MCLS

THE MATHEMATICAL COGNITION AND LEARNING SOCIETY

THE SEVENTH ANNUAL MCLS CONFERENCE

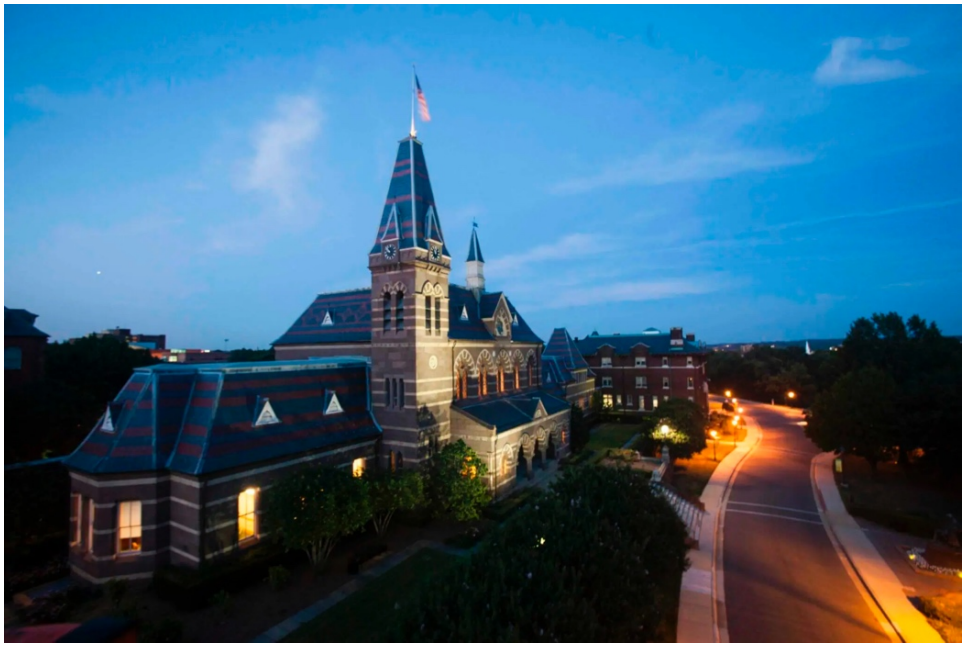
CONFERENCE PROCEEDINGS

June 26-28, 2024

Washington, DC, USA

GALLAUDET UNIVERSITY

NSF



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GENERAL INFORMATION

Conference Program

A digital version of this Program Booklet and the Book of Abstracts can be found at https://www.the-mcls.org/conferences/mcls-2024-washington-dc.

Registration/Check-in

Check-in takes place in the King Jordan Student Academic Center (SAC) near the bookstore. The registration table will act as a point of assistance throughout the conference. Registration will open on June 25 from 3 pm to 6 pm.

Wi-Fi Access

Wi-Fi is available anywhere on campus. You may use BisonNet. Eduroam is also active for those with an account.

Quiet Room

Room SAC 1210: A quiet room is reserved for anyone wishing to wind down and separate from the bustling halls of the conference. This is NOT a room for conversations, video conferencing, or making phone calls. Please respect the needs of those who want to study, read, or enjoy quiet time. People who will not respect the quiet nature of this room will be asked to leave.

Lactation Room

A private room is available in SLCC. The lactation room has a sink and refrigerator available. Please ask at the registration table if you need access to the room. You will be responsible for ensuring your items left in the fridge are clearly recognizable and for retrieving anything by the end of the conference

Map

A campus map is located at the end of this program.

Accessibility

ASL-English interpreters are available throughout the conference to support your communication needs. Each conference room has two interpreters working during the presentations. Interpreters will switch during natural pauses in your presentation. Please respect the time allowed for the symposium and avoid exceeding your time. This is to respect interpreters' needs to rest in between sessions and ensure that everyone remains equally engaged in open discussions.

You can also find interpreters at the registration table and the poster sessions. Please feel free to ask for their assistance when required. Interpreters are recognizable thanks to a blue sash and a button with the interpretation sign.

During your presentations, you will also have professional captions. Tech support is available to ensure remote captioners can hear who's speaking in the room and type onto an external display. If a microphone is in the room, please use it to ensure accessibility. **Please arrive 20 minutes before your session for proper setup before starting**. Ideally, symposium chairs should coordinate everyone's presentations.

Slide/Poster Upload

As part of your submission, all presenters have acknowledged that uploading slides/ posters before your presentation is required 48 hours ahead of time. This will ensure optimal access for individuals preferring to use personal devices to read the materials, as well as allow interpreters to prepare the materials ahead of time.

If not already done, **presenters are to upload their slides/posters using the QR codes and links below**. The same links and QR codes can be used to view the materials.

Please find the appropriate folder and timeslot matching your presentation.

June 26
rebrand.ly/mcls24june26

June 27
rebrand.ly/mcls24june27

June 28
rebrand.ly/mcls24june28

Lunches and Coffee Breaks

Lunch and coffee breaks are provided during the conference. There are morning and afternoon coffee breaks with snack options. Tables with food will be located in the King Jordan Student Academic Center (SAC).

Please note that there will be vegan, gluten-free and dairy-free options. The list of ingredients will be made available. We ask individuals with dietary restrictions to be given priority and ask for assistance from the catering staff.

Please enjoy the outdoor areas outside of SAC, the library patio, the dining tables downstairs of the conference rooms, and the poster hall as lunch locations.

Poster Hall

Poster sessions are held in the Sorenson Language and Communication Center (SLCC) atrium and hallway. Each poster board has a number, please find your poster number in the booklet as your dedicated board space.

Posters should be placed 10-20 minutes before the session and taken down promptly at the end of the session. Forgotten posters will be taken down for the next session.

Getting Around

Gallaudet University is located in Northeast Washington, DC, the capital of the United States of America. Gallaudet can be conveniently accessed via the Red Line on the Metro at the NoMa-Gallaudet U station.

Washington, DC, and the DC area are served by the Metrorail and the Metrobus, through which popular destinations, including Smithsonian museums (free of charge), the Washington Monument, the Lincoln Memorial, and the White House, can easily be reached. The payment method for these systems is the Smartrip card, which can be installed on a

smartphone without a physical card. For more information, visit https://www.wmata.com/.

Parking on Campus

If driving, you have to purchase a day pass ($10) or a weekly pass ($40) at the Department of Campus Safety (DPS). Please bring your driver's ID, car registration documents, and plate number. This process can take time; please plan enough time. Once you receive your parking permit, you may use any parking location on the map. Off of Lincoln Circle, under the Hanson Plaza, you will find ample parking. During the summer, the student-reserved parking is available for general use. On the side and behind the Athletic Center, above and below-ground parking is available. Avoid restricted areas for the Hearing and Speech Clinic or other reserved spaces, as you will remain responsible for any issued ticket.

Conference Reception 06/26

The conference reception is on Wednesday, 26 June, on the first floor of the Living and Learning Residence Hall open area from 6 pm to 7:30 pm (refreshments are included). You should receive two tickets for alcoholic beverages. Please respect local laws, **the legal age for drinking alcohol in the USA is 21.** Any underage drinking is illegal and is severely punished. If you are the mentor of an underage attendee, please ensure they are not infringing any laws. **If you are an underage attendee (<21) and received tickets by error, please donate or trash them.**

Mentoring Lunch 06/27

The MCLS Trainee Board is excited to invite you to the mentoring lunch on Thursday, 27 June, from 12:00 noon to 1:00 pm, in room SAC 1010. This event is designed to allow attendees to connect with their mentor, mentee, or buddy. During the event, attendees are encouraged to partner with another mentoring pair to share experiences, learn from each other, and build professional relationships.
The goal is to create an inclusive and welcoming environment for all attendees, so please don't hesitate to contact us if you have any questions.

MCLS Business Meeting 06/27

All MCLS members are invited to join the business meeting on Thursday, 27 June, 5:00 pm to 6:00 pm in the Multipurpose Room (MPR) in the Student Academic Center.

