#MCLSonline2020 Schedule

Date	Symposium Organizer	Symposium Title
Friday, July 10	MCLS Training Board	Conversation with Math Educator
Thursday, July 16	MCLS Training Board	Speed Networking and Coffee Break
Friday, July 24	Tom Faulkenberry	Representations and knowledge structures for fractions and rational numbers
Thursday, July 30	MCLS Training Board	Posters & Lightning Talks
Friday, Aug. 7	Francesco Sella	Learning to count: New insights on the acquisition of symbolic numerical knowledge
Thursday, Aug. 13	David Braithwaite	Cross-Representational Knowledge: Connecting Fractions and Decimals
Friday, Aug. 21	Stephanie Bugden	Exploring the predictive power of the Numeracy Screener around the world
Thursday, Aug. 27	MCLS Training Board	Posters & Lightning Talks
Friday, Sept. 4	Julia Bahnmueller	Digits grasp digits: The interplay of fingers and numbers in early numerical learning
Thursday, Sept. 10	Wenke Möhring	Unpacking the Association between Spatial and Mathematical Thinking: Investigations about Directional and Causal Effects
Friday, Sept. 18	Yunji Park	Neural Development of Symbolic Math Knowledge from Childhood to Young Adulthood
Thursday, Sept. 24	Rebecca Bull	Early intervention: Finger counting, patterning, working memory, and number games
Friday, Oct. 2	MCLS Training Board	Posters & Lightning Talks
Thursday, Oct. 8	Dror Dotan	The language of numbers: Linguistic aspects of number processing
Friday, Oct. 16	Ben Clarke	Utilizing the Curriculum Research Framework to Iteratively Develop, Test, and Explore the Impacts of Science and Mathematics Interventions
Thursday, Oct. 22	Krzysztof Cipora	Spatial-numerical associations and dissociations
Friday, Oct. 30	MCLS Training Board	Posters & Lightning Talks
Thursday, Nov. 5	Matthew Inglis	Counting and Cardinality
Friday, Nov. 13	Jenny Yun-Chen Chan	Problem-solving strategies in algebra: From lab to practice
Thursday, Nov. 19	Jérôme Prado	How environment shapes the mathematical brain: Influences of socioeconomic status, parental behaviors, and education
Friday, Nov. 27	*US Thanksgiving*	*No Presentation*
Thursday, Dec. 3	Alexandria Viegut	Fraction Interventions from Lab to Classroom
Friday, Dec. 11	Nurit Viesel-Nordmeyer	Explaining the relationship between working memory resp. related cognitive skills and mathematical learning
Thursday, Dec. 17	Sum Kwing Cheung	The roles of different domain-general and domain-specific skills in children's mathematical competence
Friday, Dec. 25	*Christmas*	*No Presentation*

To preregister for all talks, please register here (Thursday talks) ***and*** **here (Friday talks)**

All Thursday talks occur at 9am EST//2pm BST; Friday talks at 11am EST//4pm BST

Friday, July 10
Conversation with Educators

Brian Shay
Brian has been teaching high school and college level mathematics since 2000. His primary job is teaching at Canyon Crest Academy in the San Dieguito Union High School District, yet he also serves as an adjunct instructor with UC San Diego. He typically teaches Integrated Math 2, Calculus, and Linear Algebra, though he has taught all levels of high school and introductory college level mathematics courses. Brian volunteers with the California Department of Education, serving previously as an Academic Content Standards Commissioner in 2012 and on the Mathematics Framework Committee in 2012. Brian is also an active member of California Mathematics Council and National Council of Teachers of Mathematics, serving on many committees with both organizations. He was a mentor with Math for America - San Diego, where he mentored and provided professional development for emerging math teachers. He serves on the AP Calculus Exam Test Development Committee and a reviewer for the SAT Reasoning Test and Mathematics Subject Tests. Brian earned a BA and MA in Mathematics from SUNY Potsdam in 1998, and an MA in Mathematics and a MAT in Mathematics from UC Davis in 2001.

Tyron Young
Tyron Young is a middle school math and science teacher in Los Angeles. He has taught in both formal and informal K-12 settings in public and private schools in Atlanta, Chicago, New York City, and Los Angeles. While serving as an Instructor of Curriculum at Temple University College of Education and Director of Teaching Fellows at Baltimore Collegiate School for Boys, Young prepared new and preservice educators for math and science instruction to elementary and middle school students in urban schools. He also has spent time working with a number of educational research teams studying learning, cognition, and student emotions in STEM classrooms. Young brings a wealth of expertise from the perspective of a researcher, administrator, and educator. Young holds a B.A. in Child Development from Morehouse College and an M.S.Ed. in Math and Science Education from Temple University.

Patrick McLeod
Patrick is an educator in Ontario who has had the pleasure of teach every level; from Kindergarten to grade 12. While he has taught in every panel, the majority of his teaching has taken place in grade 6. From the classroom he moved into a K-8 math consultant role and is now the Vice Principal at a local 7-12 high school.

Thursday, July 16
Speed Networking and Coffee Break

Coffee breaks at conferences are the perfect opportunity to catch up with fellow researchers around the world and get to know new faces in the field of numerical cognition. As alternative, we propose a virtual coffee break which will allow just this. After a short introduction, the group will be split into random breakout rooms of 4 to 6 people, so you can get to know each other and catch up in an informal way for about 10 minutes. After 10 minutes you will be alerted that your next speed networking room is ready to get to know you and your research. So, grab a coffee, cake, beer or wine and have a chat with old and new colleagues!

Friday, July 24
Representations and knowledge structures for fractions and rational numbers

Presenters
Sabrina Di Lonardo Burr, Carleton University, Canada
David Braithwaite, Florida State University, USA
Kelsey MacKay, Katholieke Universiteit Leuven, Belgium
Tom Faulkenberry, Tarleton State University, USA

Abstract
Over the last two decades, researchers in numerical cognition have expanded their investigations beyond the context of single-digit numbers and have started to consider issues concerning numbers with more complex mathematical structure. In this symposium, we will focus on fractions and rational numbers, a field in which many open questions remain. As a result of the added complexity that fractions present, a number of new techniques and theoretical models have been brought to the field in order to tackle these open questions. This symposium will feature four talks from researchers who, as a group, reflect diverse international perspectives and multiple career stages. The talks will each provide a unique perspective on central questions about representations and knowledge structures for fractions and rational numbers, including procedural and conceptual knowledge in rational number arithmetic, number line estimation with children, the role of the base-10 system in fraction magnitude representation, and mathematical modeling of processing architectures with symbolic fractions.

Thursday, July 30
Posters & Lightning Talks

Lightning Talks
Theresa Elise Wege: Beyond representation: Young children's preference for object-based counting

When young children are asked to count collections of tangible objects as a unit they frequently and consistently make the mistake to count all objects individually instead of counting collections. For example, when asked "how many different kinds of animals?" children would often touch and count each toy animal instead of counting all sheep together, all horses together etc.

There are two possible accounts for this mistake. Young children might have a general cognitive bias for individuating tangible objects as units and counting is only a behavioural expression of what they are able to cognitively represent. Alternatively, the mistake might be unrelated to their cognitive representation of the objects and is rather an expression of their understanding of counting as a numerical action.

We conducted an experiment with 3-5 year old children (N=44). The children were asked to enumerate collections of tangible objects as units by counting or one-to-one correspondance in several trails. Trials offered increasing support for children to represent collections as units.

We found that children's object-based enumeration mistakes were independent of how well they had represented collections as units. We further found that object-based enumeration mistakes were more prevalent in counting than in one-to-one correspondence.

These findings indicate that object-based counting cannot be fully explained by children's general cognitive bias for individuating tangible objects as units, but seems to be specifically related to their understanding of counting as a numerical action.

Christina Artemenko: Calculation in the elderly brain (Collaboration Pitch)

Calculation skills are essential for everyday life up to old age. However, the mechanisms underlying calculation by using both behavioral and neuroimaging methods were never studied in elderly so far. The current project addresses this issue by using fNIRS to evaluate general cognitive processes and specific numerical processes being involved in addition and subtraction in older adults as compared to younger adults and children. The findings will open a new research field on the neurocognitive effects of aging on calculation and extend the developmental perspective on calculation skills to the whole life span. In this new project, I would like to collaborate with experts in aging.

Posters
Hannah Loenneker: Basic number processing in Parkinson's Disease - a preregistration (preregistered poster)

Due to demographic changes, occurrence of age-related Parkinson’s disease (PD) increases steadily. Recently, domain-general deficits of memory, attention and executive functions have been found to be impaired in PD. However, numerical capacities have not been investigated, despite patterns of neurodegeneration in PD overlapping with neuronal circuits of numerical cognition. Therefore, the planned study aims at investigating numerical deficits in PD. We expect (1) a higher prevalence of numerical impairment in PD compared to healthy ageing, 2) the numerical deficits in PD should also depend on domain-general deficits and 3) basic numerical tasks should predict performance in numerical activities of daily living (NADL).

Basic numerical tasks (transcoding, (non-)symbolic magnitude comparison, number line estimation) and an NADL test will be conducted alongside neuropsychological tests with N = 30 healthy control participants (HC) and N = 60 PD patients (based on power analysis).

For the basic numerical tasks, outcome variables will be compared between HC and PD with independent sample t-tests. Overall, we expect a prevalence of 20% numerical deficits in PD. In the transcoding task, performance will be characterized according to specific error types and mean error rates. We expect the PD group to show more errors. Distance effects in the (non-) symbolic magnitude comparisons and the unit-decade-compatibility effect in the symbolic task should be more pronounced in PD. The Weber fraction should be less accurate in PD. Number line estimation is assessed as deviation between estimation and actual position. Both HC and PD should not show impairment in the range 0-100, but for large numbers. Regressions are used to predict performance in each basic task with domain-general factors (attention and executive functions should have an impact). Performance in the NADL task will be predicted by performance in the basic tasks with a regression (all tasks should contribute to the prediction).

Lilia Marcelino: GBL4deaf - Game-based mathematics learning for deaf students (preregistered poster)

Deaf or Hard of Hearing (DHH) students display poor performance in arithmetic tasks that requiring verbal process (e.g. abstract counting and symbolic addition and subtraction problems tasks) but not in tasks requiring non-symbolic numerical representations (Gottardis, Nunes, & Lunt, 2011). A scientific project, namely, GBL4deaf - Game-Based Learning for Deaf Students has been undertaken to explore the impact of an educational videogame in mathematics learning for DHH students. The participants are fifth to ninth graders attended three types of schools: a developmental and educational centre specialised in deaf education, a mainstream school, and a governmental reference school for bilingual education. The videogame has been developed using non-symbolic arithmetic operations and angles intrinsically integrated in playability following the principles of game-based learning. The ongoing project pursues a convergent mixed method procedure with a qualitative/quantitative approach. It includes teachers interviews to collect data about participants background (e.g. clinic history, academic achievement); and chases a pretest game mathematics contents measure followed by the videogame exposure and posttest in two different conditions: a) exposure to the videogame at school; b) exposure to the videogame at home. The GMC - Game Mathematics Contents was based on The 15 minute norm-reference mathematics test – Basic computations and Algebra (Chinn, 2017) and it is a measure that evaluates arithmetic procedures with a follow up question, “How did you do this?”, instead of including items that require verbal process (e.g. problem-based items). The instructions of the test will be translated by a sign language interpreter. Content Analysis and General Linear Model procedure will be used to analyse the collected data. The number of exposures will be measured by Game Analytics. The qualitative and quantitative data will be collected in parallel, analysed separately, and then merged in a combined approach known as triangulation. It is expected that, despite the type of school or background/academic characteristics, the DHH students show better results on GMC measure after the exposure to the videogame.

Brian Rivera: Neural Bases of Numerical and Social Information Transfer in Autism Spectrum Disorder (preregistered poster)

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that affects sensorimotor, cognitive, and socio-communicative abilities throughout the lifespan. Social deficits observed in ASD are linked to impairments in brain systems that support theory of mind, which requires recruitment of sensorimotor simulation systems. While sensorimotor simulations are hypothesized to underlie all components of higher cognition, these components are not affected to equal measure in ASD. We will investigate neurobiological bases of sensorimotor simulations in emotion recognition vs. number processing in individuals with ASD, and their neurotypical peers. The goal is to identify spatiotemporal algorithms of routing visual information to limbic (emotion processing) vs. parietal (number-processing) brain networks, which underlie, respectively, affective and numeric components of sensorimotor simulations.

Processing of emotional gestures/body posture requires an internal simulation of the observed bodily states combined with higher-level interpretation to extract the emotional valence from the percept. A similar phenomenon is observed in the development of number sense, which is physically grounded in finger counting across cultures. Neural networks for number processing include both sensorimotor and visual systems associated with fingers (Soylu et al., 2018) and finger counting habits and finger sense predict mathematical abilities (Wasnert et al., 2016). Thus, both the processing of finger numeral configurations, which underlies high-level numerical cognition, and processing of emotional gestures and body postures require sensorimotor representation of bodily states. While deficits in the theory of mind are well-attested in autism, the theory alone does not explain findings of atypically enhanced skills in non-social areas of cognition, such as numeric processing (Frith & Happé, 1994). Using EEG, we will compare the oscillatory activity and event-related potentials (ERPs) underlying processing of emotion and numeric gestures between ASD diagnosed individuals and neurotypicals.

Method

A group of ASD diagnosed participants (ASD) and a group of neurotypical participants (TD) will be recruited to participate in the study. After completing an informational survey (including ADOS-2 for ASD participants), both groups will complete a resting-state EEG recording. Participants will then complete a mismatch task that includes validating Arabic numbers (1-4), numerical finger gestures (showing numbers 1-4), face expressions (disgust, joy, sadness, surprise) and social gesture (like, dislike, perfect, and punch) while EEGs are recorded. All validation (target) trials will be in written text. Participants will complete 12 blocks of 80 trials (about 45 minutes).

Data Analysis

Data analysis will be performed between groups (TD, ASD) and within groups (with age and ASD symptom severity). Averaged target-stimulus locked ERPs will be created to analyze differences between each of the four stimulus categories (Arabic numbers, numerical finger gestures, faces, and social gestures). Additionally, time frequency analysis of EEG signals will be performed. We will use high temporal resolution of EEG to characterize sensorimotor resonance using mu suppression metric – a widely used measure in research on number processing and ASD (Hobson & Bishop, 2016). Group data will then be modeled using a combination of microstate and network analyses (Malaia et al., 2016).

