Johnson, Karmiloff-Smith, and Mareschal (2010)
  - Brain organization is shaped by interaction with the environment
- How can neuroscience inform education?
  - **Methods of instruction**
    - the improvement in behavioral performance following practice is a function of a shift from strategic to memory-based processing. This is the analogous to the behavioral patterns and cortical shift that Rivera et al. (2005) documented for simple addition and subtraction over development, where the left inferior parietal lobe becomes increasingly specialized for addition. By contrast, in the case of complex subtraction, the continuous improvement in behavioral performance following practice is a function of increased efficiency in the frontoparietal network associated with strategic processing (Ischebeck et al., 2006).
    - These findings are important, suggesting that if the pedagogical goal is to automatize subtraction, then mathematics educators should look beyond direct

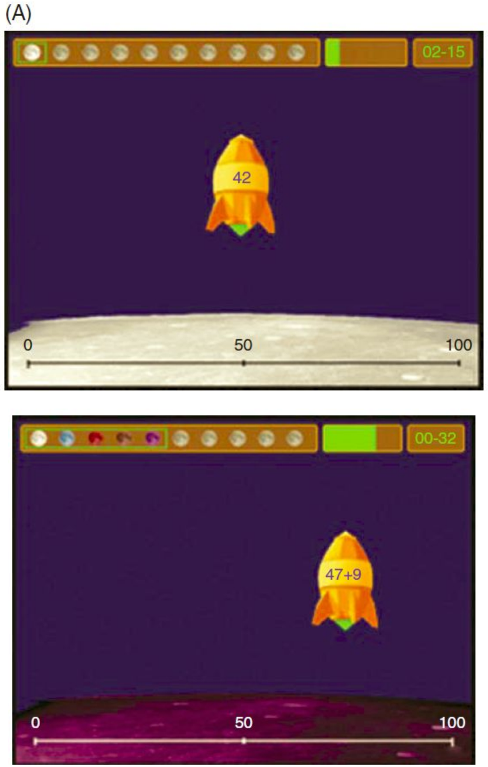
Discussion Topics

- How can we investigate the effects of the different teaching methods in math education by using neuroscience research methods?
- Neuroscience studies may demonstrate which teaching method is superior to others in math education (e.g. learning by drill versus learning by strategy) but how about teachers? Can they easily accept to use better teaching methods for their classes?
- How can we use neuroscience research results on math education for teacher education programs?

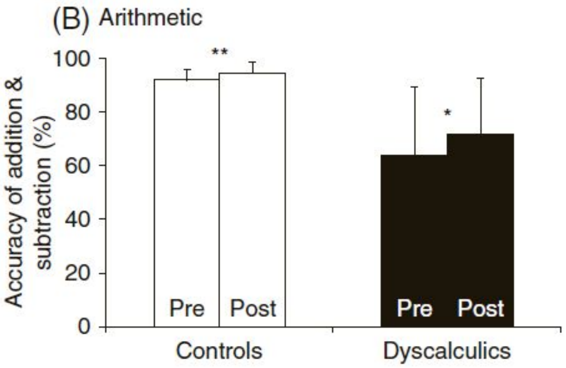
How Can Neuroscience Inform Education?

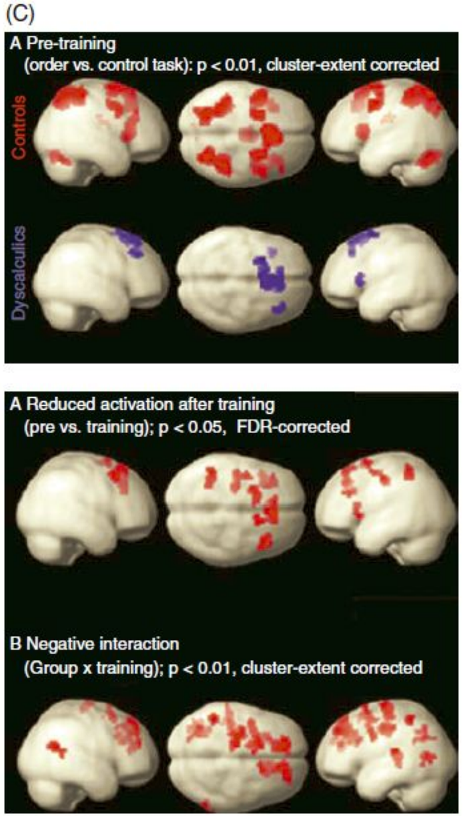
- **Methods of instruction**
- **Individual differences**
    - One needs to turn to pedagogic principles and the best practice of special educational needs (SEN) teachers to design appropriate instruction. From a pedagogical perspective, activities that require the manipulation of concrete objects provide tasks that make number concepts meaningful by providing an intrinsic relationship between a goal, the learner’s action, and the informational feedback on the action. This kind of feedback provides intrinsic motivation in a task, and this is of greater value to the learner than the extrinsic motives and rewards provided by a supervising teacher (Bruner, 1961; Deci, Koestner, & Ryan, 2001).

How Can Neuroscience Inform Education?



Kucian et al. (2011)





Discussion Topics

- Lee ve Ng'nin (2011) makalesinin iki farklı öğretim yönteminin öğrenenlerin beyin aktivatelerini nasıl etkilediği göstermesi ve bunun üzerine pegogical implicationlar da bulunması, educational neuroscience'ın bize sağlayacakları açısından bir örnek oluşturuyor bence. Diğer tarafdan ulaşılan sonuca bakınca zaten bu bilginin beyin aktivelerini monitor etmeden de söylenebileceği yani Bowers'ın da (2016) dediği gibi neuroscience'ın öğretimi desteklemede yeni fikirler sağlamadığı düşüncesine katılmama neden oluyor. **Model metodunu ilkokul seviyesinde kullanıp sembolik algebra metodunu daha ileriki yaşlarda kullanmayı önermesini, öğrenenlerin somut soyut düşünme evrelerini düşünerek de yapamaz mıyız? Okullarda da bu şekilde uygulanmıyor mu zaten?**

Future: Already close?

- Negative numbers: magnitudes or using rules?
- Place value notation
  - Incompatibility effect
- Algebra:
  - Sohn et al. (2004) investigated the neural processes associated with solving algebra equations versus story problems. They found increased bilateral PPC activation when solving algebra equations, consistent with the sequential transformations. By contrast, they found greater left IFG when solving story problems, consistent with this area's role in verbal working memory and "expressive" language.

Discussion Topics

- What do you think about math anxiety which is is mentioned in OECD report. What are the possible causes, and what do you propose for overcoming this problem which may be very common in our country. **Do you think that there is a difference in gender distribution on students having math anxiety?**

- It is proposed in the OECD report that some math question can be answered by memorising or by applying a mathematical strategy and it is important to differentiate the two case.

  Do you think that it is a problem of Turkish education system as we use multiple choice question exam for distinguishing between students. The process-focuses assessments can overcome cheating in those exams?

- Difference between 3 and three

Plan to advance in this field...

- Systematic Literature Review: Behavioral studies and neuroscience studies of metacognition in problem solving: To find a neural roadmap for educational studies in terms of metacognition in problem solving.
- Experimental Study: A time series experimental design for observing error detection and breakdown situations during problem solving activities
- To find strategies of the students about finding approximate number on the number line application.
- Literature review on “What are the indicators of students with discalculia” and as a follow-up review to investigate whether curriculum is integrated with the study findings.