Trainee Social Event 06/27

All trainees are invited to join the social event on 6:00 pm on Thursday, June 27th at Crooked Run in the Union Market area (550 Morse St. NE). For questions about the MCLS Trainee event or if you have food restrictions that do not allow you to eat pizza, feel free to contact the organizers, Lilly Roth (lilly.roth@uni-tuebingen.de) and Christina Kim (christina.kim@gallaudet.edu).

Certificate of Attendance

At the end of this booklet, you can find your certificate of attendance. Should you need a certificate with your name for your institution, please email mcls.conference.2024@gmail.com

Things to Do

Visitor information from Gallaudet University can be found here: https://gallaudet.edu/visit/. Local Austin Graff has also made guides to all 131 local neighborhoods in DC—Gallaudet is closest to Wards 5 and 6: https://austinkgraff.com/dc-guides/.
Union Market, to the west of Gallaudet's campus between 5th and 6th St NE, offers a wide variety of dining options. H St NE and the surrounding area offer a diverse dining experience.

WELCOME

I warmly extend a welcome to everyone attending the MCLS 2024 on behalf of the MCLS Governing Board! This year marks our seventh conference, as our dedicated members have remained connected even amidst the pandemic. We are joyful to add Washington to our line-up of venues alongside Oxford, Ottawa, Antwerp, and Loughborough, and our goal is to expand globally by reaching scientists in continents yet unvisited. The field of Mathematical Cognition is on the rise as researchers from various disciplines, such as Psychology, Education, and Neuroscience, among others, are making remarkable contributions to expand its scope and prominence. Our identity was built and strengthened on ethical, scientific, and open science pillars. Our community is passionate about learning from one another, exploring novel paradigms and techniques, challenging established perspectives, and fostering cross-site cooperation. We encourage you to make the most of networking opportunities carefully planned, such as workshops, symposia, and poster sessions, which will allow you to discover friends, mentors, and future co-authors. We also invite you to consider becoming involved in our Governing, Executive, and MCLS Trainee boards to closely contribute to the development and success of our society. May the MCLS 2024 become your home, a space where you can nurture vibrant, inspiring, and fruitful scientific and social exchanges.

Flavia H. Santos
Chair of the MCLS

MCLS SERVICE AWARD

The MCLS Service Award was created in 2020 to highlight exceptional service contributions from members of the society, including those serving on the governing, executive, and MCLS trainee boards. This year, we proudly recognize Professor Daniel B. Berch for his crucial role in the Society's inception, continued dedication, and invaluable contributions to the MCLS. Dr. Berch was the Founding Chair of the Governing Board and currently serves as a Special Advisor to the society, offering critical input on strategic planning and pivotal decisions. It is our pleasure to bestow Dr. Daniel Berch with the MCLS Service Award in recognition of his remarkable contribution to the growth of our society.

ACKNOWLEDGMENTS

We want to recognize that this year's MSLC conference was made accessible thanks to a Conference Award by the National Science Foundation under Grant DRL- 2348499. Any opinions, findings, and conclusions or recommendations expressed in this conference are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

The MCLS would like to extend sincere gratitude to **foundry10** for their generous support in providing travel awards for trainees to attend this year's conference. Their commitment to fostering opportunities, particularly for trainees from under-represented backgrounds, is invaluable to the advancement of our field and to creating a more diverse research community.
Further, in keeping with our mission to be an international society, the MCLS provided travel awards to attendees from under-resourced countries with the goal of enabling greater participation.

We wish to thank Gallaudet University for welcoming the MCLS conference on its campus and allowing our members to immerse themselves in a unique ASL-English bilingual world.
This conference would not be accessible without the exceptional work of our interpreters and captioners. We especially want to thank Kelsey Mitchell, our interpreter liaison, who patiently worked with us and ensured we would have the most seamless experience organizing our first fully accessible conference.

Last but not least, we thank Dr. Josh Medrano, from Kent State University, who generously gave his evening time to support the creation of the short booklet, and Xin Lu Wall, Gallaudet University, for working tirelessly on the abstract proceedings.

WEDNESDAY JUNE 26

	Room A: SAC 1011	Room B: SAC 1010	Room C: MPR	Room D: Foster
8:15-9:00	**Registration & Welcome**			
9:00-10:15 *Session 1*	S1A: Can we at least agree on the basics? In search of consensus in mathematical cognition	S1B: Mathematics vocabulary: Complexities to consider in intervention and assessment	S1C: What's the difference? Contextual factors, caregiver beliefs, and children's home math experiences	S1D: Unraveling complex relations between math anxiety and math performance in childhood: Insights from various predictors across different countries
10:15-10:45	**Coffee Break**			
10:45-12:00 *Session 2*	P1/S2A: US Government Funding Agencies (NIH, NSF, IES)	S2B: Link between language, concepts and mathematics: Influence of the semantic content in word-problem solving	S2C: Home math environment and early math development in various sociocultural contexts	S2D: A socio-cognitive perspective to mathematical development across the school years: The Role of learners' motivations and attitudes towards mathematics
12:00-1:00	**Lunch**			
1:00-2:00	**Poster Session 1**			
2:00-3:15 *Session 3*	P2/S3A: Foundations and other agencies (AERA, NaEd, foundry10)	S3B: Essential components of word-problem instruction for supporting students with mathematics difficulty	S3C: Bringing families into the equation: Collaborative approaches to family math engagement research	S3D: Mathematics anxiety in elementary and middle school: Concurrent correlates and longitudinal predictors
3:15-3:45	**Coffee Break**			
3:45-5:00 *Session 4*	S4A: Measuring mathematical skills in early childhood: Current evidence and future directions	P3/S4B: "Ask Me Anything" with Funding Panelists	S4C: Children's and parents' spontaneous mathematical focusing tendencies	L1/S4D: Lightning Talks Session 1
5:00-6:00	**Poster Session 2**			
7:00-8:30	**MCLS Social Reception**			

THURSDAY JUNE 27

	Room A: SAC 1011	Room B: SAC 1010	Room C: MPR	Room D: Foster
8:15-9:00	**Registration**			
9:00-10:15 *Session 5*	S5A: Embodied learning in mathematics: Nurturing cognitive development through motor skills, finger-based strategies, and bodily actions	S5B: How neuroscience may inform cognitive arithmetic: From individual mechanisms to intergenerational transmission	S5C: Understanding strategy use in math problem solving and learning	S5D: What about mathematics writing? Effects of instruction and training in mathematics-writing strategies
10:15-10:45	**Coffee Break**			
10:45-12:00 *Session 6*	S6A: Number and mathematics across perceptual modalities and language experiences	S6B: Neural insights into conceptual and procedural fraction understanding	S6C: Flexible and adaptive strategy use in mathematics: Enabling and hindering factors	S6D: Individualized approaches to education: Student profiles and teacher practices
12:00-1:00	**Lunch**			
1:00-2:00	**Poster Session 3**			
2:00-3:15 *Session 7*	S7A: Acquisition of early numerical concepts and numerical reasoning in deaf and hard of hearing children and adults	S7B: Exploring the relations between executive function and mathematics skills	S7C: Arithmetical skills: Hierarchical nature, early predictors and effects of schooling and age	S7D: What's confidence got to do with it? Teaching efficacy in mathematics
3:15-3:45	**Coffee Break**			
3:45-5:00 *Session 8*	S8A: Understanding perceptual influences on math cognition and learning	S8B: Numerical flexibility investigated from cognitive, neural, and educational perspectives	S8C: Multiplication fact knowledge: Integrating findings across multiple levels	L2/S8D: Lightning Talks Session 2
5:00-6:00	**MCLS Business Meeting**			

FRIDAY JUNE 28

	Room A: SAC 1011	Room B: SAC 1010	Room C: MPR	Room D: Foster
8:15-9:00	**Registration**			
9:00-10:15 *Session 9*	S9A: Training children's numerical skills in elementary school: From counting to arithmetic fluency	S9B: The development of foundational mathematics skills across the life span	S9C: Pattern learning: Empirical research about interventions, parental beliefs, and links to mathematical competence in children	S9D: Examining factors related to gender differences in early math development
10:15-10:45	**Coffee Break**			
10:45-12:00 *Session 10*	S10A: From games to gains: Enhancing early numeracy through play and technology	S10B: What do we know about children's knowledge of base-ten numeration?	S10C: Diverse methodologies to explore parental involvement in children's math learning	L3/S10D: Lightning Talks Session 3
12:00-1:00	**Lunch**			
1:00-2:00	**Poster Session 4**			
2:00-3:15 *Session 11*	S11A: Innovations in the science of mathematics instruction: Three randomized controlled trials with struggling learners	S11B: What is going on with number ordering? The role of eye-movements, emotions, and familiarity in ordinality and the reverse distance effect	S11C: Why does storybook reading matter? Influences of storybook reading on STEM disciplines	L4/S11D: Lightning Talks Session 4