Lars Orbach: Relation of Core Executive Functions (CEF) to Basic Number Skills and Arithmetic Fact Retrieval

Although research has provided evidence for a clear association of core executive function (CEF) to math performance, less studies have been carried out on arithmetic fact retrieval and considered symptoms of attention deficit hyperactivity disorder (ADHD). The present study assessed mathematical achievement on a basic number skill test in a non-timed condition and on an arithmetic fact retrieval task in a time-pressure condition. Besides math achievement, self-ratings of ADHD symptoms (attention deficits, hyperactivity, impulsivity) and core executive functions (inhibition, cognitive flexibility, working memory capacity, global index) of 646 fourth and fifth grade students (48.1% girls) are measured. CEF were evaluated by means of a tablet-based test. All coefficients between CEF and the basic number skill scores were significantly positive ($r(566) = .196$ to $.232$; $p \leq .001$), whereas no correlation between cognitive flexibility and arithmetic fact retrieval existed. Furthermore, inhibition and the global CEF index correlated significantly higher with the basic number skill test than with the arithmetic fact retrieval scores (inhibition: $z = 1.81$; $p = .035$; global CEF: $z = 2.42$; $p < .01$). Both math tests were negatively associated with inattention self-ratings. Regression analysis showed different predictors for both math abilities. While all CEF measures, inattention and impulsivity self-ratings predicted basic number skills, only inhibition, WMC and inattention self-rating were predictors of arithmetic fact retrieval. In total, all measures explained 16.7% of the variance in basic number skills and 9.4% of the variance in fact retrieval. The data yield evidence that the association between CEF and math achievement depend on the specific math skill and test type. The results underline the importance of differentiating between CEF components and specific math abilities.

Agata Sobkow: Multiple numeric competencies predict decision outcomes beyond fluid intelligence and cognitive reflection

The goal of the present study was to compare the relative contribution of different cognitive abilities and preferences to superior decision making. Additionally, we aimed to test whether skilled decision makers have better and more sophisticated long-term memory representations of personally meaningful risky situations. A large sample from the general population completed a series of tasks and questionnaires measuring cognitive abilities and preferences (fluid intelligence, cognitive reflection, and multiple numeric competencies: statistical numeracy, subjective numeracy, approximate numeracy) and decision making outcomes (a set of monetary lotteries and a self-report inventory measuring success in avoiding negative decision outcomes in real-life). We also designed a memory task in which participants were instructed to discriminate between decision outcomes presented in the first stage of the study and distractors. We found that multiple numeric competencies predicted decision making beyond fluid intelligence and cognitive reflection. Especially, the acuity of symbolic-number mapping (a measure of approximate numeracy) was the most robust single predictor of superior decision making. Moreover, a combination of different cognitive abilities contributed to a better understanding of decision outcomes. For example, superior decision making in monetary lotteries was best predicted by approximate numeracy, statistical numeracy, and fluid intelligence, while avoiding negative decision outcomes in real-life was best predicted by approximate and subjective numeracy. Finally, we demonstrated that people with high approximate numeracy had better memory for decision outcomes and produced more vivid mental representations, suggesting that memory processes can be crucial to superior decision making.

Judit Pekár: The interaction of physical size and numerical size in a novel go/nogo numerical Stroop task: An ERP study

The role of inhibition in numerical processing is a subject of debate in the current literature. Inhibitory control abilities have been associated with mathematical competence in children at various educational stages. Moreover, inhibition along with integration has been named as an important factor in the interplay between continuous magnitudes and discrete quantities. However, the exact mechanisms are yet to be understood. Therefore, the aim of our study was to develop a novel paradigm which allows us to investigate well-established neural markers of inhibition and conflict processing with numerical stimuli when numerical and physical size are concurrently manipulated. To this end, we combined the go/nogo paradigm with the numerical Stroop task while measuring EEG and reaction times. We presented participants (N=16) with Arabic number pairs and instructed them to press a button if the number on the one side was numerically larger (go trials, 75%) and to actively not press a button if the number on the other side was numerically larger (nogo trials, 25%). We manipulated the physical size of the number pairs to create congruent trials (numerically larger number is physically larger), incongruent trials (numerically larger number is physically smaller) and neutral trials (equal physical size). Behavioural results confirmed the well-established numerical distance and numerical Stroop effects. Our preliminary analysis of electrophysiological data revealed the classical go/nogo ERP effects with numerical stimuli: larger N2 and larger P3 components for nogo than for go trials on frontal and midline electrodes. When 9haracter the congruency effects, we found larger positivity for congruent versus neutral trials in go trials only, and also a larger negativity for incongruent versus neutral trials in nogo trials only. Thus, physical size seems to have facilitatory as well as interference effects on the processing of numerical size and this effect may be modified by the task requirements.

Yip Eason Sai Kit: Sixth graders' reasoning ability on invalid conditional inferences predicts concurrent algebraic achievement

Reasoning ability has been proposed to be associated with mathematics achievement, but empirical evidence is needed to specify such an association. The current study aimed at exploring students' conditional reasoning ability and its relationship with algebraic achievement. Sixth graders (n = 101) were assessed on their conditional reasoning ability and algebraic achievement, in addition to control variables (e.g., intelligence, working memory) and potential mediator (ability to detect violation of arithmetic principles). Factor analysis using scores from four inferences in true, false and abstract contexts yielded a 4-factor structure. Subsequent regression revealed that the ability to identify invalid conditional inferences (i.e., affirmation of consequent (AC) and denial of antecedent (DA)) in true and false contexts significantly predicted concurrent algebraic achievement, controlling for all control variables and mathematics achievement at the fourth grade. Further mediation analysis showed that the ability to detect violation of arithmetic principles partially mediated the relation between conditional reasoning and algebraic achievement. The study demonstrated the contribution of conditional reasoning ability to a specific mathematical domain in elementary school level and provided evidence for the potential mechanism behind the relation.

Winnie Wai Lan Chan: Young Children's Understanding of Multi-digit Numbers in Hong Kong and the U.S.

Multi-digit understanding, or the place-value concept, plays an important role in mathematical development. Previous research has shown that young children start to make sense of multi-digit numbers well before they are taught formally in school. In the present study, we aimed to examine how well young children could represent multi-digit numbers using the Arabic symbols and make sense of the magnitudes represented by these numbers. We compared the early knowledge of multi-digit numbers among children in Hong Kong and the U.S. to see if there existed any cultural differences. One hundred and fifty-eight Chinese-speaking children in Hong Kong and 81 English-speaking children in the U.S. completed a number writing task and a number comparison task. These children fell into three age groups: 4-, 5-, and 6-years-old. Results showed that in the number writing task, Hong Kong children from all age groups were more accurate than the U.S children in writing two-digit numbers. When writing three-digit numbers, the 5-year-olds in the U.S. were more accurate than their counterparts in Hong Kong, whereas the 6-year-olds in Hong

Kong were more accurate than their counterparts in the U.S. No cross-cultural difference was observed in four-digit number writing. In the number comparison task, cross-cultural difference was found only in the 6-year-olds, where children in Hong Kong were more accurate than their counterparts in the U.S. These findings suggest that young children do possess some knowledge of multi-digit numbers prior to formal instruction, and cross-cultural differences may appear during this early stage.

Joyce Lok Yin Kwan: Interaction between Parental Beliefs about the Nature of Mathematics on Children's Motivation to Learn Mathematics

Introduction: This study aimed to examine how parent's static belief (i.e., mathematics as a formal set of rules and procedures) and dynamic belief (i.e. mathematics as a dynamic process of inquiry and a continually expanding body of knowledge) about the nature of mathematics (Thompson, 1992) were related to children's motivation in early mathematics learning.

Methods: A sample of 349 Hong Kong parents with children who were at the first to third year of kindergarten (aged 3-6) were invited to complete a Chinese questionnaire that measured their beliefs about nature of mathematics and their children's behaviors during mathematics learning. The 12-item Beliefs about the Nature of Mathematics scale developed in the Teacher Education and Development study (TEDS-M) was modified to assess parents' static/dynamic belief about the nature of mathematics and the 11-item scale of Berhenke (2013) was adopted to measure children's approach/avoidance motivation to learn mathematics.

Results: Results of hierarchical regression analysis showed that there was significant interaction effect between parents' static and dynamic beliefs about the nature of mathematics on children's approach motivation in mathematics learning. Simple slope analysis revealed that parents' static belief was only significantly positively related to children's approach motivation when they had strong dynamic belief. Both the main effect of dynamic belief and the interaction effect between static and dynamic beliefs on children's avoidance motivation were not significant but the main effect of static belief was significant, suggesting that children who had parents with stronger static belief showed higher tendency of avoidance behaviors in mathematics learning.

Conclusions: Results of this study suggested that the static and dynamic nature of mathematics were not two independent and opposing constructs in underpinning parents' beliefs in children's mathematics learning. Future studies may also explore how these two beliefs interact to affect parents in upholding their home mathematics practices and essentially children's numeracy outcome.

Friday, August 7

Learning to count: New insights on the acquisition of symbolic numerical knowledge

Presenters
Francesco Sella, Centre for Mathematical Cognition, Loughborough University, UK
Emily Slusser, San Jose State University, US
Attila Krajcsi, ELTE Eötvös Loránd University, Hungary
Darko Odic, University of British Columbia, Canada

Abstract

Humans have developed symbolic systems to represent and efficiently manipulate numerical information. Children gradually learn the rules and principles characterizing the number system and how number words and numerals represent exact numerical quantities. The acquisition of symbolic number knowledge is a long and error-prone process that occupies children for several years, starting from the age of two until the first years of primary school, and it represents a crucial stepping stone for future mathematical achievement. In the symposium, we provide new insights on the acquisition of the symbolic numerical knowledge throughout development, including in how children initially learn number words, how they understand that they refer to number (as opposed to other dimensions of quantity), and how this achievement eventually leads to benefits in how number words relate to symbolic mathematics.

The first talk (Slusser) explores the developmental trajectory of children's understanding that number words refer to discrete numerical quantities, rather than continuous dimensions (e.g., "small", "a lot"). Children fully grasp the discrete nature of number words when they are 3-knowers, at an intermediate stage toward the mastering of the cardinality principle.

The second talk (Krajcsi) revalidates the widely used Give-a-Number task, in which children create numerical sets according to a required number (e.g., "give me four apples"). The current literature describes a sudden change in performance and strategy implementation when children extend their cardinal knowledge beyond four (i.e., cardinal-principle knowers). Contrary to this prevailing view, the proposed re-evaluation highlights the presence of a smooth, rather than sudden, change in performance as children slowly acquire the numerical meaning of number words beyond four, challenging traditional accounts of number words being learned through a sudden insight into general counting principles.

The third talk (Sella) describes how the mastering of different numerical concepts relate to the understanding of the exact numerical magnitude represented by number words and Arabic numbers. The mastering of the predecessor knowledge (i.e., removing one item from a set leads to the preceding number word in the counting list) and the knowledge of the spatial order of numbers relate to the performance in number comparison tasks beyond the acquisition of the cardinality principle and the later-greater principle.

The fourth talk (Odic) shows how the eventual mastery of number words leads to other benefits in children's numerical skills, most notably in children's ability to associate symbolic number words with their intuitive sense of number (the Approximate Number System; ANS), with non-numeric dimensions (e.g., estimating the length of a line), and as a source of error detection in symbolic mathematics.

The combination of the four talks provides an overview of the development of symbolic numerical knowledge from children who have just begun learning number words to those who have largely mastered it while giving new insights challenging current theoretical views.

Thursday, August 13

Cross-Representational Knowledge: Connecting Fractions and Decimals

Presenters
Hilma Halme, University of Turku, Finland
David Braithwaite, Florida State University, USA
Ilyse Resnick, University of Canberra, Australia
Jo Van Hoof, KU Leuven, Centre for Instructional Psychology and Technology, Belgium

Abstract

Fractions and decimals are uniquely important and uniquely difficult in children's mathematical development. Much previous research has investigated children's understanding of fractions and decimals separately—that is, within-representational knowledge. This symposium will investigate individual differences in children's cross-representational knowledge—that is, knowledge of relations between fractions and decimals. The four talks comprising the symposium will discuss children's ability to switch between fraction and decimal representations (Halme), fraction versus decimal comparison and its relations to rational number arithmetic skill (Braithwaite), the parallel development of fraction and decimal magnitude knowledge and its relations to math achievement (Resnick), and the development of learners' understanding of the dense structure of fractions and decimals (van Hoof). The findings indicate that cross-representational knowledge predicts various outcomes above and beyond the contribution of within-representational knowledge and that some aspects of rational number understanding may develop with decimals earlier than with fractions.

Friday, August 21
Exploring the predictive power of the Numeracy Screener around the world

Presenters
Jo-Anne LeFevre Institute of Cognitive Science, Carleton University
Ouhao Chen, National Institute of Education, Nanyang Technological University, Singapore, and Centre for Math Cognition, Loughborough University
Krzysztof Cipora, Department of Psychology, University Tubingen, and Centre for Math Cognition, Loughborough University
Stephanie Bugden, Post-doctoral scholar, Department of Psychology, University of Pennsylvania

Abstract

Screening tools that assess children's understanding of exact numerical magnitude hold promise for identifying children who struggle with learning math. The Numeracy Screener is a 2-minute paper-and-pencil assessment of children's knowledge of magnitudes less than 10. Children are presented with pairs of dots (i.e., dot comparison) or pairs of digits (i.e., digit comparison) and are asked to draw a line through the larger magnitude. Studies from Canada have shown that performance on the digit comparison condition of the Numeracy Screener is a stronger predictor of arithmetic performance than dot comparison (e.g., Hawes et al., 2019; Nosworthy et al., 2013). This finding supports the view that knowledge of symbolic magnitudes is a key early numeracy skill. However, with growing efforts to improve the quality of math education around the world (World Bank, 2016), it is important to understand how findings from Canada generalize to other cultural contexts. In this symposium, our goal is to explore how performance on the digit and dot comparison conditions of the Numeracy Screener relate to individual differences in math abilities in young children from different countries – including children from countries with limited access to quality education. Collectively, we will present data from Chile, Singapore, Poland, Ghana, and Cote d'Ivoire. We will evaluate the reliability and validity of the Numeracy Screener in assessing numerical magnitude knowledge across cultures. Exploring how cultural contexts influence the relationships between digit and dot comparison performance and general math abilities is important for informing theory and practice.

In "Is digit comparison useful for identifying kindergarten children who struggle in math?" Jo-Anne LeFevre, Professor from the Institute of Cognitive Science at Carleton University, will evaluate whether digit comparison is associated with arithmetic and problem solving even when controlling for other early numeracy skills in Kindergarten children from Chile. LeFevre and colleagues show that digit comparison, not dot comparison, is a significant unique predictor of problem solving and arithmetic performance.

In "Singapore pre-school children's symbolic and non-symbolic knowledge," Ouhao Chen, a lecturer from the National Institute of Education, NTU Singapore, will explore the reliability and validity of the Numeracy Screener in assessing number knowledge in pre-school children from Singapore. Chen demonstrates that both digit and dot comparison are associated with math fluency performance.