POSTERS

Poster Session 1 (Wednesday, 1:00-2:00 PM)

1. **Relations between speeded naming of small exact quantities and numeracy development for 7- to 8-year-old children**

Jenna Rice[1], Jo-Anne LeFevre[1], Erin Maloney[2], Helena Osana[3], & Sheri-Lynn Skwarchuk[4]
[1]Carleton University; [2]University of Ottawa; [3]Concordia University; [4]The University of Winnipeg

Subitizing, the rapid identification of small non-symbolic quantities (i.e., 1 to 3), has been proposed as a core quantitative skill that supports the development of symbolic numeracy skills. However, its role in numeracy development has not been thoroughly investigated. In the present study, we explored the link between the rapid naming of quantities within the subitizing range (i.e., 1-3), and change in 7- and 8-year-old students' symbolic numeracy skills over one year. Students (N = 147, Mage = 7.8 years) completed measures of rapid automatized naming of non-symbolic quantities (RAN-Q), rapid automatized naming of letters (RAN-L), cognitive skills in grade 2, and arithmetic, number comparison, and number line estimation in grades 2 and 3. Both RAN tasks are assumed to measure students' efficient access to phonological representations. We assumed that RAN-Q also captures math-specific variance through efficient access to small quantities. Thus, we hypothesized that RAN-Q performance would predict change in students' mathematical skills over one year, even after controlling for RAN-L. To test this hypothesis, we conducted a multiple regression analysis for each mathematical outcome in grade 3, controlling for grade 2 mathematical skills and RAN-L. RAN-Q accounted for additional unique variance in grade 3 number comparison. RAN-Q and RAN-L accounted for significant shared variance in the number line task. However, neither RAN measure accounted for significant unique variance in arithmetic. These findings provide a nuanced view of the relations between children's numerical skills and quantity knowledge in the development of mathematics.

2. **Are digital multiplication fact recall tasks an appropriate measure of children's multiplication recall and wider mathematics achievement?**

Natasha Guy[1], Charlotte Wilks[2], Joanne Eaves[1], Lucy Cragg[2], & Camilla Gilmore[1]
[1]Loughborough University; [2]University of Nottingham

Mathematical number fact fluency provides a solid foundation for future maths learning (Geary, 2011; Nelson et al., 2016). In England, a statutory digital assessment of multiplication fact recall has recently been introduced for all 8- and 9-year-old children. However, it is currently unclear if assessing fact recall this way is an accurate measure of children's multiplication fact knowledge and how performance on the assessment relates to wider mathematics skills. We investigated the relationship between digital assessment of multiplication fact recall and performance on an applied multiplication task. We also explored the extent to which children's sustained attention and speed and accuracy of entering numbers on a digital device accounted for variance in digital fact recall task scores. 96 children aged between 8 and 9 years (M = 8 years 10 months, SD = 3 months) completed five paper and pencil and computer-based tasks. Measures included digital and written multiplication recall tasks, an applied multiplication task, a Sustained Attention to Response Task (SART) and a task assessing children's speed and accuracy at entering numbers on the digital device. Results indicate digital multiplication fact recall was significantly associated with performance on an applied multiplication task. However, both sustained attention and speed and accuracy of digital number input were found to be significantly associated with performance on digital multiplication fact recall. Findings have important policy implications as they are the first to demonstrate how appropriate digital assessments are both as a measure of children's fact recall ability and their wider multiplication skills.

3. **Pathways to early success with fractions and their relation to cognitive and mathematical skills**

Elena Silla[1], Alexandria Viegut[2], Eva Redican[1], Christina Areizaga Barbieri[1], Ilyse Resnick[3], Nora Newcombe[4], & Nancy Jordan[1]
[1]University of Delaware; [2]University of Wisconsin-Eau Claire; [3]University of Canberra; [4]Temple University

Our previous work (Viegut et al., 2023) revealed large individual differences in early fraction knowledge prior to formal instruction. In the current study, we used latent profile analysis (LPA) to explore if there are multiple pathways to this early fraction understanding. We also examined whether profiles are differentially related to whole number knowledge, cognitive skills, and later math knowledge. In fall and spring, we examined 210 first graders' (M = 6.68 years) knowledge of five components of early fraction knowledge: equal sharing, fraction equivalence, adding equal parts, word mapping, and fraction notation. Students also completed measures of whole number knowledge (fall and spring), cognitive skills

(winter), and general math performance (spring). Using the components of early fraction knowledge as profile indicators, LPA revealed three distinct patterns of early fraction knowledge: Understanding Fraction Equivalence (P1, n ~ 108), Understanding Adding Equal Parts (P2, n ~ 43), and Limited Understanding of Equivalent Fraction Parts (P3, n ~ 53). Children in P1 showed relatively strong performance across all components, with near perfect performance on fraction equivalence items. Children in P2 performed similarly to P1 but struggled more with equivalence. Children in P3 struggled on all components. Across all profiles, children had limited knowledge of symbolic fraction notation. Profile membership predicted end-of-year math knowledge, with students in P1 and P2 outperforming P3. Interestingly, P2 outperformed the other two profiles on end-of-year fraction knowledge and proportional reasoning. These results emphasize the importance of examining heterogeneity and provide evidence for multiple pathways to early fractions understanding.

4. **Problem characteristics affecting one-digit multiplication solving in children from grades 5 to 8**

David Maxime Mueller[1], Jérôme Prado[2], & Catherine Thevenot[1]
[1]University of Lausanne; [2]University of Lyon

This study examines how response times and accuracy associated with solving one-digit multiplication problems are affected by factors such as problem size, operand order effect or tie effect in children. The study also aims to assess the explanatory power of different interference models on children's performance. A total of 380 children from Grades 5 to 8 in French public schools participated in the study, comprising 44 fifth graders (10-11 years), 170 sixth graders (11-12 years), 94 seventh graders (12-13 years), and 72 eighth graders (13-14 years). Children were asked to solve multiplication problems ranging from 3x3 to 9x9 presented on a computer screen. Children had to enter their responses on the keyboard as quickly and accurately as possible. Each multiplication fact was presented three times across three blocks. Our results are compared with previous data of the literature, noticeably studies conducted in Northern America several decades ago. These findings may help establish a clear picture of children's difficulties when solving multiplication problems and locate the source of these difficulties, which could help in designing teaching or remediation tools for children with or without difficulties.

5. **Disentangling stimulus energy from temporal duration to probe the operational momentum effect in the time domain**

Marie Jacquel[1], Arnaud Viarouge[1], & André Knops[1]
[1]Université Paris Cité

The Operational Momentum Effect (OME) is the tendency to overestimate the result of additions and to underestimate the result of subtractions. Recently, a similar effect to OME has been described in the time domain by Bonato and colleagues, coined the Temporal Momentum Effect (TME). These results are interpreted as evidence for common coding principles for numerical and temporal information. In previous experiments, the temporal duration was confounded with the emitted stimulus energy by the use of continuous sounds as 'operands'. To conclude that the observed over- or underestimation for additions and subtractions, respectively, has its origin at the cognitive level (i.e. pertains to the combination of the cognitive representation of duration), the current experiment uses empty intervals, i.e intervals delimited by a start and a stop stimulus. The aim of this study was hence to replicate and investigate whether the TME reflects a bias that pertains to the integration of stimulus energy (sensory integration hypothesis) or to a common mechanism driving numerical and temporal processes.25 adults had to produce, via button-presses, the outcome of additions and subtractions of auditory intervals of two types (filled and empty). For both stimulus types we replicate the TME, i.e. a tendency to overestimate the duration of additions and underestimate the duration of subtractions when compared to a baseline. These results suggest that the TME is not solely due to the sensory integration of stimulus energy. Bonato, M., D'Ovidio, Umberto., Fias, Wim., & Zorzi, M., (2021) A momentum effect in temporal arithmetic. Cognition, 104488.