In "Numeracy Screener Validation in Poland – a look at discriminant validity," Krzysztof Cipora, at that time Lecturer at Loughborough University, will present the results from a validation study conducted in Poland assessing the reliability and validity of the Numeracy Screener. Digit and dot comparison correlate with arithmetic performance; however, they do not remain significant predictors when letter naming is added as a control variable.

In "Dot comparison performance predicts math achievement in primary school children from Ghana and Cote d'Ivoire," Stephanie Bugden, a post-doctoral scholar from the University of Pennsylvania, will present two studies demonstrating that dot comparison, but not digit comparison, accounts for significant variance in math skills even when controlling literacy, socio-emotional, and executive function skills in Ghana and Cote d'Ivoire.
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Thursday, August 27
Posters & Lightning Talks

Lightning Talks
Jenny Yun-Chen Chan: Using clickstream data to better understand students' algebraic thinking (Collaboration pitch)

We would like to invite potential collaborators to explore rich clickstream data to better understand student behavior in From Here to There (FH2T) and to examine how behavior in FH2T may relate to students' algebraic thinking.

FH2T is an interactive application in which mathematical terms are transformed into digital objects that can be tapped and moved around the screen (Weitnauer et al., 2016). For example, students can dynamically manipulate algebraic notations by performing mouse-action or touchscreen gestures (e.g. dragging, tapping) that apply mathematical transformations to expressions (e.g., commuting, combining terms). In each FH2T problem, students are presented with an initial expression and a mathematically equivalent goal state. The objective is to transform the expression into the specified goal state using a series of gesture-actions on the screen. The system provides opportunities to experience mathematical operations and properties though actions and immediate visual feedback. For instance, the system responds to users' gesture-actions by enacting valid transformations (e.g., tapping the subtraction sign turns $4x-3x$ into x), and provides error feedback by shaking the expression (e.g., tapping the addition sign in $5+2x$ makes the expression shake) and not enacting the invalid transformation. The system records clickstream logs of all interactions from all students. For each problem, we log when (i.e., timestamps) and what actions (i.e., transformation steps, errors, resets, hint requests, etc.) students made, and the time spent on each attempt of reaching the goal state. In prior work, we have found that working with FH2T is positively associated with an increase in students' algebra performance and engagement compared to non-motion based methods of instruction (e.g., Ottmar et al., 2015, 2017; Weitnauer et al., 2016). We currently have clickstream data from a pilot study with 350 students, and we will collect clickstream data from 1,500 additional seventh-grade students this fall.

Roland H. Grabner: Neurophysiological evidence for fact retrieval rather than compacted procedures in small addition problems

There is broad consensus that adults solve single-digit multiplication problems by fact retrieval (i.e., retrieval of the solution from an arithmetic fact network). In contrast, there has been a long-standing debate on the cognitive processes involved in solving single-digit additions. This debate has evolved around two theoretical accounts. The fact-retrieval account postulates that these are similarly solved through fact retrieval, whereas the compacted-procedure account proposes that solving very small additions (i.e., problems with operands between 1 and 4) involves highly automatized and unconscious compacted procedures. In the present electroencephalography (EEG) study, we put these two accounts to the test by comparing the neurophysiological correlates of solving very small additions and multiplications. We assessed the evidential strength for similarities and differences across operations using Bayesian statistics. During EEG recording, 40 healthy adults worked on an arithmetic production task with all 72 (non-tie) single-digit additions and multiplications. Afterwards, strategy self-reports for each problem were assessed. In the EEG analyses, we focused on induced activity (event-related synchronization/desynchronization) in three frequency bands (theta, lower alpha, upper alpha) because these measures have turned out to be associated with cognitive strategies in arithmetic. Across all frequency bands, we found higher evidential strength for similar rather than different neurophysiological processes accompanying the solution of very small addition and multiplication problems. This was also true when $n + 1$ and $n - 1$ problems were excluded from analyses. In two further control analyses we showed that induced EEG activity can differentiate between self-reported problem-solving strategies (retrieval vs. procedure), and even between n + 1 and n + m problems in very small additions, demonstrating its high sensitivity to cognitive processes in arithmetic. The present neurophysiological findings suggest that both very small additions and multiplications are solved through similar cognitive processes and, thus, clearly support the fact-retrieval account.

Hippolyte Gros: Keeping an eye out for cardinality: an eye-tracking study of arithmetic problem solving

Recent evidence suggests that general, non-mathematical knowledge about the entities described in an arithmetic word problem may interfere with its encoding, to the extent that even math experts may struggle to solve problems embedded in a semantically incongruent context. In this study, we used behavioral and eye tracking measures to investigate how the use of specific quantities (weights, prices, collections) may foster a cardinal representation of the numbers mentioned in a problem, whereas other quantities (durations, heights, number of floors) may favor an ordinal representation. We thus hypothesized that cardinal quantities would lead to a set-based encoding of the problems' values, whereas ordinal quantities would lead to an axis-based encoding instead. We designed isomorphic word problems meant to only appear solvable to those who constructed an axis-based encoding of the described situation. Those problems were implemented either with cardinal or with ordinal quantities. We asked 50 pre-service teachers to assess the solvability of these problems while we recorded their eye movements to gather insights into their encoded representations. On problems featuring cardinal quantities, we found that specific sentences describing elements relevant in a cardinal understanding of the problems but irrelevant otherwise were looked at longer and were the focus of a higher number of backward eye movements. Additionally, participants made more errors and took a longer time to solve problems evoking a cardinal encoding, thus suggesting that correctly solving a problem featuring cardinal quantities required to semantically recode the constructed representation. Finally, increase in pupil dilation on correctly solved cardinal problems also supported the idea that participants needed to engage in a semantic recoding process when facing semantic incongruence. Overall, these results support the growing line of evidence that daily-life knowledge about the quantities featured in a problem may interfere with its solving by promoting one of two competing representations.

Ami Feder: On the Mental Representation of Exponents

Little is known about the mental representation of exponential expressions. The present study examined the automatic processing of exponential expressions under the framework of multi-digit numbers, specifically asking which component of the expression (i.e., the base/power) is more salient during this type of processing. In a series of four experiments, participants performed a physical size comparison task. They were presented with pairs of exponential expressions that appeared in frames that differed in their physical sizes. Participants were instructed to ignore the stimuli within the frames and choose the larger frame. In all experiments, the pairs of exponential expressions varied in the numerical values of their base and/or power component. We manipulated the compatibility between the base and the power components, as well as their physical sizes and the location of the power relative to the base component (to create a standard vs. nonstandard syntax of exponential expressions). The results revealed that although the size congruity effect was modulated by the components' compatibility, it was consistently stronger for the physically larger component, regardless of its location or mathematical meaning. Our findings support componential processing of exponents by demonstrating that participants were drawn to the physically larger component, even though in exponential expressions, the power, which is physically smaller, has the greater mathematical contribution. Accordingly, the syntactic structure of an exponential expression that conveys the unique mathematical roles associated with its components is not processed automatically.

Posters

Stijn Van Der Auwera : Flexible use of subtraction by addition in the number domain op to 1000 in 10-12-year-olds

Introduction.

Previous studies by Torbeyns et al. (2009, 2011) showed frequent, efficient and flexible use of subtraction by addition (SBA) in adults. A recent study by Torbeyns et al. (2018) provides evidence that also 6th-graders make frequent, efficient and flexible use of SBA. In the present study we investigated the use of direct subtraction (DS) versus SBA when mentally solving subtractions up to 1000 in even younger children with different levels of mathematical achievement.

Method.

In accordance with Torbeyns et al. (2018), we relied on Lemaire and Siegler's (1995) model of strategy change, which defines strategy competencies in terms of four parameters: strategy repertoire, frequency, efficiency and flexibility. We offered 153 4th- to 6th-graders multi-digit subtractions up to 1000 in one choice condition (choice between DS or SBA) and two no-choice conditions (mandatory use of either DS or SBA). Half of the subtractions had a very small difference (e.g., 504-476=__) between the minuend and the subtrahend whereas in the other half that difference was very large (e.g., 616-28=__).

Results.

Concerning strategy repertoire and frequency, most 4th- to 6th-graders reported using SBA at least once during the choice condition, even though their mathematics instruction only aimed at the mastery of DS. Regarding efficiency, SBA was used more accurately and faster than DS in the no-choice condition in all grades, particularly on small-difference subtractions. Finally, concerning strategy flexibility, 4th- to 6th-graders fitted their strategy choices to both numerical item characteristics and individual strategy efficiency. All these findings applied equally to children from different grades and mathematical achievement levels.

Conclusion.

Children from varying grades and mathematical achievement levels apply the untaught SBA strategy frequently, efficiently and flexibly to solve multi-digit subtractions. These results challenge mathematics instruction practices that focus heavily on DS.

Serena Rossi: The role of feedback in primary school children while performing a mental calculation task

Many forms of assessment at school are considered a major source of stress for students (Ramirez & Beilock, 2011), especially in mathematics (Beilock, 2008; Caviola et al., 2017).

The aim of this study was to investigate how fifth-grade children react to different types of feedback during a math task. A sample of 242 children was initially screened for fluid intelligence, mathematics abilities, and emotional aspects. Based on this initial assessment 159 children were randomly assigned to three different conditions (Negative-, Positive-Feedback and control conditions). The experimental phase was characterized by a computerized math task, where predetermined feedback appeared after each trial. In the Negative condition, children were presented with 75% of negative feedback on the overall amount of trials, conversely, on the Positive condition, 75% were positive reinforcements. For the control-condition, no feedbacks were provided.

Before and after the task children were asked questions about their perceived competences in the task. Moreover, during the math task, some psychophysiological measures (heartbeat, skin conductance, and respiration) were recorded.

Results showed that, although math performance increased in both feedback conditions, the reception of repeated negative feedback led to a drop in the feeling of competence and valence while increasing in worrying responses. Furthermore, the analysis of their physiological indexes showed greater negative arousal. In conclusion, our findings explain the importance of feedback at school, not only for children's math performance but also for their personal and academic well-being.

Brianna Devlin: Young Children's Mental Organization of Arithmetic Relates to Specific Number Skills and Understanding of Mathematical Equivalence

Mental organization of arithmetic around equivalent values (e.g., generating 4+2 and 3+3 given target 6) is associated with second graders' formal understanding of math equivalence (e.g., solving 3+4+5=3+__ correctly; Chesney et al., 2014). This study aimed to replicate that finding and identify early predictors of beneficial mental organization.

Kindergarteners' (N = 26 boys, 23 girls) completed two tests of specific early number skills (number sets and number line) along with Griffin's (1994) number knowledge test as a measure of general number knowledge. In first grade, children were asked to generate combinations equivalent to target values (e.g., given target 8, 4+4 is one combination). Children also were asked to solve simple math equivalence problems (e.g., 3+4=__+5).

Accuracy on math equivalence problems was near floor ($M = 0.18$ of 3), so logistic regression was used to predict the log of the odds of solving any problem correctly with number of combinations as the predictor, controlling for general number knowledge. For every standard deviation increase in combinations, children were three times more likely to solve at least one problem correctly, $b = 1.09$, Wald = 5.21, $p = .022$.

To examine predictors of this mental organization, multiple regression was used to predict combinations in first grade from kindergarten number sets and number line skills, controlling for general number knowledge. Number sets was predictive, $b = .35$, $t(48) = 2.26$, $p = .031$, but number line was not (for 0-20 line, $p = .26$; for 0-100, $p = .38$).

Results replicate the association between mental organization of arithmetic and understanding of math equivalence in a younger sample. They also suggest differences in mental organization of arithmetic may be present near the start of formal schooling, and that beneficial mental organization is predicted by an earlier understanding that numbers are made up of smaller sets.

Mariuche Rodrigues de Almeida Gomides: Interference impairs the learning of novel arithmetic facts

Learning multiplication tables requires the memorization of problem-response associations with recurring digits, and inhibition of concurrent responses. In this study, we investigated whether interference produced by heightened digit recurrence impacts learning new multiplication problems. Fifty seven undergraduate students (mean age = 21.9 years, SD = 3.13, 39 females) learned to solve two lists of 6 two by one digit multiplication problems with three-digits responses (e.g., 38 x7 = 266). Lists differed by digit recurrence (Low and High Interference Blocks: LIB vs. HIB). Participants needed more trials, $t(56) = 4.33$; $p < 0.001$; $d = 0.69$, and committed more false association errors, $t(56) = 5.55$; $p < 0.001$; $d = 0.95$, to learn the HIB compared to LIB. Analysis of reaction time showed a main effect of block, $F(1,56) = 15.59$, $p<.001$, $\eta^2=.218$, no main effect of problem size, $F(1,56) = .224$, $p=.638$, $\eta^2=.004$, and no interaction between block and problem size, $F(1,56) = 3.27$, $p=.076$, $\eta^2=.055$. In contrast, analysis of accuracy showed a main effect of block, $F(1,56) = 5.95$, $p<.018$, $\eta^2=.096$, a main effect of problem size, $F(1,56) = 8.63$, $p<.005$, $\eta^2=.134$, and an interaction between block and problem size, $F(1,56) = 11.51$, $p<.001$, $\eta^2=.177$. The results suggest that interference hampered multiplication learning, although this should be interpreted with caution since problem size also influenced learning. The results corroborate evidences showing that interference uniquely predicts the performance of multiplication. Pedagogical impact should be further investigated.

Isabelle de Vink: Creative problem solving in 5th grade mathematics education

Introduction.

Previous research has demonstrated the importance of number sense and working memory as predictors of mathematical ability. However, recent research has demonstrated that creative problem-solving comes into play when children face mathematical problems for which no standard solution is available (Leikin, Koichu, & Berman, 2009). Currently, the exact influence of these creative thinking skills in relation to other predictors of mathematics achievement remains unclear. In order to do justice to diversity, both domain-general (working memory) and domain-specific (number sense, mathematical creative problem-solving) predictors of mathematical ability are taken into account in this study, as well as children's divergent and convergent thinking.

Methods.

Data is collected in a sample of around 200 5th grade children. Working memory is assessed using a visuo-spatial updating and verbal backwards recall task. To get insight into children's number sense, the symbolic and non-symbolic comparison subtasks from the MathPro battery are used (Karagiannakis & Baccaglini-Frank, 2014). Mathematical creative problem-solving is measured using a multiple solution task (Schoevers, Kroesbergen, & Kattou, 2018), while general creative problem-solving is measured using different visual and verbal divergent and convergent thinking tasks. To assess mathematical ability, GPA scores for mathematics are used, which include mental arithmetic and geometry.

Results.

Preliminary analyses show that verbal convergent thinking is correlated with mathematical ability ($r = .313$, $p < .01$), but visual convergent and divergent thinking are not. Furthermore, qualitative analyses indicate differences in creative problem-solving between mathematically gifted children and children with mathematical learning difficulties.

Conclusion.

Preliminary analyses indicate possible relations of creative problem-solving with mathematical ability. Further analyses will be performed using structural equation modelling (SEM) to investigate the relative influence of number sense, working memory and creative problem-solving on mathematics ability. Results will be presented at the conference.

Andrea Diaz-Barriga Yanez: Learning to run the number line: The development of attentional shifts during single-digit arithmetic

Increasing evidence indicates that our ability to process numbers is grounded in spatial representations, with numbers oriented from left to right on a mental number line (MNL). Recent studies have suggested that in adults, spatial associations may not be limited to number processing per se, but might also be observed during arithmetic calculation. For example, Mathieu et al. (2016) presented adult participants with single-digit addition, subtraction and multiplication problems in which operands and operator were shown sequentially on the screen. Although both the first operand and the operator were presented at the center of the screen, the second operand was presented either to the left or to the right side of space. Mathieu et al. (2016) found that addition problems were solved faster when the second operand appeared to the right and subtraction problems were solved faster when the second operand appeared to the left. No spatial bias was observed for multiplication, which suggests direct retrieval from memory. Here, we explored in two experiments (n=101 and n=68) the developmental time-course of these spatial biases. We presented 8 to 11-year-old children with the same paradigm as Mathieu et al. (2016). We found that subtraction problems were increasingly associated with a leftward bias from 8 to 11, such that only older children showed an association between subtraction problems and the left side of space. In contrast, no developmental increase in rightward bias was observed in this age range for either addition or multiplication. Whereas we did not find evidence that multiplication problems have any spatial bias, we found some evidence that children may already associate addition problems with the right side of space by age 9. This later effect, however, may depend on children's levels of arithmetic fluency. Theoretical implications of these studies will be further discussed.

Lilia Marcelino: Screening and preventive intervention for first-grade students with low early number competence

Developing math proficiency is a central educational goal. Not only is linked to graduation and higher education, but also with employment (Bynner & Parsons, 1997; Parsons & Bynner, 2005). For the last decades, cognition researchers from educational neuroscience and developmental psychology scientific areas have been concerned to identify the foundations of mathematics competence in order to construct valid screening measures and intervention programs (Alcock et al., 2016). Early number competence (ENC) (counting, number relations and basic arithmetical operations) has been pointed as the key for first grade mathematics achievement (Hornung, Schiltz, Brunner & Martin, 2014). Children who started first grade with early low numerical competence remained low mathematics achievement at the end of first grade (Jordan, Kaplan, Locuniak, & Ramineni, 2007; Marcelino, Sousa, & Lopes, 2017). The present study was conducted to explore the impact of a preventive mathematics intervention on students with low ENC. An early number competence screening test (Jordan, Glutting, & Ramineni, 2010) was adapted to the Portuguese population (n=2246) (Marcelino, 2015) and applied in 1557 first-grade students in the region of Azores at the beginning of first grade. Using Portuguese norms, 293 students (133 were boys and 160 girls) were identified with low numerical competence. Thirty Special Educational teachers were trained with a ECN intervention method (45 hours of training). The preventive intervention was based on the "Kieler Zahlenbilder" manual (Rozenkranz, 1994), namely Method Kiel – Numerical Images, and transformed on training programs to stimulate counting, number relations, number identification and basic arithmetical operations. The 293 students with low numerical competence were divided in two groups: an experimental group where students have access to the intervention once a week during 24 sessions of 90 minutes each (n = 80); and a control group only with access to the formal mathematics curriculum (n = 90). Posttest results show better results on the experimental group with significant statistical differences between the two groups. The results show a significant preventive intervention effect for first-grade students early screened with low numerical competence.

Sinead Rhodes: Cognitive strategies and learning mathematics in children with ADHD: insights from pupils and their teachers

Children with Attention Deficit Hyperactivity Disorder (ADHD) can struggle with mathematics learning. Understanding the use of strategies by teachers and indeed pupils to support learning is vital to raising numeracy attainment in these children. Ten primary school pupils with ADHD (aged 6 to 11 years) and their teachers took part in semi-structured interviews that focused on 1) the child's strengths, 2) the child's biggest challenges at school, 3) strategies in place for support and their efficacy, and 4) any gaps where support is still needed. Thematic analysis revealed challenges in numeracy and cognitive factors were amongst academic and non-academic factors impacting learning. Importantly, we were able to consider these issues from the perspectives of both children and their teachers. Further to this, strategies of support for specific challenges were discussed in the context of how effective or useful children found these. The focus of these strategies for both children and teachers tended to be on external aids (e.g. visual aids, timers, planners) and only some participants referred to cognitive strategies (e.g. rehearsal, chunking). This is surprising given the established link between cognitive function and mathematics learning in these children. The findings have implications for the development of school based interventions in terms of supporting existing use of external aids and introducing and promoting use of cognitive strategies.

Hannah Smith: Dynamic vs. Static: Which Worked Examples Work Best?

Worked examples provide students with complete derivations to mathematics problems as a tool for learning. Studies on algebra learning have shown that providing worked examples in classrooms significantly improves student performance in solving algebraic equations (Booth et al., 2013). With the advancement of educational technology, it is now possible to provide students with worked examples that demonstrate the dynamic process of solving algebraic equations (e.g., dragging 3 across the equal sign to initiate the inverse operations and divide both sides by 3 in 3x = 6). The current study utilizes Graspable Math (GM; Weitnauer et al., 2016), a dynamic algebra notation tool, to explore the benefits of different worked example presentation formats. We compare short and extended versions of traditional static worked examples (displaying complete derivations in one image) with sequential worked examples (showing derivations line by line in a looping GIF) and dynamic worked examples (where equations are manipulated and transformed in GM and displayed as looping GIFs). Students are randomly assigned to one of six worked example conditions in an online problem set. Participants complete an eight-item pretest on algebraic equation solving, view six worked examples, immediately complete paired practice problems, and then finish by completing a posttest mirroring the pretest, all in one 45-minute session.

This preregistered study is deployed online and will be completed by over 300 middle-school students. The sample size affords 80% to detect effects of f = 0.08 or larger. Results from this study will be analyzed using a 6 (worked example type) $\times$ 2 (pre- vs. post-tests) repeated measures ANOVA to examine the effects of viewing different worked example representations. We expect that this study will help better understand different ways students can learn from worked examples. Results and implications will be presented.

Caren Frosch: Children and adults differ in the role non-mathematical reasoning skills play in their mathematics abilities

Recent empirical evidence (e.g., Morsanyi et al., 2018) supports a link between logical reasoning and mathematical cognition in children. We investigate how the relationship between mathematical cognition and domain general reasoning processes may differ between adults and children. In five studies we measured mathematical ability using standardised fluency and calculation measures (i.e., WoodcockJohnson-III and WIAT). In Studies 1-3 we measured general reasoning ability using an extended Cognitive Reflection Test, this task contains mathematical content (Primi et al., 2016; Toplak et al., 2014). In our first study, 68 undergraduate students' reasoning abilities were also measured using a belief-bias conditional reasoning task, in our second study, a further sample of 76 undergraduate students completed the Ravens Progressive Matrices and in our third study 89 children aged 9-11 completed all five tasks. In Studies 5 and 6, we tested 71 undergraduate students and 65 children aged 9-11, respectively and measured non-mathematical reasoning with the Ravens Progressive Matrices, a relational reasoning task (English, 1998) and a spatial relational reasoning task (Byrne & Johsnon-Laird, 1989). Across both participant groups all measures of general reasoning skills correlated with the maths calculation scores. However, hierarchical regression analyses revealed that general reasoning skills play a larger role in predicting performance on the calculation task in child participants when compared to adults. Hence, our findings suggest developmental differences in the extent to which mathematical skills are related to domain general reasoning abilities. We discuss the implications of these findings for research on the link between mathematical ability and reasoning skills and the importance of taking a lifespan perspective in exploring the relationship between cognitive abilities.

Friday, September 4
Digits grasp digits: The interplay of fingers and numbers in early numerical learning

Presenters
Amandine Van Rinsveld, Post-doctoral researcher, Université Libre de Bruxelles, Belgium
Ursula Fischer, Assistant Professor of Development & Intervention in Early Childhood, University of Konstanz, Germany
Roberta Barrocas, PhD student, Leibniz-Institut für Wissensmedien, Tübingen, Germany
Firat Soylu, Assistant Professor of Educational Psychology & Neuroscience, University of Alabama, USA

Abstract

Numerical cognition has long been considered the perfect example of abstract information processing. However, in recent years there is accumulating evidence suggesting that the representation of number magnitude presents a specific case of embodied cognition. In particular, the embodied perspective refers to the idea that the way we process numbers may be at least partially grounded in sensory and bodily experiences. The primary example of such an embodied view of numerical cognition is the use of fingers for counting and calculation. This specific association between fingers and numbers is supported by extensive behavioral and neurofunctional findings. Nevertheless, the mechanisms driving this relation, its developmental trajectories as well as the functional relevance of finger use for numerical and mathematical learning are not yet fully understood. In this symposium, we will present new insights into different aspects of finger-based strategies and finger-related skills (finger gnosis, fine motor skills) and their relation to different aspects of numerical processing and learning in young children.

In the first presentation, Amandine van Rinsveld contrasts influences of finger gnosis and finger pattern recognition skills on numerical processing in a longitudinal setting. In this study, rapid-automatized-naming (RAN) of finger configurations rather than finger gnosis was related to later numerical skills. Building on the idea of a functional association between fingers and numbers, Ursula Fischer presents recent findings evidencing an age-dependent association of finger-related skills (i.e., finger gnosis and fine motor skills) and numerical abilities, in that fine motor skills predict finger counting and montring in all children, but finger gnosis is predictive only in younger children. On the other hand, finger-related skills predicted calculation performance only in older children. In light of a recent study, Roberta Barrocas discusses the influence of domain-general cognitive abilities and sensorimotor skills on the development of preschool numerical abilities. Results suggested that finger-related skills predicted measures of number knowledge, cardinality and part-whole relations significantly, however their predictive value decreased with age whereas the relevance of cognitive abilities increased. Finally, Firat Soylu proposes an integrative theoretical framework on the association of fingers and numbers which encompasses insights from different disciplines and research methods. Considering behavioral, evolutionary and neural findings derived partially from his own research, Firat Soylu argues in favor of an evolutionary approach to the origins of finger-number associations.

In sum, our proposed symposium incorporates both empirical findings and theoretical considerations aiming at shedding some light into developmental aspects of the complex interplay between fingers and numbers which in turn may stimulate and inform future research endeavors.

Thursday, September 10

Unpacking the Association between Spatial and Mathematical Thinking: Investigations about Directional and Causal Effects

Presenters
Yunfeng He, Post-doctoral researcher, University of Tübingen
Ilyse Resnick, Assistant Professor of Learning Sciences, University of Canberra
Katie Gilligan, Lecturer Developmental Psychology, University of Surrey
Tobias Kahl, PhD student, University of Basel

Abstract

Spatial and mathematical thinking are closely linked across development. This conclusion builds on work connecting students' spatial abilities to their later entry into and success in science, technology, engineering, and mathematics (the so-called STEM) disciplines (e.g., Kell, Lubinski, Benbow, & Steiger, 2013; Shea, Lubinski & Benbow, 2001). In line with these findings, several correlational studies indicated robust relations between spatial skills and mathematical performance in children and adults (for an overview, Mix & Cheng, 2012). Yet, the causal nature of this relation is not clear as of today. One seminal study indicated that spatial skills may help children to represent numbers more accurately which in turn increases mathematical performance (Gunderson, Ramirez, Beilock, & Levine, 2012). Specifically, it was found that children with higher spatial abilities represent numbers on a more linear mental number line. In such a numerical representation, numbers are mentally represented on a left-to-right continuum and this representation has often been investigated by measuring participants' number line estimations or SNARC (Spatial-Numerical Association of Response Codes) effects. The present symposium aims to qualify previous studies about underlying mechanisms and will deepen our understanding of directional and causal effects in the correlation between space and mathematics. The first study (Yunfeng He, Post-doctoral researcher, University of Tübingen) investigates relations between the SNARC effect and mathematical performance using a sample of 165 mathematically gifted children and typically developing children from China. Interestingly, the study provides no support of a difference in children's SNARC effects on the basis of classification as mathematically "gifted" even though children differed with respect to their mathematical proficiency. The second study (Ilyse Resnick, Assistant Professor of Learning Sciences, University of Canberra) examines potential mechanisms underlying the relation between magnitude estimation and mathematical achievement in samples from Australia and the United States. Findings indicate that this relation is mediated by children's ability to develop an accurate spatial representation of magnitude that can be flexibly and proportionally scaled. The third presentation (Katie Gilligan, Lecturer Developmental Psychology, University of Surrey) will increase our understanding about potential causal relations between space and mathematics using a training study. More concretely, the authors examine whether an embodied spatial training elicits higher mathematical learning in a sample of 240 British children as compared to a non-embodied or control training, highlighting the role of action experience for improving spatial and mathematical abilities. Finally, the fourth presentation (Tobias Kahl, PhD student, University of Basel) will extend previous longitudinal studies that have often focused on investigating how early spatial skills are related to later mathematical abilities. Using a cross-lagged-panel design, the authors investigate bidirectional relations between spatial skills, executive functions, and mathematical achievement in a sample of 76 Swiss children. Overall, the present symposium combines several methodological approaches, samples with different nationalities, statistical analyses techniques in order to increase our understanding about the relation between spatial and mathematical thinking. Implications for teaching and learning mathematics will be discussed.

Friday, September 18

Neural Development of Symbolic Math Knowledge from Childhood to Young Adulthood

Presenters
Alyssa J. Kersey, Department of Psychology, University of Chicago
Stephanie Bugden, Department of Psychology, University of Pennsylvania
John V. Binzak, Department of Educational Psychology, University of Wisconsin, Madison
Yunji Park, Department of Educational Psychology, University of Wisconsin, Madison

Abstract

The acquisition of symbolic number knowledge is critical for mathematical development. As such, researchers have focused on understanding neurocognitive mechanisms of symbolic number knowledge that can be leveraged to help support young math learners. Throughout development, these underlying mechanisms interact consistently with different cortical networks and eventually with educational environments. Understanding the interactions between functional networks, structural connectivity and developing competence during symbolic math acquisition may inform design principles for more effective approaches to math instruction. In this interdisciplinary symposium, four presenters will discuss functional and structural brain changes associated with the development of symbolic math competence in early learners and across childhood. The overarching goal is to better understand the neural mechanisms underlying changes in expertise with different aspects of symbolic number knowledge and to explore how neural function and structure are impacted by educational experience. The first two talks will discuss how early math knowledge of whole numbers emerges and how it is expected to change across development. The second two talks will go beyond whole number concepts, to focus on the concept of fractions and how functional and structural signatures relate to fraction knowledge.