6. **A meta-analysis of the cross-sectional and longitudinal relations between executive functioning and math in early childhood**

Bijan Tabrizian[1], Jane Hutchison[1], Ander Avdellas[1], Nina Bajnauth[1], Deborah Phillips[1], & Ian Lyons[1]
[1]Georgetown University

Mathematical thinking and executive functioning (EF) skills are thought to be tightly linked across the early childhood years. While there are multiple existing meta-analyses on the relation between EF and math, few if any have focused specifically on early childhood education. Here, we examined whether the strength of the EF↔Math relation in this age-group depends on measurement factors, socio-economic status (SES), and the nature and direction of longitudinal relations. The overall average EF↔Math relation was r=.350 (95% confidence-interval: .338-.361), and all variations of EF and math measures considered here yielded significant EF↔Math relations,

which speaks to the overall robustness of this association. Therein, we also found significant variation. Composite or overall achievement measures of EF and math generally led to substantially higher estimates of the EF↔Math relation relative to measures that attempt to isolate EF subprocess or specific math skills; however, we attribute this primarily to measurement as opposed to theoretical or developmental factors. We also found evidence that EF measures using numerical stimuli inflate estimates of the EF↔Math association by roughly 40%. In terms of SES, the strongest effects were found in low SES samples. Considering longitudinal associations, those that do not adjust for time-1 measurement of the outcome variable lead to inflated estimates of directional associations. After making these adjustments, we nevertheless found evidence for significant bidirectional relations between EF and math. Methodological, theoretical and educational implications of these results are discussed.

7. **Triangulating cognitive processes in mathematics and reading: An invitation to unify theories of learning systems**

Garret Hall[1], Matthew Cooper Borkenhagen[1,2], Wilhelmina van Dijk[3], & Jason Chow[4]
[1]Florida State University; [2]Florida Center for Reading Research; [3]Utah State University; [4]Vanderbilt University

The purpose of the current presentation is to describe the links between a dominant theory in math cognition, the Triple Code Model (Dehaene, 1992), and the Triangle Framework (Harm & Seidenberg, 2004), an influential connectionist theory that explains the learning mechanisms underlying reading development to better understand mechanisms underlying reading-math connections. Despite the parallels in these theories and the evidence for reading-math covariance, they have developed mostly in isolation in their respective fields. We highlight how the process of division of labor described within the Triangle Framework (i.e., the shift from reliance on phonology in connections between orthography and semantics to a more direct orthography-semantics connection) parallels the mechanisms posited within the Triple Code Model, specifically those that facilitate the connections between magnitude and number meaning, symbolic number processing, and number language. In drawing these parallels, we highlight recent correlational as well as causal work supporting these theoretical connections (e.g., Hall et al., 2023). We also invite interdisciplinary work on these potentially overlapping learning processes in order to understand the potential mechanisms of reading-math covariance in human development. Hall, G., van Dijk, W., Chow, J., & Comella, S. (2023). Decrypting the Codes: Investigating a Reading Intervention's Impact on Math Problem Solving and Calculation Fluency. PsyArXiv. https://doi.org/10.31234/osf.io/jvyzwHarm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. Psychological Review, 111(3), 662–720. https://doi.org/10.1037/0033-295X.111.3.662Dehaene, S. (1992). Varieties of numerical abilities. Cognition, 44(1), 1–42. https://doi.org/10.1016/0010-0277(92)90049-N

8. **The interplay between learning to think and thinking to learn: An intervention on metacognitive monitoring in arithmetic**

Elien Bellon[1], Elisa Filevich[2], Wim Fias[3], & Bert De Smedt[1]
[1]KU Leuven; [2]Eberhard Karls Universität Tübingen; [3]Ghent University

Already in 1979, in his pivotal paper, Flavell theoretically posited that metacognition has an important effect on performance. Recently, we empirically demonstrated that metacognitive monitoring, a specific aspect of metacognition (i.e. the subjective self-assessment of how well a (cognitive) task will be/is/has been performed; Nelson & Narens, 1990) is a powerful unique predictor of concurrent and later arithmetic performance in primary school children (Bellon et al., 2019, 2020, 2021). Although these correlational data help us understand the association between metacognitive monitoring and arithmetic performance, they do not answer the question of the causality of this association. Such causal evidence is however critical to ground educational interventions to improve arithmetic performance. To obtain this causal evidence, we carefully designed a randomized controlled arithmetic learning experiment to study if 1) We can improve monitoring skills in a short period of time within an arithmetic training; 2) Whether a monitoring element within an arithmetic training boosts arithmetic learning and 3) Whether that potential effect generalizes to other academic domains (spelling). We investigated this outstanding issue in about 200 primary school children in Grade 2 (i.e. 7-8 year-olds) and Grade 3 (i.e. 8-9 year-olds). We used a randomized pretest-posttest design with three conditions. The 3 conditions all involved 4 training sessions (+- 30 minutes) in which children solved single- and double-digit arithmetic items with our without metacognitive component. Preregistered ANOVA analyses, potential mechanisms underlying the results, and (educational) implications will be discussed.

9. **Evaluating the influence of symbolic sequence type and familiarity on order verification performance and strategy reporting**

Michael Slipenkyj[1], James Vellan[2], Erika Ikeda[1], Jo-Anne

LeFevre[2], & Ian Lyons[1]
[1]Georgetown University; [2]Carleton University

Order processing is a core component of numerical cognition and predicts arithmetic performance in children and adults. An important finding in ordinality research is higher performance when judging ordered sequences that are adjacent (e.g. 1-2-3) compared to judging non-adjacent ordered sequences (e.g. 2-4-6). This effect has been called the reverse distance effect (RDE). Recent research has argued that the source of the RDE is the use of memory retrieval strategies for familiar adjacent sequences. However, separate research has found that the RDE is larger in ordering tasks with double-digit numbers, where memory retrieval strategies are less likely. This suggests that familiarity effects may not be the sole source of the RDE. In this planned pre-registered study, we aim to evaluate the impact of retrieval strategies and familiarity on the RDE. We will utilize triplet order judgement tasks with common and uncommon letters and numerals, collecting strategy reports after every trial. We will compare the RDE across tasks with repeated measures ANOVAs. Counts of self-reported strategies will be analyzed through Poisson regression models. Consistent with prior work, we hypothesize that the RDE will be larger in uncommon order judgement tasks. Moreover, we predict that reports of memory strategies will decrease, while reports of recitation and counting strategies will increase, in the uncommon tasks. In other words, we hypothesize that larger RDEs will be associated with fewer reports of memory retrieval strategies. The results of this study may help in determining the role of familiarity and memory retrieval strategies in the RDE.

10. Is there a relationship between frequency of home mathematical activities and children's mathematical outcomes? Data harmonisation and secondary analyses of UK-based datasets

Benjamin Hunt[1], Abbie Cahoon[1], Emma Blakey[2], Ella James-Brabham[2], Danielle Matthews[2], & Victoria Simms[1]
[1]Ulster University; [2]University of Sheffield

Despite the widespread belief that frequent engagement in home mathematics activities (HMA) supports children's later maths abilities, inconsistencies in the relation between the two constructs are found throughout the literature (Cahoon et al., 2021; James-Brabham et al., 2023). Socioeconomic circumstances (SEC) has been proposed as a factor that may explain the variation in findings (Blakey et al., 2020). In addition, the majority of the research on HMAs has been carried out in North America, often using small sample sizes (Daucourt et al., 2021). To address some of the weaknesses of HMA research, we harmonised nine UK-based datasets (n=969) containing data from parent-child dyads and explored the association between frequency of HMA engagement, maths ability and SEC. Previous research has tended to employ factor analysis to identify clusters of HMA variables (Andrews et al., 2022). However, in the current study, latent profile analysis (LPA) was used, with the advantage of being able to identify subgroups of dyads who share patterns of HMA engagement. Three profiles of HMA engagement (high/intermediate/low) were identified using LPA. Results of logistic regression established that children in the intermediate (n= 418) and low engagement (n=146) profiles were more likely to have lower mathematics scores compared to children in high engagement dyads (n= 405), but no SEC differences were found between profiles. We discuss the benefits of using LPA in this research, the role HMAs may play in early maths, and why there might be inconsistent findings with regards to the role of SEC in home learning.