Kersey et al. will first present data describing networks involved both in young children's counting and the more advanced concept of mathematical equivalence. This talk will highlight interactions among number and language networks for acquisition of basic symbolic math concepts. The next talk by Bugden et al. will discuss how number networks function during the period of whole number word acquisition. The authors will present results showing congruity effects observed in the brain when spoken number words are simultaneously presented with corresponding visual quantities.

Moving beyond whole number concepts, Binzak et al. will present work proposing cognitive primitives for processing rational numbers in adolescents along with relevant findings among children and adults. By looking at neural engagement for nonsymbolic and symbolic fractions, the talk will discuss the extent to which sensitivity to nonsymbolic ratio magnitude may serve as a built-in system for supporting symbolic fractions acquisition.

Whereas the first three talks will focus on functional signatures of numerical processing, the last talk will focus on structural connectivity in the brain and its relationships with fractions processing. In the fourth talk, Park et al. will present data showing changes in structural connectivity associated with symbolic fractions knowledge during the years of early fraction instruction. This work will help better understand changes in functional network for symbolic math knowledge. Taken together, the talks in the proposed symposium will offer cutting edge data regarding the emergence of underlying mechanisms for symbolic math knowledge centered upon functional and structural brain changes associated with educational experience.

Thursday, September 24

Early intervention: Finger counting, patterning, working memory, and number games

Presenters
Josetxu Orrantia, the Universidad de Salamanca, Spain
Nore Wijns, KU Leuven, Belgium
Anna Shusterman, Wesleyan University, USA
David Munez, the National Institute of Education, Singapore

Abstract
As we become increasingly knowledgeable about the skills that predict later mathematics achievement, we are better positioned to design interventions that support those skills in the hope that all children can reach their full potential. In the current symposium we present four interventions focused on core domain-specific and domain-general skills that have been found to predict later math achievement; these include an understanding of cardinality, patterning, number counting, magnitude understanding, ordinality, operations, and working memory. All interventions were developed for children in the preschool and early primary years. Furthermore, in a bid to ensure ecological validity and sustainable wide-scale use by teachers, all interventions were, or have the potential to be, implemented by classroom teachers during regular curriculum time. In the first talk, Josetxu Orrantia (Professor at the Universidad de Salamanca, Spain) describes an intervention that explores the role of fingers as a medium to support children's understanding of cardinality. In the second talk, Nore Wijns (PhD student at KU Leuven, Belgium) describes an intervention focused on repeating and growing patterns and the impact of this on patterning and broader numerical skills. In the third talk, Anna Shusterman (Associate Professor at Wesleyan University, USA) presents an intervention using math games in the context of guided play that focus on counting, cardinality, order, magnitude and operations. In the final talk, David Munez (Research Scientist at the National Institute of Education, Singapore) explores the effectiveness of computerised game-based interventions for students who are low achievers in mathematics on entry to primary school. The interventions target working memory, early numeracy, or a combination of both. The findings presented in these talks will provide researchers and educators with valuable information regarding the effectiveness (or indeed ineffectiveness) of different target interventions for children of differing ability and will allow educators to consider the feasibility of such interventions in their own classroom context.

Friday, October 2
Posters & Lightning Talks

Lightning Talks
Anne van Hoogmoed: The role of ordering in numeracy in kindergarten

Introduction

Ordering has been shown to play an important role in mathematics in older children and adults (e.g. Goffin & Ansari, 2016; Lyons et al., 2014). However, research on the role of ordering in young children is scarce and results are mixed (e.g. O'Connor et al., 2018). This study examines the role of different kinds of ordering (visual vs auditory; symbolic vs non-symbolic; order judgement vs order production) in numeracy in kindergarten. Moreover, eye tracking was used to gain insight into task approach on order judgement tasks.

Methods

One-hundred-and-fifteen children in second grade of kindergarten participated in this study. Order construction (symbolic and non-symbolic) and order judgement tasks were administered. Symbolic and non-symbolic order judgement were administered in the visual and auditory domain. Eye-movements were measured in part of the order tasks. Order working memory, counting, digit comparison, number lines and arithmetic were also measured.

Results

Preliminary analyses showed that the correlations between different types of ordering are low to moderate. Digit order production and visual non-symbolic order judgement predict arithmetic when controlling for counting and digit comparison. None of the ordering tasks was related to number line estimation when controlling for digit comparison and counting. Eye movement data are currently being analyzed.

Discussion

The low to moderate correlations between different order tasks suggest that ordering is not a unidimensional concept. The results suggest that ordering may be more important for arithmetic than for number line estimation, which was against the hypothesis. Results from the eye movement analyses will reveal whether there are differences in task approach between children who perform well and less well in order judgement. These results may inform future research on training ordering skills.

Posters
Erin Ottmar: Examining Relations of Math Anxiety and Algebra Performance in Two Technology Interventions

This study utilizes data from a randomized controlled trial of two math learning technologies: From Here to There (FH2T) (Ottmar & Landy, 2015) and ASSISTments (Heffernan & Heffernan, 2014), to examine how the relations of math anxiety on math performance vary with technology interventions. FH2T is a digital algebraic notation system where students can explore mathematical principles by dynamically transforming expressions or equations among mathematically equivalent states. ASSISTments is an online learning system where students solve problem sets with hints and feedback. Although research has found that math anxiety is often negatively related to student performance (e.g., Sorvo et al., 2017), these relations have not been observed after students play FH2T. This study aims to replicate these findings and examine possible mechanisms.

The results presented are from 507 6th-7th grade students. A regression controlling for pretest scores showed that students who were randomly assigned to the FH2T condition performed significantly higher on the posttest than the students in the ASSISTments hints and feedback condition (B=0.18, p<.05). Next, regressions examined the effect of three facets of math anxiety (negative reaction, worry, and numerical confidence; Ganley et al., 2016) on math performance. Overall, negative reaction was negatively related to posttest performance.

Àngels Colomé: Ordinal judgements in highly math-anxious individuals

Introduction:

People with high math-anxiety (HMA) frequently show poorer arithmetical performance than their low math-anxious peers (LMA). Judgment of the relative order of a set of numbers is a robust predictor of arithmetic skills. However, although it has been suggested that poor basic numerical skills might be on the basis of math anxiety, there are almost no studies on math anxiety and ordinality. Our aim in this experiment was to explore ordinal judgments in HMA individuals.

Method:

Two groups of HMA and LMA participants had to decide whether a triplet of numbers was displayed in ascending order. One-digit and two-digit number triplets were presented. Distance between the numbers in the triplet was also manipulated: they could be consecutive (counting trials), keep a constant distance of two or three (balanced trials) or have different distances between the numbers (neutral). Last, unordered triplets could break the order in the second or the third number (respectively D2 and D3 conditions).

Results:

There was no main effect of math anxiety but HMAs differed from their peers in two senses: first, HMA participants were less accurate when judging counting and balanced one-digit ordered triplets than their LMA peers. Furthermore, HMAs were slower and more error-prone on D2 unordered sequences than the LMA participants. Both groups also differed in a symmetry complex span task. Performance on this working memory test was only related to the differences found in the ordered trials.

Discussion:

Math anxiety effects are explained in terms of an attentional control deficit and, more specifically, as a difficulty to suppress an action when no longer relevant. Effects of the updating function of working memory are also discussed.

Belén González Gómez: The SNARC effect in highly math-anxious individuals: Evidence from event-related brain potentials

Introduction:

The SNARC effect refers to the phenomenon of responding faster to small numbers with the left hand and to large numbers with the right hand in a binary classification task. Previous studies have shown that this effect is stronger in people with weaker inhibition abilities and it has been suggested that highly math-anxious (HMA) individuals have difficulties to inhibit the influence of irrelevant information in numerical tasks. Moreover, a larger SNARC effect had been previously found in HMA individuals. The aim of this study was to examine whether this larger SNARC effect in individuals high in math anxiety would be also reflected in their brain response measured by event-related brain potentials (ERP).

Method:

Twenty HMA and 20 low math-anxious (LMA) university students were presented with a comparison task where they had to decide whether a single digit (1-9) was smaller or larger than 5.

Results:

Behavioral results showed that only the HMA group had a clear SNARC effect in RTs. As for the ERP analysis, HMAs showed a smaller centro-parietal P3 in the spatial-numerical incongruent trials (e.g., larger numbers answered with the left hand) than in the congruent ones (e.g., larger numbers-right hand). This effect was only found for the higher magnitude digits. Congruent and incongruent of trials did not differ in the LMA group.

Discussion:

We replicated previous findings showing a larger behavioral SNARC effect for HMA individuals and extended this result to their brain response. Since lower amplitude in the centro-parietal P3 has been linked to difficulties in response inhibition, our results add further support to the association between high math anxiety and deficits in the executive function of inhibition control.

Geneviève Trudel: Math anxiety mediates the relation between gender and math achievement

Stereotypes about the inferiority of females in science, technology, engineering, and mathematics (STEM) are longstanding and this belief is popular among children, adolescents, parents and teachers (Lindberg, Hyde, Petersen, & Linn, 2010). This has led to years of research on whether males truly outperform females in mathematics and, if so, what factors contribute to this difference. We hypothesized that although a gender difference in math achievement can be observed, this difference is better explained by levels of math anxiety. 411 undergraduate students (125 identified as male; 286 identified as female) completed assessments of their general levels of anxiety, their math anxiety, and basic demographics. Participants were also given a variety of fifth (average age 10 years) to seventh grade (average age 12 years) mathematical questions to assess the five strands of mathematics evaluated by the curriculums of Ontario, Canada. More specifically, an individual was asked to answer questions in data management and probability, measurement, number sense and numeration, algebra, and geometry and spatial sense. In all five strands, there was a significant relation between gender and math performance, whereby males outscored females. Importantly, in all five strands, this relation between gender and math performance was mediated by math anxiety (even after controlling for general anxiety). These results emphasize that although gender differences in math achievement seem to exist, these differences might be better explained by varying levels of math anxiety in the genders rather than differing levels of aptitude. (Note: here we use the term gender rather than sex because participants were asked to identify their gender in the demographic questionnaire).

Marcus Lindskog: Measuring toddlers approximate number system acuity without asking for "more"

Much research has investigated the Approximate Number System (ANS; Halberda et al., 2008) and its relation to mathematical ability. However, surprisingly few studies have investigated the ANS in 18-36 month-olds, where symbolic number concepts begin to emerge, and the extent results indicate poor performance.

We tested 93, 2.5 year-olds recruited from two sites (Ulster and Uppsala). They completed a dot-comparison task and a Give-N task. The dot-comparison task was performed on a tablet and consisted of a demonstration, a contingency learning, and a test phase in all of which children were presented with two spatially separated dot-arrays. In the demonstration phase, children were shown, but not verbally instructed, how pushing the more numerous array resulted in a fun movie clip being played. The contingency learning and test phases presented 6 and 12 trials with dot-arrays of two (1:4, 1:2) and three ratios (1:4, 1:2, 2:3), respectively. A correct response in the former resulted in the movie being played, while no feedback was given in the latter.

Participants performed above chance ($H0=.5$) in both the contingency learning ($M=.59$, $t(82)=4.7$, $p<.001$) and test ($M=.58$, $t(80)=6.1$, $p<.001$.) phases with performance above chance for all ratios separately (all $ps < .004$). We found no relation between performance on the dot-comparison task and knower-levels ($r(77)=.17$, $p=.14$). Our results warrant two conclusions. First, verbal instructions involving the concept of more are not necessary to measure the ANS of 2.5 year-olds. Second, the development of a symbolic number concept seems independent of the development of non-symbolic number representations but may become artificially related when researchers use quantifiers such as "more" to measure the former.

Nicole Scalise: Mediators of the relation between ANS and math achievement

Introduction
There is evidence of a reliable relation between the approximate number system (ANS) and later math achievement (Schneider et al., 2016). Various mediators to account for this relation have been proposed, including executive functioning (EF), numeral knowledge, and math language (e.g., Fuhs & McNeil, 2013; Goffin & Ansari, 2019; Purpura & Logan, 2015). The goal of the present study is to determine which skills significantly mediate the relation between preschoolers' ANS and math achievement.
Methods
Data from 125 preschoolers (mean=4.2 years) in the Midwestern United States were collected in the fall and spring. Children's ANS (Panamath, Halberda et al., 2008), EF (cognitive flexibility, Zelazo, 2006; inhibition, Gerstadt, Hong, & Diamond, 1994; verbal working memory, Alloway, 2007), math language (Purpura & Logan, 2015), and numeral knowledge (numeral identification, sets-to-numerals, Purpura, Baroody, & Lonigan, 2013) were assessed in the fall. Children's math achievement was assessed in the fall and spring (PENS-B; Purpura et al., 2015).
Four mediation models were tested using structural equation modeling (SEM) in Mplus. Three separate models were run testing each of the proposed mediators (EF, numeral knowledge, math language) on the relation between fall ANS and spring math achievement, controlling for children's fall math achievement, age, sex, and parent education. The fourth model included the three mediators simultaneously.
Results and Conclusions
Numeral knowledge and math language were significant mediators in both individual and full models. EF was not a statistically significant predictor of math achievement in either model. Although ANS predicts math achievement, the relation is fully mediated by children's math language and numeral knowledge. Future research should further investigate the relations between math language, numeral knowledge, and early math achievement using methods that allow for causal inference.

Sabrina Di Lonardo Burr: A middling problem: What is the midpoint for atypical number lines?

Adults use benchmarks, both implicit (e.g., unlabelled midpoint) and explicit (e.g., labelled endpoint), to locate targets on number lines. Although similar benchmark strategies are used on typical- and atypical-range number lines, error patterns differ across the two types of lines. Estimation accuracy is lower for atypical than for typical number lines, with error percentages forming a tent-shaped pattern when graphed. In contrast, when error percentages are graphed for typical lines, a flattened M-shaped pattern emerges, with less error around the labelled endpoints and implicit midpoint than on the rest of the line. We hypothesized that the difference in error patterns across types of lines occurs because people have difficulty calculating the implicit midpoint for atypical number lines. To test this idea, 34 adults completed a number line estimation task with both a typical (i.e., 0-10,000) and an atypical (i.e., 0-7,000) number line. Eye-tracking was used to identify strategies. Participants were randomly assigned to either the implicit- or explicit-midpoint condition. Endpoints were always explicit (i.e., labelled with tick marks and numerical values). Accuracy on the typical number line did not differ across the two conditions. In contrast, on the atypical number line, participants in the explicit-midpoint condition made significantly more accurate estimates than those in the implicit-midpoint condition. Furthermore, in the explicit-midpoint condition, participants showed an M-shaped pattern of error, replicating the pattern seen in typical number lines whereas those in the implicit-midpoint condition had a tent-shaped pattern of error. Overall, the results suggest that the difficulties in estimating on atypical number lines stem from incorrect calculations of the numerical value of the midpoint.

Robyn Pinilla:An Iterative Design Process for Early Spatial Reasoning Cognitive Interview Protocols

The Measuring Early Mathematics Reasoning Skills (MMaRS) project proposes two learning progressions, Numeric Relational Reasoning and Spatial Reasoning. Spatial reasoning serves a unique purpose for humans, allowing use of spatial dimensions to create frames through which one can view and solve problems (National Research Council, 2006). Despite evidence that spatial reasoning is critical to later mathematics success (Frick, 2018; Pruden, Levine, & Huttenlocher, 2011), many early childhood educators' math anxiety and fear of teaching mathematics (Bates, Latham, & Kim, 2013) may impede their facilitation of children's spatial reasoning growth. At the current phase of the MMaRS project, our primary aim is to empirically validate the learning progressions that will be used to develop a formative assessment for K-2 students. To do so, a cognitive interview protocol was developed through multiple iterative design cycles. The protocol presented items with content and reasoning questions for each skill statement in the learning progression. To ensure that items were eliciting intended conceptual and procedural thinking, we conducted a series of item development cycles, including two rounds of interview try-outs, to finalize the interview protocol. This iterative process allowed us to synthesize trends in student responses and perceived misconceptions, and to refine and replace items to elicit the intended spatial reasoning constructs. The finalized items were administered to children in Grades K-2 in winter 2019-2020 cognitive interviews. We found that the iterative cycles to refine the protocol were essential in producing items aligned to the learning progression. By employing refinement cycles, we had confidence in item construct validity and quality of data obtained through the interviews which will feed the empirical recovery of the ordering and conceptualization of the learning progression.

Thursday, October 8

The language of numbers: Linguistic aspects of number processing

Presenters
Julia Bahnmueller, Leibniz-Institut für Wissensmedien, Tuebingen, Germany
Verena Dresen, Department of Psychology, UMIT – Private University for Health Sciences, Medical Informatics and Technology, Hall/Tyrol, Austria
Dror Dotan, Mathematical Thinking Lab, School of Education and School of Neuroscience, Tel Aviv University
Silke Göbel, Department of Psychology, University of York, York, UK and Department of Special Needs Education, University of Oslo, Oslo, Norway

Abstract

Eighty years ago, Benjamin Lee Whorf hypothesized that language is a core human ability that shapes our thoughts and concepts. An extreme version of this hypothesis, according to which language underlies most high-level cognitive activities, was repeatedly refuted with respect to numerical and mathematical abilities: we now know that there are domain-specific number-processing mechanisms that do not depend on language. Nevertheless, language and number processing may still be tightly related: language, or particular features of language, may influence some numerical and/or mathematical abilities; domain-general mechanisms may support both language and numerical processing; and cognitive mechanisms of numbers and language - even when separate - may be organized according to similar principles. In this symposium, we will examine four different aspects of the composite relations between language and number processing.

The first two presentations will present influences of specific language aspects on specific numerical abilities. In the first presentation, Julia Bahnmueller and her colleagues will show that phonological skills, a general linguistic skill required for proper development of word reading, are also associated with number-writing abilities in a very specific manner, so that particular phonological skills predict specific number-writing abilities.

In the second presentation, Verena Dresen and Silvia Pixner will show that the development of cardinality, which is considered a major developmental step in numerical cognition in young children, is predicted by a domain-specific linguistic skill – the knowledge of the semantic meaning of quantifiers.

The third presentation will claim that even when linguistic and numerical mechanisms dissociate, they may still involve similar cognitive constructs. Dror Dotan will argue that although multi-digit numbers are represented in the cognitive system by a domain-specific numerical mechanism, this mechanism represents the syntactic structure of numbers similar to how we represent the syntactic structure of sentences.

The last presentation will highlight that within the domain of numerical cognition, language-related mechanisms – in particular, the ability to transcode verbal numbers into digit strings – are important for developing mathematical skills. Silke Göbel will show that the ability to write digit strings to dictation uniquely predicts a much more advanced mathematical skill – the ability to handle fractions.

Friday, October 16

Utilizing the Curriculum Research Framework to Iteratively Develop, Test, and Explore the Impacts of Science and Mathematics Interventions

Presenters
Ben Clarke, University of Oregon
Christian Doabler, The University of Texas
Lina Shanley, University of Oregon
Maria Longhi, The University of Texas

Abstract

Significant numbers of U.S. students struggle to become STEM literate, particularly in mathematics and science (Morgan et al., 2016). Consistent findings across longitudinal datasets point to the strong, stable relationships between early and later achievement in both mathematics (Bodovski & Farkas, 2007; Morgan, Farkas, & Wu, 2009) and science (Morgan et al., 2016) One proposed solution for getting all students, including those with learning difficulties (LD), proficient in these content areas is to design and implement intensive STEM-focused interventions in the early elementary grades (i.e., kindergarten or ages 5-6 to second grade or ages 7-8).

This panel will present findings from four, multi-year, large-scale research projects funded by the National Science Foundation (NSF) and the Institute of Education Sciences (IES). Guided by the Curriculum Research Framework (CRF) proposed by Clements (2007), each research project focused on the development and rigorous testing of early STEM interventions for students with LD. The CRF, which centers on iterative cycles of development, field-testing, analysis, and revision, is comprised of three primary phases: (a) a priori foundations, (b) learning models, and (c) evaluation. While the initial phases of the CRF focus on researchers collecting early implementation data on intervention prototypes, later phases encourage researchers to scale up their investigations to establish the potential impact of intervention programs in more summative research. To demonstrate the role and potential utility of the CRF in STEM-focused interventions, this symposium presents four projects staged at different phases of the CRF.

The first presentation details an NSF-funded development project (Sci2) aimed at developing and testing a second-grade, science program focused on core scientific ideas and practices identified in the Next Generation Science Standards. Feasibility data collected in recent Sci2 implementation studies involving over 300 students from 13 classrooms will be shared. The second presentation discusses the Precision Mathematics project, an NSF-funded development project focused on developing and testing a first-grade mathematics intervention that addresses concepts of early measurement and data analysis. Results from a rigorous pilot study involving 100 students with LD demonstrated the promise of Precision Mathematics to improve student mathematics achievement. The third project (Fusion), is an IES-funded Efficacy Trial aimed at testing the impact of a first-grade mathematics intervention that targets whole number understanding. The Fusion project, which involved 459 students with LD investigated questions related to overall intervention impact and impact variation by group size composition and initial skill status. The final presentation (Project MAP) merges Fusion efficacy work with cognitive science. Project MAP is an NSF-funded project aimed at identifying patterns of performance on critical mathematics constructs, their underlying neural signatures, and achievement outcomes for on-track learners, at-risk controls, responders, and non-responders within the context of a randomized controlled trial of the Fusion intervention.

Thursday, October 22

Spatial-numerical associations and dissociations

Presenters

Nicolas Masson, Université catholique de Louvain, University of Luxemburg

Sara Aleotti, Università degli Studi di Padova

Jean Philippe van Dijck, Thomas More University of Applied Sciences; Ghent University

Krzysztof Cipora, Department of Psychology, University of Tubingen; Centre for Mathematical Cognition, Loughborough University

Abstract

Spatial-Numerical Associations (SNAs) are phenomena demonstrating bi-directional links between numerical information and different aspects of space. Keeping in mind quite established correlations between spatial and mathematical skills, as well as the fact that quite often basic cognitive processes underlie more complex ones, one could expect that SNAs can be a useful mean to measure math skills and support math skill development. Nevertheless, the literature on this topic contains several contradictory findings. On the other hand, a closer look at the literature reveals that SNAs have been operationalized in a very different ways: spatial aspect has been operationalized either as extensions or specific directions in space. At the same time, the numerical aspect has been operationalized as ordinality, cardinality, mathematical functions, and place-value processing. Last but not least, the association has been operationalized as implicit (the SNA is revealed indirectly as a specific behavioral or physiological pattern) or explicit (overt and controllable behavior that the participant is placing specific numbers in space). Such massive variety in tasks has been ignored by taking an implicit (and rather bold assumptions) that all these SNAs are a reflection of the same latent construct. At the same time, specific tasks may put very strong constraints on what kind of SNA can be observed. For instance, bimanual setup with two response keys arranged horizontally allows only detecting whether there is a horizontal SNA or not, and in which direction it goes. It misses completely all other mappings that could be observed in 3D space. Similarly, testing implicit SNAs does not necessarily need to tell something about explicit ones and vice versa. Crucially, the construct validity of such broad category as SNAs has rarely been directly investigated. In this symposium we will present accumulating evidence for dissociations between different SNAs. We hope the symposium will raise vital questions on the nature of SNAs and will contribute to our understanding of them.

The first speaker, Nicolas Masson (Université catholique de Louvain, University of Luxemburg) will present dissociations between explicit and implicit directional SNAs in right-to-left readers.

The second speaker, Sara Aleotti (Università degli Studi di Padova) will present how the hallmark phenomenon of SNAs, the SNARC effect changes as a function of a spatial plane being under scrutiny.

The third speaker, Jean-Philippe van Dijck (Thomas More University of Applied Sciences; Ghent University) will present data showing that depending on whether extension or directional SNAs are investigated, the ordinal or cardinal aspect of number seem to be associated with space.

Finally, Krzysztof Cipora (University of Tuebingen, Loughborough University) will present results of a study conducted in Amazon tribe Tsimane and in German university students showing how participants arrange numbers when given a 2D grid rather than a unidimensional setup.

Friday, October 30
Posters & Lightning Talks

Lightning Talks

Jimin Park: Impact of Fraction Reducibility on Task Performance

Previous studies of how people understand fractions have focused on fractions that are irreducible (e.g., 2/3, 7/9), leaving the question of how people understand reducible fractions (e.g., 6/9, which reduces to 2/3) largely unexplored. In this study, we investigate whether people automatically reduce fractions to lowest terms, even when it is disadvantageous to do so. 25 (of an anticipated 35) participants completed a fraction comparison task and a fraction span task. In the faction comparison task, they compared which of two fractions is greater. Each pair varied in type (common numerators, common denominators, unit fractions, or no common components) and reducibility (reducible, e.g., 4/6 vs. 2/5, or irreducible, e.g., 2/3 vs. 2/5). For the fraction span task, participants encoded, maintained, and recalled 4 fractions from working memory. In one condition two fractions were reducible (e.g., 7/6, 4/2, 5/7, 3/9); in the other condition, all fractions were irreducible. For the fraction comparison task, there was a significant type × reducibility interaction, $F(3, 192) = 4.64$, $p < 0.01$, $\eta p2 = .036$. Participants had slower comparison times for reducible (vs. irreducible) fractions in all but the control condition, presumably because they performed the additional reduction step before making their comparison. For the fraction span task, there was a significant difference between the conditions, $t(24) = -2.49$, $p = .019$, $d = .23$. Accuracy was lower for the reducible sequence ($M = 5.94$, $SD = 1.31$) than for the irreducible sequence ($M = 6.25$, $SD = 1.36$), presumably because participants could not help but automatically reduced the reducible fractions, and thus could not recall their original form. These findings suggest that people automatically reduce fractions, even when doing so negatively impacts task performance. This work sets the stage for a future study of strategic variability when processing reducible fractions.

Parnika Bhatia: The Behavioral Processing of Fractions in Adults with and without Dyscalculia

Introduction

Competence with fractions is a pre-requisite for understanding advanced mathematics concepts. Yet, a majority of children, adolescents, and adults struggle to understand fraction concepts and procedures. Researchers and educators have so far mainly focused on the difficulties faced by typically developing children and adults. Few have addressed the difficulties faced by adults with dyscalculia (Lewis & Lynn, 2018). Here, we investigated the conceptual and procedural difficulties with fraction understanding faced by adults with dyscalculia.

Methods

38 individuals -18 dyscalculic ($M = 22.9$, range = 19-28, 16 females) and 20 typical adults ($M = 22.4$, range = 19-29, 10 females)- participated in this study.

Participants were administered various tests to assess their cognitive, mathematical, and reading skills. To be classified as having math difficulty, participants had to have been diagnosed by a clinical specialist, complained of mathematics difficulties since school, and perform at or below the 10th percentile on at least one of the math sub-tests and below 25th percentile on the average of the math sub-tests of fluency and applied problems.

Participants were also administered a paper-pencil based, un-timed, Fraction Achievement Test. The test included a total of 24 questions with different sub-parts composed of competencies such as part-whole representations, number line estimation, comparing and ordering fractions, solving mixed fractions, fraction arithmetic, representing symbolic fractions in verbal form and vice versa, and word problems. For the purpose of analysis, these competencies were categorized to fraction concepts, procedures, word problems, and number line estimation (similar to Rodrigues et al., 2019).

Results

Exploratory analyses revealed higher scores for typical adults in all the categories as compared to adults with dyscalculia (medium to large effect sizes). In typical adults, fraction concepts were correlated with number line estimation ($r = 0.468$, $p = 0.038$) and fraction procedures were correlated with word problems ($r = 0.912$, $p < 0.001$). In contrast, whereas fraction procedures remained correlated with word problems in adults with dyscalculia ($r = 0.520$, $p = 0.027$), there was no correlation between fraction concepts and number line estimation ($r = 0.085$, $p = 0.737$).

Fanny Ollivier: On statistical implication relationships between fine motor skills, mental representation of fingers, finger use and first calculation

Many children use their fingers to calculate when they first add and subtract. Jordan, Kaplan, Ramineni and Locuniak (2008) show that using one's fingers for calculation is positively linked to performance in the early stages of arithmetical learning. The literature review brings out components involved in finger use, especially fine motor skills and mental representation of fingers. The relationship between these components, finger use and calculation performance have already been studied (Asakawa & Sugimura, 2014) in mainly correlational studies, but these relationships have rarely been studied together and as asymmetric relationships (Bonneton-Botté, Hili, De La Haye, & Noël, 2015).

The aim of our study is to test the hypothesis of a link between these components, finger use and calculation performance, and to specify this link. Indeed, this study aims at highlighting asymmetric, chained, implication relationships (i.e. if a, then b) between fine motor skills, mental representation of the fingers, finger use and performance in simple addition and subtraction.

Items were thus selected in order to assess fine motor skills, mental representation of the fingers, finger use and first calculation, and submitted to eighty-nine French children attending inclusive school. The data, still being collected, are analysed within a graphical extension of the Rasch model with a statistical implication interpretation.

Our first results show a representation of items from all the components in a scale, and provide some evidence of asymmetric, chained, implication relationships within a single dimension, thus lending support to the hypothesis of a cumulative learning process, from body to cognition.