11. Developing a rubric to evaluate how researchers report on the development of caregiver training: A systematic review

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To promote children's mathematics achievement, recent work has explored the implementation of mathematics interventions with caregivers as facilitators, often in informal learning environments (i.e., the home; Berkowitz et al., 2015; Dulay et al., 2019; Purpura et al., 2021; Schenke et al., 2020). A recent meta-analysis of mathematics interventions conducted in informal learning environments revealed interventions with caregiver training and follow-up support may have greater impacts on child learning (Nelson et al., 2023). Yet, published studies do not always fully report caregiver training components. To bridge research to practice, educational stakeholders who implement interventions in informal learning environments must have access to high-quality information about caregiver training. Based on the Division for Early Childhood (2014; DEC) Recommended Practices and current literature, we developed a rubric to code over 50 early childhood mathematics intervention studies for different aspects of caregiver training. In this poster, we will present the results of a systematic review of the literature in which we evaluated studies using the rubric in an effort to improve overall caregiver training development and the reporting of researcher engagement with families.

12. Engagement-sensitive involvement: Parents adjust math practices based on child engagement

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Research on the role of parents in children's math learning generally focuses on how parents support children (for a review, see Eason et al., 2022). However, children are active agents in the socialization process, often shaping parents' interactions with them (e.g., Collins et al., 2000). The current research examined how children's engagement of math strategies contributes to parents' math practices. Children's (N = 529, Mage = 7.5 years; 49% girls) engagement of math strategies and the level of these strategies were coded while they worked with their parents (80% mothers; 65% White, 20% Black; 33% without a bachelor's degree) on a challenging math activity over 12 min. Parents' autonomy support vs. control and the level of their prompts vs. statements were also coded. Multi-level minute-to-minute modeling indicated that when children engaged in math strategies one minute, parents were more autonomy-supportive and less controlling the next minute, adjusting for these practices the prior minute, Cohen's ds > .31, ps < . 001, but there were no effects on the level of their prompts. The more advanced children's strategies, the more advanced parents' prompts the next minute, adjusting for the level of their prompts the prior minute, Cohen's ds = .19, ps < .001, but there were no effects on parents' autonomy support or control. Parents' math practices appear to be finely tuned to their children's engagement of math strategies, offering support as necessary when children are engaged and matching their support to children's level of engagement.

13. **Exploring the home math environment: A comparative study of time diaries and questionnaires in predicting young children's math performance**

Xinyun Lyu[1], Xinan Liu[1], Mingyue Pu[2], & Jike Qin[1]
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We conducted three studies to assess the efficacy of integrating time dairies with a home math environment questionnaire to predict young Chinese children's mathematical performance. In Study 1, 190 3- to 5-year-old Chinese children and one of their parents participated. Children underwent a battery of numerical tests while parents completed a home math environment questionnaire. Study 2 expanded the cohort with 110 additional children, wherein their parents provided time diary records alongside the questionnaire. Study 3 involved another 174 children, where a battery of numerical tests was administered to children and their parents provided both time diaries and questionnaire responses. Our findings revealed that consistent with prior research, advanced formal math activities reported in the questionnaire were the strongest predictors of children's counting and numeration skills, even after controlling for children's age and their family's socioeconomic status (SES). This predictive power holds even when time diary data was considered, indicating that parent-reported information from the questionnaire alone suffices to predict children's early math performance. (164 words)
Keywords: home math environment, questionnaire, time dairy, children, early math performance.

14. **Mothers' and fathers' number talk to toddlers and associations with toddlers' number skills**

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Parents' math engagement in the home is important for their children's math skill development prior to school entry (Daucourt et al., 2021). Both the frequency and type of parental number talk (discussions of number concepts) is related to children's math performance (Levine et al., 2010; Gunderson & Levine, 2011). However, previous research exploring numeracy engagement in the home focused primarily on mothers of young children, and particularly those with preschool- and school-aged children. We aimed to examine how mothers and fathers use number talk with their toddlers, and how their number talk may relate to their toddlers' number skills. In a sample of 124 children aged 2-3 years (M=30.8 months, SD=3.36 months, 52% female) and their mothers and fathers, we found that mothers and fathers did not differ in their overall rate of number talk to toddlers during semi-structured observations, t(123) = 0.13, p = .896. Additionally, mothers' and fathers' rates of number talk to toddlers were significantly correlated (r=.20, p=.029). Critically, there were associations between mothers' rate of number talk and toddlers' number skills (assessed as performance in Point-to-X and Give-N tasks), even when controlling for fathers' rate of number talk (beta=-0.18, p=.055). However, no significant associations were found between fathers' number talk and toddlers' skills. These results may indicate that mothers' number talk is more compensatory compared to fathers', and more work is needed to understand how parents can best support toddlers' early number skills.

15. **Home numeracy and developmental delay: Lessons learned through a collaborative design process with children with disabilities**

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Drake[1], & Gena Nelson[1]
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The importance of the home math environment (HME) has received increasing attention, both by researchers and policy makers in recent years. Despite the positive impacts the HME has on children, little HME research has included children with disabilities. This study is part of a multi-year project focused on the HME experiences and perspectives of children with disabilities and their caregivers. In year 1 of the project, nine parent-child dyads will be assigned to one of three home numeracy activity sets, comprised of storybooks, board games, or everyday routines. Children will be 4-5-years-old and have a documented Developmental Delay (DD). The research team will collect data to assess strengths, challenges, and feasibility of the caregivers' use of these materials with children with DD over a period of 3 weeks. Data collected will include demographics, parent-child math talk, parent-reported HME information, implementation fidelity, and social validity. The first year of the project is aimed at gathering rich, qualitative feedback from parents of children with DD about materials in the HME that previous research has indicated are effective at improving the math achievement of typically developing preschool children. The findings from the brief learning trials will be used to determine how the HME activities may need to be adapted for children with DD for year 2 of the project. Results presented will include this feedback and inform future development of HME materials.

16. **The causal role of the home environment on children's numerical skills. A pre-registered study of a familial intervention in preschoolers**

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Associations between the frequency of home numeracy activities and children's numeracy skills face two limitations. First, previous correlational findings do not provide evidence for a potential causality of these associations. Second, the limited number of intervention studies, while showing some positive effects on children's numeracy skills, have been done in very formal settings (with strong parental supervision and training), challenging their ecological validity. To address these two issues, we set up a familial intervention. Participants were 117 preschoolers (Mage = 4.68 years; 47% girls) and their parents, who were randomly assigned to an experimental (numeracy, n = 58) or an active control (language, n = 59) conditions. The 6-week intervention was designed to ensure optimal ecological validity (i.e., by offering a set of activities without extensive parental training or strict monitoring of the implementation). Participants in the intervention condition received a set of playful materials with numerical content (dominos, board and card games, picture book). The active control group received a set of equivalent playful materials without numerical content (bingo and memory games, picture book). Home learning environment and children's skills in numeracy, mathematical language and non-verbal reasoning were assessed before and after the intervention. The intervention resulted in significant positive effects on numerical skills. These data provide evidence for a causal and specific effect of a home numeracy intervention on children's numeracy skills. They show that low-cost home-based numeracy interventions tailored to real-life situations effectively support the development of children's skills.