Posters

Elayne Teska: Teaching Multiple Solutions to Proportion Problems: Benefits of Worked Examples

Learning to use multiple strategies for solving the same problems can be a powerful learning tool, yet this is challenging to many students and in complex math topics such as proportional thinking (Begolli et al, 2018). This study examines how worked examples can support learning multiple ways to solve proportion problems, specifically comparing Fully-Worked-Examples (FWE), Partially-Worked-Examples (PWE), or Problems-Only (PO-no examples provided). Theoretically, providing worked examples should reduce students' cognitive resource load and allow them to allocate attention to the broader conceptual frame (Booth et al., 2015).

Worksheets were randomly assigned on a within-classroom basis to 308 4-6th graders from schools with primarily underrepresented, low income youth. For the first problem, students either studied a FWE showing an "equivalent fractions" strategy, completed a PWE showing the same strategy, or solved the problem with no worked example provided. Students then used the same strategy on two near-transfer problems, followed by the same procedure for unit-ratio.

Analyses examined students' problem solving attempt, set-up, procedures and accuracy. Students in the FWE and PWE conditions were equally likely to attempt the correct strategy for near-transfer problems, $t(1,124)=1.31, p=.193$. Examination of the PO condition compared to PWE shows students were less likely to attempt the correct strategy, and for students that did attempt the correct strategy, they were likely to have errors in their set-up for both the equivalent fraction and unit ratio strategies. The FWE condition showed highest accuracy, and the PWE was more accuracy than the PO condition, $F(2,173)=8.94, p<.001$.

Results suggest that providing full or partial worked-example worksheets encouraged students to attempt proportional reasoning strategies, though only the full worked example led to increased use of proportional reasoning strategies, accuracy and transfer, suggesting that in cognitively demanding mathematics, more complete worked examples may be particularly advantageous.

Alexandria Viegut: Gesture use in a nonsymbolic and symbolic fraction comparison task

Fractions are notoriously difficult. Many common misconceptions about fractions stem from misapplication of whole number concepts. This “whole number bias” promotes a focus on the individual components of fractions, rather than on holistic fraction magnitudes. Little work has examined methods of communicating and measuring fraction knowledge beyond accuracy and reaction time—particularly for nonsymbolic representations of fractions. The current study examines the gestures that students produce when explaining their fraction comparison strategies. Undergraduates (N=41) compared pairs of symbolic and nonsymbolic fractions (10 items each) and described their strategies for determining the larger fraction to an experimenter. Based on prior eye-tracking evidence (e.g., Obersteiner & Tumpek, 2016), we hypothesized that students would engage in horizontal gestures (e.g., gesturing between the two numerators) when using componential strategies and vertical gestures (i.e., gesturing within the numerator and denominator of a single fraction) when using holistic strategies. We also hypothesized that nonsymbolic representations may be less susceptible to whole number bias and thus elicit more vertical gestures. In line with our hypothesis, nonsymbolic representations of fractions elicited vertical gestures on more trials than symbolic representations did ($p < .001$). Both representations elicited horizontal gestures on a similar number of trials. We also found main effects of representational format ($p < .001$) and gesture direction ($p < .001$). Nonsymbolic fractions elicited gestures on more trials than symbolic fractions, and participants used vertical gestures more often than horizontal gestures overall. These gesture patterns are consistent with the eye-tracking patterns found in symbolic fraction comparison tasks, and these results offer new insight into students’ thinking about nonsymbolic fractions. Coding is ongoing and will allow us to examine whether particular gestures tend to occur with specific verbal strategies. These findings will inform an experimental study to determine whether seeing specific gestures influences students’ fraction comparison strategies.

Lindsey Clark: E-Stories Promote Understanding of Fractions in Preschoolers: Evidence from fine motor and gesture tasks

Introduction

We investigated how preschool-aged children understand and solve fractional problems involving wholes and fractions using “equal sharing.” Mathematics tasks were presented in two formats – paper and pencil format and in context as E-stories displayed on a touchscreen. We also measured how fractional reasoning ability correlates with both fine motor skills by using a peg board and usage of gestures during a counting task.

Methods

Participants included 50 preschoolers aged 4 to 5 in two United States public schools. Children were tested individually inside the school. Mathematics tasks were developed to evaluate subjects’ fractional reasoning ability. The mathematics questions were presented in either a paper and pencil format or as E-stories displayed on a touchscreen laptop. Children who received the paper and pencil version were presented with items as pictures on a sheet of paper and asked to split up or share items “evenly” and “fairly” amongst people or other objects. The E-stories included the same mathematics stories and directions as the paper and pencil version. Accuracy for the paper and pencil version was computed by dividing the total points possible by the total points achieved.

For the E-stories, the child's number of attempts and the amount of time taken to complete each question determined accuracy. After the mathematics task, children completed a counting task where they were instructed to use their fingers and count out loud the number of dots in a box on paper. A behavioral analysis of gesture recorded their accuracy, synchrony, hand morphology, and whether or not subitizing occurred during the task. Lastly, children completed the Grooved Pegboard test to assess fine motor ability. This included two trials, once with their dominant hand and once with their nondominant hand.

Results

We found that performance on our mathematics measure significantly predicts fine motor ability as assessed by the Grooved Pegboard test. A step-wise linear regression positioned total score on the mathematics stories as the outcome variable and the independent variables were pegboard dominant hand time, nondominant hand time, dominant hand drops, and nondominant hand drops. The model shows the number of nondominant hand drops explains 25.8% of the variance of the outcome variable. The paper and pencil mathematics stories had a maximum score of 76 and a minimum score of 8 with an average score of 40.36. Mean accuracies for the paper and pencil stories and the E-stories were compared with an independent samples T-test. E-stories yielded significantly more accuracy than paper and pencil version. Preliminary analysis of gesture during a dot counting task indicates that gestural accuracy is associated with improved mathematics ability.

Conclusions

Preliminary analyses suggest that embedding fractional concepts within a social context may be more beneficial to mathematics learning during the preschool years. These results also provide insight into the strength of the relationship between fine motor and cognitive development and are relevant in their support and extension of previous research suggesting that these two functions display similarly protracted time courses during development.

Elena Sixtus: The role of finger counting gestures and number words in children's number comprehension

Finger counting gestures are assumed to play a supportive role in numerical development. It is argued that their non-arbitrary and self-experienceable sensory-motor representations are easier to learn than other numerical representations and that they contribute to early number word comprehension. However, Nicoladis et al. (2010) report better performance of children in a give-N task with number words than with manual number gestures. In a pilot study with preschool and school children (N=50, age range 4-11), we also found an advantage of conditions comprising number words. Specifically, we compared the comprehensibility of finger counting gestures, auditory number words, dice patterns (as control condition, containing transparent but not self-experienceable numerical representations), and bimodal conditions, namely number words paired with gestures or dice patterns, in a computerized version of a give-N task on a tablet PC. Children were presented the target stimulus and responded by touching the corresponding number of dots (out of ten visually presented dots) and subsequently touching a depicted basket.

We hypothesized that finger counting gestures allow better processing efficacy than other numerical representations and that they facilitate the understanding of number words in bimodal conditions. Preliminary results, however, suggest highest performance with auditory stimuli and question the expected advantage of bimodal conditions. Then again, incorrect responses were overall sparse, suggesting that in our convenience sample most children were too old to exhibit the expected effects: Gunderson et al. (2015) report higher accuracy of children in a number labelling task with finger gestures than words only when children had not yet learned the cardinal principle, i.e. that the last word during a count represents the counted set's size. We now plan a registered report on a follow-up study with a controlled sample of younger children and a reduced, select stimulus set to further investigate the development of children's number comprehension.

Joshua Jaffe: The effect language has on mathematics: an electroencephalogram study

Introduction:

The linguistic complexity of word problems can give young students as many challenges as the numeric complexity. Previous studies have shown that students use different strategies based on the linguistic complexity but aren't exactly sure on the thought process behind different problems. This study will look at different brain activations, using Electroencephalogram (EEG) and event related potentials (ERP). I ask the question, will different areas of the brain be used depending on linguistic components of problems?

Methods:

For the study, we will measure the brain activity of 50 first and second graders from the Washington, D.C. area, using an EEG Enobio 32 channel cap. Participants will complete six phases: numerical problems (4+3=7), numerical problems written out (Four plus three is seven), simple word problems (John has four apples. Mary gave John three apples. John now has seven apples), simple word problems with pseudo-nouns (e.g., 'blinkets' instead of 'apples'), non-symbolic arithmetic videos, and logic statements (John only eats red fruit. Mary gave John a red apple. John ate the apple). Each phase will consist of 40 statements. Students will determine if the statements are correct or incorrect.

Statistical Analysis:

Mean accuracy for each phase will be recorded. Response time (RT) will be recorded as the difference between the time the answer is shown to the time a response is recorded (key pressed). EEG and ERP analysis will document brain activity for correct and incorrect responses, mainly in the parietal and occipital regions. The analysis will explore the differences in brain activations, accuracy, and response times when answering numerical and linguistic problems. I predict that problems with linguistic components will show different activations in the brain and will result in longer response time and more inaccuracies.

Evie Smith: The development of two mathematical measures for use in research with EAL children

In order to ensure that research investigating a set of skills in a group of individuals is of a high quality, it is important to use appropriate instruments of measurement, or to develop bespoke measures when suitable measures cannot be found. Two bespoke measures were developed for use in a project investigating performance on different mathematical tasks in Key Stage 2 children with English as an Additional Language (EAL) and the linguistic and cognitive predictors of this. These were a measure of mathematical vocabulary knowledge and a measure consisting of two parallel tasks designed to investigate the influence of language on mathematical performance by presenting the same questions both as arithmetic problems and within word problems. The measures were developed with reference to the national curriculum and then piloted on 22 children from two primary schools. Following this, the Classical Test Theory method of item analysis was used to assess the quality of each item on each test. Based on this, the measures were reduced in length by excluding poor quality items. Some items, as well as the format of the tasks, were also amended, and the final versions of the tasks were created. These measures provide quick and simple methods of assessing mathematical vocabulary knowledge and assessing the role of language in different mathematical tasks in Key Stage 2 children, making them particularly useful for working with or assessing EAL children.

Evie Smith: Investigating the relationships between language skills and mathematical achievement in children with English as an additional language

Children in English schools who are learning English as an additional language (EAL) perform less well academically than those whose first language is English (FLE). While EAL children have been shown to have comparable decoding-based language skills to FLE children, EAL children struggle with comprehension-based skills such as vocabulary and reading comprehension. Recent research has started to suggest EAL children also underachieve compared to FLE children in mathematics and that this is likely to be through their linguistic disadvantage, due for example to the emphasis placed on word-based mathematical problems within the national curriculum. The current project is investigating and comparing performance on arithmetic problems and word problems in EAL and FLE children across the course of Key Stage 2, and the contribution of comprehension-based language skills and decoding-based language skills such as reading accuracy and phonological awareness to performance on these mathematical tasks. It is hypothesised that FLE children will outperform EAL children on mathematical word problems but not on arithmetic problems, and that comprehension skills will predict performance on word problems while decoding skills will predict performance on both mathematical tasks. The hypotheses are being tested using standardised language-based, cognitive and mathematical measures, as well as a bespoke task consisting of parallel arithmetic problems and word problems and a bespoke task measuring knowledge of mathematical vocabulary. The study has a cross-sequential design, with data being collected for groups of Year 3 and Year 5 children who will then be seen again a year later. Cross-sectional differences between the performance of EAL and FLE children on the different tasks over the course of Key Stage 2 will be analysed using MANOVAs, and regression analysis will be used to examine the contributions of the predictors to performance on each mathematical task. The change over time in the two groups of participants will also be analysed in the same way.

Jenny Yun-Chen Chan: Relational language predicts number relation skills but not number counting/identification skills in kindergarten students

Children's knowledge of relational language (e.g., more, equal, before, next) positively correlates with their early numeracy skills (Purpura & Logan, 2015), and predicts growth in mathematical skills (Toll & Van Luit, 2014). Although relational language can be applied to other mathematical concepts, it may be particularly important for number relations skills that involve knowledge of cardinal (e.g., 5 is more than 4) and ordinal (e.g., 5 comes after 4) number principles. Here, we examine whether children's relational language knowledge predicts later number relation skills above and beyond their concurrent number relation skills, executive function, and general verbal knowledge. We test whether the influence of relational language on number relation skills is unique by comparing regression models substituting number counting/identification skills (knowledge of counting sequence and the mapping between representations of numbers) for number relation skills.

Participants were 104 kindergarteners (46 boys; mean age: 5.9 years) from a larger study. Children's skills in number relations and number counting/identifications were each measured twice, approximately five weeks apart. Their relational language knowledge, executive function skills, and general verbal knowledge at Time 1 were included as the focal predictor and additional covariates, respectively. The first regression model revealed that relational knowledge scores significantly predicted later number relation scores above and beyond the combined predictive value of number relation skills, executive function, and general verbal knowledge at Time 1, $ß=.159$, $p<.05$, $\Delta R^2=.012$. When we repeated the analysis with number counting/identification scores, we found that relational language scores did not predict later number counting/identification scores above and beyond the covariates, $ß=-.0001$, $p=.999$.

In summary, relational language predicted later number relation skills but not number counting/identification skills. The findings suggest that relational language may be particularly important for number relation skills, and number relation skills may be a potential pathway through which relational language influences mathematical skills.

Thursday, November 5

Counting and Cardinality

Presenters
Elisabeth Marchand, Doctoral Student, University of California San Diego, USA
Pierina Cheung, Research Scientist, National Institute of Education, Singapore
Theresa Wege, Doctoral Student, Loughborough University, UK
(Discussant) Bert De Smedt, Professor, KU Leuven, Belgium

Abstract

When counting a set of objects, the last number in an accurate count sequence indicates how many objects there are in the set. This, the so-called cardinality principle, is an essential step on a child's path to deeper numerical understanding. Whether or not a child understands the cardinality principle has classically been assessed by the give-a-number task (e.g., Wynn, 1990). In the standard version of this task, a child is asked to give a certain number of objects to a puppet. For instance, they may be asked to give four chestnuts to a squirrel. Many 2-4 year old children who can count fail at the give-a-number task (e.g., Le Corre, Van de Walle, Brannon & Carey, 2006), which has been interpreted as evidence that they lack an understanding of the cardinality principle.

In this symposium we explore children's understanding of cardinality in three talks. First, Elisabeth Marchand (Doctoral Student, University of California San Diego, USA) asks how reliable the give-a-number task is. Across two experiments she reports that the task can reliably distinguish subset knowers from cardinal principle (CP) knowers, but that it is less effective at reliably classifying which specific numbers children can comprehend. Elisabeth concludes by offering methodological recommendations useful for researchers who may be considering using the give-a-number task in future studies. In our second talk, Pierina Cheung (Research Scientist, National Institute of Education, Singapore) asks whether CP-knowers, as assessed by the give-a-number task, actually understand cardinality. Specifically, she asks whether CP-knowers understand under what conditions the last word of a count sequence indicates the number of items in the counted set. Pierina reports a study in which CP-knowers were asked to observe a puppet counting inaccurately (perhaps they violated the word-object correspondence principle for instance). She found that some CP-knowers would accept that a set contained n objects despite the puppet having miscounted, as long as the final number in the puppet's count sequence was n. Finally, Theresa Wege (Doctoral Student, Loughborough University, UK) investigates children's acquisition of number meanings before understanding cardinality. She evaluates training materials based on the use of contrasting objects to highlight the common abstract property of set size. Theresa reports that this kind of contrast training led to improvements in number discrimination compared to children in a control group. Our symposium concludes with a discussion from Bert De Smedt (Professor, KU Leuven, Belgium).

Friday, November 13
Problem-solving strategies in algebra: From lab to practice

Presenters
Jeffrey Bye, Department of Educational Psychology, University of Minnesota
Jenny Yun-Chen Chan, Learning Sciences and Technology, Worcester Polytechnic Institute
Jon Star, Graduate School of Education, Harvard University
(Discussant) Martha Alibali, Department of Psychology, UW-Madison

Abstract

In order to become proficient in algebra, students must develop procedural knowledge for multiple problem-solving strategies, and the ability to identify and apply more efficient strategies (Star & Rittle-Johnson, 2008). Prior studies have demonstrated that algebra knowledge influences the development of strategy selection, flexibility, and efficiency (e.g., Newton et al., 2019). This symposium aims to enrich our understanding of problem-solving strategies in algebra by bringing together research conducted in an experimental lab setting (Bye et al.), with learning technology (Chan et al.), and through classroom interventions (Star et al.). We hope the presentations will stimulate conversations between research fields, and help advance our knowledge in basic and applied science to improve algebra learning.

First, Bye and colleagues will present findings on students' (in)flexibility in strategy choice for solving missing-operand algebra problems. Using a computer-based task, they measured undergraduates' response time to solve missing-operand algebra problems (e.g., $x + 3 = 5$) and 'decoded' individual strategy choice by regressing on their time to verify arithmetic facts related to the direct, arithmetic pattern-matching strategy (e.g., $2 + 3 = 5$) and to the inverse algebraic transformation strategy (e.g., $5 – 3 = 2$). As validated by participant self-reports, they found individual differences in strategy preference (direct vs. inverse), particularly for larger problem sizes (e.g., $7 + 9 = 16$).

Second, Chan and colleagues will present findings on the relation between pause time before solving problems and strategy efficiency in an online algebra learning platform. They will present two studies that examine the unique influences of pause time on strategy efficiency (i.e., solution steps). In ninth- (Study 1), sixth- and seventh-grade students (Study 2), they found that (a) longer pause time was associated with fewer steps taken to solve algebra problems; (b) percent pause time significantly predicted step efficiency beyond algebra knowledge, math self-efficacy, and math anxiety; and (c) algebra knowledge, math self-efficacy, or math anxiety did not moderate the relation between percent pause time and step efficiency.

Third, Star and colleagues will present findings on the effects of comparing and discussing multiple strategies on students' algebra learning. They will report the results of a year-long investigation of the effectiveness of a supplemental algebra curriculum that encourages comparison and discussion of multiple strategies. Sixteen Algebra I teachers (with their 550 students) implemented the supplemental curriculum, while 13 teachers (with their 498 students) served as a business-as-usual control group. Results suggest that using their curriculum encouraged teachers to compare multiple strategies, use small groups, and have mathematical discussions much more frequently than would have happened otherwise. These practices likely led to higher posttest scores, particularly for conceptual knowledge and flexibility, compared to business-as-usual instruction.

Finally, discussant Martha Alibali will highlight connections amongst the presentations, discuss how these findings can inform theories of algebra learning and development, and suggest future directions for research on this topic.

Thursday, November 19

How environment shapes the mathematical brain: Influences of socioeconomic status, parental behaviors, and education

Presenters
Teresa Iuculano, Laboratory for the Psychology of Child Development and Education, CNRS & Université de Paris, France
Ece Demir-Lira, Department of Psychological and Brain Sciences, University of Iowa, USA
Cléa Girard, Lyon Neuroscience Research Center, University of Lyon, France
Merel Declercq, KU Leuven, Belgium

Abstract

Children's math development is characterized by marked individual differences that impact their future personal and professional life. Because children are exposed to vastly different numeracy experiences in and out of school, environmental influences may critically contribute to these differences. For example, studies have found that math skills depend on socio-economic status (SES), quality and frequency of math activities and resources provided by parents at home (i.e., the home numeracy environment), as well as teaching methods in the classroom. Yet, very little is known about the way these environmental factors may affect the neural circuits supporting math learning in children. This symposium will fill this gap by bringing together four researchers at different stages of their careers (2 PhD students and 2 Assistant Professors) and from different countries (France, Belgium, and USA) whose work relates to environmental influences on the developing math brain. The presentations will feature a unique combination of studies making use of different neuroimaging methods – functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) – to study children from preschool to elementary school. Collectively, this research seeks to understand how brain circuits supporting math learning are affected by SES, home numeracy environment, and educational instructions. It also aims to explore how environment-related neural changes may affect math learning and whether these findings may pave the way for future interventions.

Teresa Iuculano will present an fMRI study investigating the impact of SES on the neural mechanisms supporting math problem-solving in 7- to 9-year-olds. Preliminary results indicate that, compared to higher-SES peers, low-SES children showed hypo-activations in the medial temporal lobe, the intraparietal sulcus (IPS) and the dorsolateral prefrontal cortex. Low-SES children were also characterized by lower math skills and greater math anxiety than higher-SES peers. Ece Demir-Lira will describe fNIRS work exploring the neural mechanisms that underlie the relation between SES and math performance in younger children (4-5 years old). The results will show whether brain regions supporting non-symbolic number processing differ in children from different SES backgrounds. They will also examine whether numeracy interactions between parents and children account for SES-related differences in the brain. Cléa Girard will present further fMRI evidence that SES disparities are associated with differences in the neural processing of symbolic quantities in the IPS of 8-year-olds, over and above differences in parents' and children's arithmetic skills. The results also show that, in addition to SES, quality of the home numeracy environment relates to the IPS processing of non-symbolic quantities. Finally, Merel Declercq will describe a training study exploring how an educational intervention may change the brain circuits underlying arithmetic processing. The study measured fMRI activity before and after 10-year-olds learned to retrieve double-digit multiplication problems. Results indicate that multiplication training was associated with an increase in accuracy for trained problems and a decrease in IPS activity, suggesting a decrease in the use of procedural strategies. Together, these presentations will demonstrate how neuroimaging may shed light on the way environmental factors interact with the neural mechanisms supporting math learning in children.

Thursday, December 3
Fraction Interventions from Lab to Classroom

Presenters
Jing Tian, Post-Doctoral Researcher, Temple University (USA)
Alexandria A. Viegut, Graduate Student, University of Wisconsin-Madison (USA)
Nancy C. Jordan, Professor, University of Delaware (USA)
Jake McMullen, Post-Doctoral Researcher, University of Turku (Finland)

Abstract

Fractions continue to pose major difficulties for students throughout the world, despite efforts to improve instruction. Misunderstandings about fraction magnitudes, concepts, and operations abound. These pervasive difficulties can have lasting consequences, as fraction understanding is essential for students' success in higher mathematics and access to higher education (Siegler et al., 2012; Torbeyns et al., 2015). This symposium will present research exploring some interventions based on design principles gleaned from cognitive science to support fraction understanding in lab and classroom settings.

Numerical cognition research has recently seen an explosion of investigations on fractions. Even in the seven years since Siegler, Fazio, Bailey, and Zhou (2013) dubbed fractions "the new frontier", the field has made significant discoveries regarding the ways fractions are processed. How can we apply the results of fraction cognition research to help educators and students? What steps are necessary to bridge the separation between lab and classroom?

Our symposium will present four different fraction interventions that all seek to apply principles of fraction processing to instruction. The interventions target a range of grade levels, from 1st to 7th, and a range of fraction ideas, from estimation and comparison to ""fraction sense"" more broadly. Importantly, the work spans the lab-to-classroom spectrum, with two lab-based studies and two classroom-based studies.

All four interventions feature number line representations: In the first talk Tian et al. will prompt us to reconsider whether number line models are really more effective than area models for learning about proper and improper fraction magnitudes. Then, Viegut and Matthews will present evidence that analogical reasoning and children's existing whole number estimation knowledge can be used to build fraction magnitude knowledge. In the third talk, Jordan et al. will tackle similar questions in an ecologically valid context. They will provide encouraging results from a classroom intervention for struggling learners. Finally, McMullen et al. will evaluate the effects of a pair of digital educational games on rational number knowledge in classroom contexts, inspiring questions about the role of student motivation and affect in math cognition and learning.

As a whole, this symposium provides an example of translational research bridging numerical cognition and education. Lab studies (e.g., Tian et al.; Viegut & Matthews) are important to help us understand causal mechanisms and test intervention effects under optimal conditions. But if we seek to improve fraction education in schools, classroom studies (e.g., Jordan et al.; McMullen et al.) to test interventions in context are essential. Speakers will reflect on challenges and opportunities related to their efforts at conducting translational intervention research.

Friday, December 11

Explaining the relationship between working memory resp. related cognitive skills and mathematical learning

Presenters

Nurit Viesel-Nordmeyer Center for Research on Education and School Development, TU Dortmund University

Dana Miller-Cotto Weill Institute for Neurosciences, University of California, San Francisco Sandler Neurosciences Center

Ana Cubillo, Jacobs Center for Productive Youth Development, Zurich Center for Neuroeconomics, University of Zürich, Switzerland

Joerg-Tobias Kuhn, TU Dortmund University, Germany

Abstract

Research points to an important role of cognitive abilities in mathematical learning processes (e.g. Geary, Nicholas, Li, & Sun, 2017) while especially the involvement of working memory has been discussed. Three main points emerged: (1) To what extent can a number of contradicting findings be explained with inconsistence in the usage of mathematical or working memory measurements (e.g. Dornheim, 2008)? (2) Does the relationship between different working memory components and divergent mathematical abilities change over time (e.g. Miller-Cotto & Byrnes, 2019; Viesel-Nordmeyer, Ritterfeld, & Bos, 2020)? (3) Finally, it shouldn´t be overlooked to what extent are mathematical learning processes supported by further cognitive skills that seems to be related to the cognitive processes involved in working memory.

Using data of the Kindergarten Class of the Early Childhood Longitudinal Study (ECLS-K; n = 725), Dana Miller-Cotto (1) reports findings regarding the direction of relationships of different mathematical skills (mathematical fluency, math recall) and differentiated measurements of the central executive using latent-class analyses from Kindergarten to 5th grade. Founded on longitudinal data of the German National Educational Panel Study of the Starting Cohort Kindergarten (NEPS, n = 354) and a smaller, more elaborated data set (n = 43), Nurit Viesel-Nordmeyer (2) discusses a reversing relationship pattern between divergent working memory components and mathematical skills of different measurements using path analyses between age 4 to 8. Due to the high importance of working memory for mathematical learning processes - also shown in the first two studies - Ana Cubillo (3) presents the potential influence of working memory training in school (training/control group: n = 14) on important cognitive skills for successful learning (attention, inhibition) as well as on different mathematical skills (arithmetic, geometry). Deficits in working memory, in related cognitive skills for successful learning (attention, inhibition) as well as in mathematical achievement where frequently found in children with the cognitive impairment of attention-deficit/hyperactivity disorder (ADHD) (e.g. Alderson et al., 2015). Joerg-Tobias Kuhn (4) questions the frequent simultaneous occurrence (n = 86) of a math disability disorder (MD) in children with ADHD focusing basic numerical skills as a possible shared risk factor using classical and Bayesian analysis of variance (age 6-10).

The symposium seeks to advance a comprehensive insight into the relationship of mathematical skills, working memory and related cognitive processes exemplifying findings from different research angles.

Thursday, December 17

The roles of different domain-general and domain-specific skills in children's mathematical competence

Presenters
Xiujie Yang, Assistant Professor, Beijing Normal University
Winnie Wai Lan Chan, Assistant Professor, The University of Hong Kong
Sum Kwing Cheung, Assistant Professor, The Education University of Hong Kong
(Discussant) Kerry Lee, Professor, The Education University of Hong Kong

Abstract

To solve mathematical problems, individuals are required to comprehend the problem statements, process the information presented in the problem statements, and draw on related mathematical concepts to respond to task requirements. This suggests that mathematical problem solving may not only require domain-specific skills (i.e., mathematical skills), but also domain-general cognitive skills (such as language, phonological processing skills and processing speed). To date, the roles of some domain-general and domain-specific skills in certain types of children's mathematical competence are still underexplored. In this symposium, we will present three studies which investigate the contributions of a wide array of domain-general and domain-specific skills to various aspects of children's mathematical competence.

In the first presentation, Xiujie Yang (Assistant Professor, Beijing Normal University) will report a study that examines the relationships of two sets of domain-general skills – phonological processing and processing speed – to fraction computation fluency among fourth graders in mainland China. Path analysis revealed that when age, vocabulary and non-verbal intelligence were controlled, rapid automatic naming and phonological memory (two components of phonological processing skills) not only had direct associations with fraction computation fluency, but also indirect associations via processing speed. Phonological awareness (another component of phonological processing skills), however, was not a significant correlate.

In the second presentation, Winnie Wai Lan Chan (Assistant Professor, The University of Hong Kong) will draw attention to a domain-specific skill that has often been overlooked in early math screening tools – multi-digit understanding, and share the findings of a study conducted in Hong Kong. In the study, upper kindergarteners were administered a variety of tasks related to multi-digit understanding. Factor analysis suggested that different from the case of older children, upper kindergarteners' performance on these tasks loaded on only one factor. Regression analysis further showed that after controlling for various domain-general skills, multi-digit understanding in the upper kindergarten year could still account for mathematical achievement in the first grade.

In the third presentation, Sum Kwing Cheung (Assistant Professor, The Education University of Hong Kong), Katrina May Dulay (Research Officer, University of Oxford) and Catherine McBride (Professor, The Chinese University of Hong Kong) will report data collected in Cebu, the Philippines. Their study explored what domain-general and domain-specific skills contributed to young children's performance on various types of addition story problems. Regression analysis found that when early numeracy skills were taken into account, the predictive power of phonological processing skills disappeared, whereas vocabulary knowledge remained predictive of performance on combination problems. Unlike object counting and rote counting skills, numerical magnitude comparison skills only predicted performance on combination and change problems, but not comparison problems. Addition fact knowledge, unexpectedly, was not a significant predictor at all.

Based on the three presentations, the discussant (Kerry Lee, Professor, The Education University of Hong Kong) will lead a discussion about the roles played by various domain-general and domain-specific skills in different types of mathematical abilities, as well as the implications of findings emerged in this research area. Possible future directions for investigation will also be put forward."