17. **Assessing the home mathematics environment and its relation with mathematics attainment: A cross-country study of Mexican and Cuban dyads**

Abbie Cahoon[1], Melissa Aloma[2], Nancy Estévez[2], Carolina Jiménez Lira[3], Daniela García[3], Elia Veronica Benavides Pando[3], & Victoria Simms[1]
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Bronfenbrenner's Bioecological model (Bronfenbrenner & Morris, 2007) suggests that the home learning environment is situated within cultural contexts that could impact a child's development. However, prior research has also suggested that some home mathematical practices may be universal and not country dependent (Cahoon, et al., 2024). The current study extends research on the home mathematics environment (HME) and mathematics attainment to caregiver-child dyads in Mexico and Cuba. The study team began by ensuring a measure of HME was relevant for Mexican and Cuban families by adapting the Pre-school Home Mathematical Questionnaire (adPHMQ) in response to a recently published interview study with Mexican and Cuban caregivers (Cahoon et al., 2024) and translating the questionnaire into Spanish. Subsequently, 171 Cuban parents and 112 Mexican caregivers completed the adPHMQ. Similar factor structures were observed for the HME in Cuba (8-factor structure; 27 items) and Mexico (10-factor structure; 34 items), with more complex structures found for data from these families than for participants in Northern Ireland (Cahoon, et al., 2021). 72 parents in Cuba and 84 caregivers in Mexico completed the adPHMQ; their children (3-5-years-old) were assessed using a standardised mathematics test. Mathematics attainment was only predicted by children's age in the Cuban sample, whereas age and the mathematical language factor from the adPHMQ were significant

predictors of mathematics attainment within the Mexican sample. This study adds to the literature that suggests that mathematics is a language-dependent skill (Purpura et al., 2021). Caregivers expectations of their children's academic success were also explored.

18. Examining intervention effects on mathematics and domain general skills in first grade

Lina Shanley[1], Madison Cook[1], Ben Clarke[1], & Derek Kosty[2]
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As efforts to improve elementary mathematics instruction have increased and early mathematics interventions have proliferated, commensurate efforts to better understand how students develop mathematics knowledge and why students respond to mathematics intervention have also emerged (Nelson & McMaster, 2019). Given known correlations between domain general skills and mathematics achievement, the current study explored the impact of mathematics intervention on the development of both mathematics and domain general skills for 470 first-grade students at risk for mathematics difficulties. Results indicated that domain general skills were associated with mathematics achievement, and gains in working memory were associated with gains in mathematics achievement. Students demonstrated the largest gains in fluid reasoning with an average gain of approximately 0.55 standard deviations. Average gains in visual-spatial processing, phonological memory, and working memory were smaller (0.27, 0.24, and 0.18 standard deviations, respectively). Participating in a mathematics intervention did not affect domain general skill development, despite the positive effect of mathematics intervention on mathematics skills. Results also indicated evidence of differential response to mathematics intervention based on initial domain general skills. Teaching strategies based on cognitive science could help students mitigate domain general demands when completing mathematics tasks and learning new material. Implications for mathematics intervention, curriculum development, and future research are discussed. References Nelson, G., & McMaster, K. L. (2019a). Factors that may influence treatment effects: Helping practitioners select early numeracy interventions. Learning Disabilities Research & Practice, 34(4), 194-206.

19. Dosage response in intensive math interventions for early elementary students with or at-risk for mathematics difficulties

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In this systematic review and meta-analysis, we examined the effect of dosage on outcomes of mathematics interventions for at-risk students in kindergarten through third grade. This is a conceptual replication of a non-linear meta-analysis that examined dosage response of reading interventions in students with reading difficulties (Roberts et al., 2022). The current paper adapted search, screening, and analysis methods to test a similar non-linear model in mathematics interventions. We reviewed 23 experimental and quasi-experimental studies with 163 effect sizes. Results of the non-linear model showed that it was not a good fit to the data, and a linear meta-analysis would be a better fit to the data. Utilizing robust variance estimation (RVE), results revealed an overall pooled mean effect size of $\beta = 0.59$ (95% CI [0.28, 0.91]). Mixed-effects meta-regression analyses revealed that dosage (i.e., total hours spent in intervention) significantly predicted intervention effects such that for every one-hour increase in dosage, there was an increase of 0.03 effect size units $\beta = 0.03$ (95% CI [0.003,0.07]). The main effect of dosage was no longer significant after controlling for theoretical moderators. However, proximity of outcomes to intervention did significantly predict the dosage-response relationship, such that effect sizes of proximal outcomes increased at a higher rate as a function of dose than did distal outcomes. Intervention effects were also moderated by group size. Recommendations for future research and implications for mathematics intervention are discussed.

20. Equipartitioning learning of a neurodivergent student: Emerging understandings and emerging questions

Angela Crawford[1]
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Learning trajectories comprise sequenced goals and tasks designed to build upon progressions of mathematical understandings that are typical of the general population of students. As such, they are useful frameworks for exploring how the learning of neurodivergent students may be similar or different from their peers. The equipartitioning learning trajectory (EPLT), based on the cognitive operation of splitting, is theorized to be a basis for rational number understandings (EPLT; Confrey et al., 2009; Confrey et al., 2014). In addition to detailing an empirically supported sequence of goals and tasks in the EPLT, Confrey and colleagues (2014) describe a framework of mental actions, called cognitive elements, which facilitate a student's increasingly sophisticated conceptual understanding of equipartitioning. Across eleven 45-minute individualized sessions, the EPLT guided a teaching experiment (Confrey & Lachance, 2000; Cobb et al., 2003) focused on early rational number concepts

that was conducted with a neurodivergent student. The analysis reported here describes how the student's ideas progressed and how the student evidenced the cognitive elements. These findings illustrate how a student's actual trajectory can be focused on developing a many-to-one meaning for fractions and relational reasoning, rather than strictly adhering to the sequence of proficiencies hypothesized by the EPLT. Further, the student's engagement with cognitive elements suggests numerous areas for future research at the intersection of cognition and learning environments for neurodivergent students.

21. It's about time: A deep dive into the contribution of timed elements in mathematics instruction

Rene Grimes[1]
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The What Works Clearing House (WWC) guide, Assisting Students Struggling with Mathematics: Intervention in the Elementary Grades (WWC, 2021), includes timed activities as one of the six recommendations for interventions for elementary students with mathematics learning difficulties. The recommendation was based on a thorough systematic review of studies published between 2004 and 2018 meeting the rigorous inclusion criteria. However, using timed activities during math instruction is a source of debate (e.g., Stokke, 2023). Therefore, the current narrative review describes the characteristics of the 27 studies in the WWC guide over and above what is provided in the appendix and extends the current research by reviewing studies published since 2018. The studies included in this review vary from the WWC review by including any study including K-12 students that employed a timed activity for mathematics improvement (i.e., not limited to studies including students with math learning difficulty). The purpose of including other demographics was to describe how timed activities may benefit other learner profiles. Results suggest further study is necessary, specifically contrasting timed to untimed activities as the sole independent variable. Additionally, the review includes plausible contributions of specific instructional procedures in the studies, beyond the timed activities, which may have increased the probability of academic growth. Limitations of this narrative review include not extending the search of studies to other populations conducted during the same time frame as the WWC review and including only studies published in English. Comments and suggestions for future research are welcome.

22. Impact of guided play from numerical learning trajectories in kindergarten

Yovanna Galaz[1], Christian Peake[1], & Esmeralda Dionicio[2]
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The emphasis on formal schooling in kindergarten contradicts the discourse of play at this level. Therefore, solutions are sought to articulate the benefits of play with traditional teaching, such as "guided play" (Weisberg et al., 2015). The present research proposes to link guided play with the "learning trajectories" approach presented by Clements and Sarama (2004; 2014) for teaching early mathematics. The research questions to be answered are how the use of guided play based on numerical learning trajectories impacts the mathematical performance of kindergarten children, and if this differs when planned autonomously by educators or when planned with accompaniment. To answer this question, an experimental study will be carried out in three kindergarten classrooms in Chile (n=100, age=5 to 6 years old); the academic performance of students will be evaluated with the Applied Problems subtest of Woodcock-Muñoz Batería IV test (Spanish version). There will be one control classroom with traditional instruction and two experimental classrooms varying in the autonomy the teachers have to design and implement mathematical guided play (autonomous vs supervised by the research team). Intervention will consist in 2 sessions per week for 8 weeks. It is hypothesized that the use of guided play based on the numerical learning trajectories approach will have a favorable impact on the mathematical performance of the children when compared to the control group and that the mathematical performance of the experimental group with accompaniment will have a greater positive effect than that of the autonomous experimental group.

23. Latine Dual Language Learners' (DLLs') bilingual development in mathematics and cognition: A longitudinal latent profile analysis

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Introduction: While a surge of research has focused on Latine DLLs in the last decade, few studies have examined heterogeneity in their bilingual mathematical and cognitive development during the transition from preschool through kindergarten. Even fewer studies have described contextual variables associated with profile membership. Method: 243 DLLs who were enrolled in Head Start at this studies onset participated. The WJIII/Batería III, which directly measures English and Spanish mathematics and cognitive skills, were administered at the end of preschool, and at the beginning

and end of kindergarten. Mixture models were used to examine the within-group variability of participants' bilingual mathematical and cognitive development. Results: The three-profile solution was the optimal solution, including Average, High, and Low Average Achievers. Learners' W scores indicated that all subgroups improved in cognition and mathematics in English and Spanish. While children's standard scores for English achievement kept up with norm-referenced expectations, improvements evidenced for Spanish achievement did not. There also was a rank ordering where children with the highest scores for cognition had the highest mathematics scores. From among contextual variables, hours of teacher professional development for teaching DLLs and years of teacher classroom experience were highest for High Achievers followed by Average and Emerging Achievers, respectively. Conclusions: This study provides encouraging evidence that most DLLs were poised for educational success and that teacher characteristics are important to their development. The rank ordering of scores for cognition and mathematics is correlational evidence that cognitive advantages confer benefits for mathematics achievement, at least among Latine DLLs.

24. Exploring the casual impact of language transparency on early numerical acquisition in children: A preregistration report

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[1]Xi'an Jiaotong-Liverpool University

The effect of the transparency of counting systems (e.g., the straightforward structure of 'ten-one, ten-two' in Chinese versus the less transparent 'eleven, twelve' in English) on children's numerical abilities has been studied by many researchers using correlational methods. This preregistration report presents a study aimed at elucidating the potential causal relationship between language transparency in counting systems and early numerical acquisition in young children. The study will involve 40 four-year-old Chinese-English bilingual children, randomly assigned to either Chinese or English counting training groups. The children's numerical abilities will be evaluated in both pre- and post-test sessions, with mixed-effect modeling applied to analyze performance changes. A marked improvement in the Chinese training group compared to the English training group in the post-test scores would indicate a causal effect of language transparency on early numerical acquisition. The findings of this study are expected to substantially advance our understanding of how language affects early mathematical development. Keywords: language transparency, early numerical acquisition, casual impact, children.

25. Examining the interplay of language, executive function, and early numeracy skills

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Early numeracy consists of specific skills that vary in complexity and language demands. It is necessary to understand how EF may differentially relate to various numeracy skills and how this relation may be moderated by initial vocabulary knowledge. The current study includes majority (98%) Black preschoolers (an underrepresented group; N = 95; Mage = 4.19 years) and examines the relation between EF and counting, numerical relations, numeral knowledge, and arithmetic operations. For numeracy skills that are more complex (i.e., numerical relations, numeral knowledge, and arithmetic operations), we expected the relation between EF and numeracy to be stronger for children with more vocabulary knowledge. Data were collected during the 2021-2022 school year. Children were directly assessed on the following skills: EF - HTKS (Ponitz et al., 2008); Vocabulary - PPVT (Dunn & Dunn, 2007); Early Numeracy - PENS (Purpura et al., 2015). Regression analyses suggested that arithmetic operations was the only specific early numeracy skill that EF significantly predicted, while controlling for age, sex, prior vocabulary skills, and prior numeracy skills. Children's vocabulary skills moderated the relation between EF and arithmetic operations, such that the association between EF and arithmetic operations was stronger for children with higher vocabulary skills. Results of this study suggest that children with higher vocabulary may be better prepared to use their EF skills to solve simple addition problems, which require knowledge of language and number composition. Future work should investigate contextual factors that promote vocabulary and EF development needed to acquire advanced numeracy skills.

26. A cross-national study of math language learning

Taeko Bourque[1], Chang Xu[2], Victoria Simms[3], Sheri-Lynn Skwarchuk[4], Helena Osana[5], Erin Maloney[6], Jo-Anne LeFevre[1] & Judith Wylie[2]
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Students around the world are taught mathematics in many languages; often, the language of instruction is different from their home language. Does this language disparity influence children's mathematical learning? Immersion contexts provide a natural situation where the language of instruction (e.g., French, Irish) is separate from general language knowledge (e.g., English), allowing a clear test of this question. In the present research, we

studied the relations between mathematical vocabulary and mathematical reasoning and arithmetic fluency for 7- to 9-year-olds from four groups: (1) children learning math in L1 (English) in Manitoba (n = 59), (2) children learning math in L1 (English) in Northern Ireland (n = 92), (3) children learning math in L2 (French-Immersion) in Manitoba (n = 88), and (4) children learning math in L2 (Irish-Immersion) in Northern Ireland (n = 64). We examined the concurrent and longitudinal relations between mathematical vocabulary and performance, controlling for domain-general skills (receptive vocabulary, working memory) and quantitative skills. Hierarchical multiple regression analyses indicated the importance of mathematics vocabulary, especially in immersion settings. Challenges in cross-country research collaborations are also discussed.

27. Expressive and receptive language skills of children with and without mathematics difficulty

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Language skills had a great impact on children's mathematics performance. Children with mathematics difficulties (MD) have poorer language skills than peers without MD (Chow et al., 2021). Little has been explored about the association between language skills and MD in early childhood. This study aims to examine the overall language skills of children with and without MD and to explore the different patterns of variability across language domains. The sample is 140 kindergarten children from a large urban and suburban school district in central Virginia. We administered the Kaufman Test of Educational Achievement (KTEA-3) for MD classification and used the Test of Auditory Comprehension of Language (TACL) and the Test of Expressive Language (TEXL) to determine both expressive and receptive language skills. We will use multivariate analysis of covariance to examine the overall difference in language skills of children with and without MD, controlling for cognitive skills and other demographic variables. We predict that the overall group differences will be statistically significant and explore whether differences emerge across different domains of expressive and receptive language. Previous research on the language skills of children with MD have primarily used measures of receptive language. Reference: Chow, J. C., Majeika, C. E., & Sheaffer, A. W. (2021). Language skills of children with and without mathematics difficulty. Journal of Speech, Language, and Hearing Research, 64(9), 3571-3577.

28. Comparison of technical ASL and manually coded English for learning quantitative content

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Deaf and hard-of-hearing (DHH) students in the US consistently lag behind their hearing peers in math. One possible factor contributing to this gap is the heightened impact of math anxiety within the deaf community. We propose that presenting quantitative content using conceptually-motivated signs in American Sign Language (ASL) might reduce the negative impact of anxiety on learning. If math anxiety is related to decreased conceptual understanding, providing clear visuospatial representations of quantitative content will likely improve learning, making this learning less susceptible to the negative effects of anxiety. This proof-of-concept study will collect data from 30 signing adults to compare the effects of two different science styles on learning. Technical ASL (tASL) emphasizes visuospatial depiction of quantitative content (e.g., a solid is molecules packed together), whereas Manually Coded English (MCE) uses fingerspelled terms and literal English translations (e.g., solid is the sign for rock). Participants will watch four counterbalanced mini-lectures on different quantitative topics, two in each signing style. To measure learning, we will conduct a within-subject analysis of the differences in pre- and post-assessment scores for content learned in tASL vs. MCE. We will correlate participant's scores from the Academic Anxiety Inventory (AAI) with their performance data to investigate differences in learning for participants with increased math and science anxiety. This exploratory study aims to determine if differences in signing style can impact learning and anxiety within the constraints of short mini-lectures, guiding future work on how a visual language could support quantitative learning in math-anxious students.

29. Does the structure of numerals in Colombian Sign Language impact deaf children's understanding of the additive composition of numbers?

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Recent studies suggest that the structure of the counting sequence triggers the understanding of natural numbers (Cheung & Ansari, 2022; Guerrero et al., 2020; Schneider et al., 2021). Like other number systems, complex numerals in sign languages adhere to a 10-based structure. However, some also incorporate a sub-5-base (Leybaert & Van Cutsem, 2002). In Colombian Sign language (CSL), the signs for 1, 2, 3, and 4 (extended fingers) are combined with flexion in the second phalanx to represent numbers 6, 7, 8, and 9. This grammatical

component implies an additive base of 5 (Guerrero et al., 2018, 2013). We explored the relationship between base five and children's comprehension of the additive composition. The study involved 34 CSL-speaking Deaf children and 15 Spanish-speaking hearing children. Two additive tasks were used: verbal and dot sums. Total Sum (5-9 vs. 10-15) and Inclusion of Five (with five vs. without five) were included as within-subjects factors in both tasks, and language (CSL vs. Spanish) was considered as a between-subjects factor. Two independent covariance analyses were conducted on children's sum scores, with their highest count score as a covariate. The results showed a significant main effect for Total Sum in both tasks. Interactions were observed between language X Total Sum and language X Inclusion of Five in the verbal sum task and between language X Total Sum X Inclusion of Five in the dots sum task. These results suggest that the base's structure could affect children's comprehension of numbers and arithmetic operations.

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30. Relations between children's math vocabulary and error patterns when solving math word problems

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Mathematical vocabulary is foundational to mathematical knowledge (Powell et al, 2017; Ünal et al., 2021) and is positively associated with performance on both equations and word problems (Powell et al., 2020). The present study builds on this evidence to examine how math vocabulary correlates with particular problem-solving errors. Children in grades 3, 4, 5, and 7 (N = 103) answered six single-step word problems and completed a math vocabulary measure. We used a series of regression models to determine the predictiveness of math vocabulary for problem-solving accuracy and error type (Kingsdorf & Krawec, 2014). As hypothesized, math vocabulary predicted problem-solving accuracy, even when controlling for grade ($b = 0.77$, $t(102) = 8.07$, $p < .001$, $rp = .63$). Within incorrect answers, error types were explored by schema (2 total, 1 change, 2 equal groups, 1 difference). Math vocabulary positively predicted sound conceptual errors (e.g., computation errors) for "total" ($b = 2.98$, $t(27) = 3.60$, $p = .001$, $rp = .58$) and "change" ($b = 9.68$; Wald $(1, N = 36) = 4.57$, $p = .033$). Math vocabulary negatively predicted poor conceptual errors (e.g., omission errors) for "total" ($b = -2.20$, $t(27) = -2.08$, $p = .048$, $rp = -.38$) only. Thus, math vocabulary skills, beyond supporting problem-solving accuracy, are related to understanding of simpler addition schemas, practiced in earlier grades. This relates to prior work indicating math vocabulary and computation relations being stronger in third grade than fifth (Powell et al., 2017). Overall, results inform research regarding targeted mathematics interventions.

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31. Early math at home: The impact of board games on caregivers' math knowledge, interest, and confidence

Clarence Ames[1] & Emmett Speed[1]

[1]Utah STEM Action Center

Kindergarten math entry scores predict future academic and career outcomes more directly than parent income, parent education status, a child's disability status, early behavior issues, English Language Learner status, and a host of other variables. Kindergarten math entry scores predict future reading scores better than kindergarten reading entry scores. Caregivers' effective engagement in math-based play with toddlers is most reliably predicted by their recognition of the significance of early math education. In a recent study, 100% of caregivers participating in a Head Start program were unaware that teaching math concepts to children aged 0-5 was important. The Math Introductions and Learning Opportunities (MILO & Friends) program provides information and resources to caregivers to help make math fun for Utah families. Family engagement events and short conversations with caregivers focus on ways to effectively engage in math play in daily activities. The STEM Action Center, in support of families and early math learning, has reached over 8,000 Utah families with resources and information for early math engagement. More than 90% of participants surveyed (N = 424) indicated that participation in MILO & Friends programming increased their knowledge, interest, and confidence in working with preschool-aged children to build math skills; dependent t-tests indicate that these increases are statistically significant, $t > 12.52$, $p < .001$.

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32. The SNARC effect in Mayan numerals: Effects of language transparency and reading direction on novel symbolic number understanding

Emmett Speed[1], Cassandra Ivie[1], & Kerry Jordan[1]

[1]Utah State University

This dissertation (in data collection at time of submission) studies the development of a vertical SNARC effect in Western undergrads learning the indigenous Mayan numerical system. Thirty undergraduates participated in an 2.5 hour online course designed to teach written Mayan numerals and spoken Kaqchikel Mayan number words. The participants were split into two instructional groups that reflect the two different number naming strategies

from modern and historical Kaqchikel with opposite directions of vertical numeral-reading- the Pan-Mayan Count (PMC) and Modified Kaqchikel Count (MKC). The intervention course, broken into five 30 minute sessions, covered the vigesimal (base-20) Mayan numerical system in-depth, covering topics from finger-counting to multiplication as well as relevant historical and cultural information. Participants were assessed online at several time points using a Mayan numeral size-congruency Stroop task and a Western Arabic numeral size-congruency Stroop task to investigate the development of automaticity of numeral processing in the numerical system that they are learning. I hypothesized that the participants who learn to count using the MKC will experience a significant increase in performance over time on the Mayan Numeral Size-Congruency Stroop in comparison to the PMC group. Participants also took a Mayan numeral parity judgement task. I hypothesize that exposure to the vertical structure of the written Mayan numerical system will create a vertical spatial numerical association response code (SNARC) effect, though this SNARC effect may be moderated by the transparency of order and reading direction of the number-naming system that the participant learns (PMC or MKC).

33. Math gender beliefs in kindergarteners utilizing mosaic approach

Macarena Angulo[1]
[1]Universidad Diego Portales, Chile/Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT)

Given that early math skills are crucial predictors of later academic success, the results from the latest standardized math test which measures the quality of Chilean education system are alarming. These results reveal a significant setback in gender equality in mathematical learning, particularly affecting girls from low socioeconomic status (SES) backgrounds. Neuroscience indicates that both men and women share a similar biological basis for mathematical learning. Hence, the observed gender gap may be attributed to social beliefs associating math more with masculinity than femininity. In many different countries this gap exists, and similar beliefs have been found. In Chile, studies have demonstrated that these stereotypes are prevalent among teachers, families, and children as young as 5 years old, even more so than in other countries. To analyze in-depth the discourse on gender and math beliefs of kindergarten children, this project proposes a Mosaic Approach which is intended to genuinely listen and provide opportunities for participation to children. As these beliefs vary based on gender and SES, this research will work with a group of kindergarten children from a low SES school and a group from a high SES school. Multiple instruments (that include drawings, short stories and discussion about them, modelling play dough, interviews, and field notes) will be applied along two phases: the first of data collection and the second phase for discussing the data with the participants. Data will be collected since March 2024, then a thematic analysis will be carried out.

34. Does sharing distract you? Effects of perceptual features on third graders' partitioning strategies

Caitlin Macevicius[1] & Helena P. Osana[1]
[1]Concordia University

Equal-sharing situations (e.g., “Four children are sharing 10 brownies equally. How many brownies will each child get?”) are often presented in the classroom to introduce fractions concepts to young children. Visual representations that resemble real-world objects often accompany equal-sharing problems, but little is known about the impact of different types of representations on children’s problem-solving performance. Performance can be supported when external representations are “grounded,” namely, when they activate students’ prior knowledge about familiar experiences. In contrast, when images contain visual details that are irrelevant to the problem’s solution, performance can suffer. Third graders (N = 70) were presented with equal-sharing word problems accompanied by representations that were either (a) grounded without irrelevant details, (b) grounded with irrelevant details (e.g., pepperonis on pizzas), or (c) not grounded (i.e., abstract shapes). Because some shapes are more difficult to partition than others, we also tested the effect of shape (i.e., rectangles, circles) on children’s performance as a within-groups factor. The quality of children’s partitioning was impaired, as was their identification of the quotient in the visual representation after partitioning, when the representations contained irrelevant details than when they did not. The mathematical accuracy of the partitioning of rectangles was greater than circles, but the perceptual details on the representations had no effect on this measure. Finally, transfer effects were revealed: Children demonstrated higher-quality partitioning strategies and could more accurately identify the quotient in the representation when they first solved problems with non-grounded representations than when they first partitioned images containing irrelevant details.

35. Are math-related individual differences associated with COVID-19-related graph interpretation accuracy?

Sharon Jaramillo[1], Abigail O’Brien[1], Lauren Schiller[1], Charles Fitzsimmons[2], Dan Scheibe[1], Jennifer Taber[1], Karin Coifman[1], Percival Matthews[3], Marta Mielicki, & Erika Waters

[1]Kent State University; [2]University of North Florida; [3]University of Wisconsin – Madison, Department of Education

Imagine a map of the U.S., with almost every state shaded red, where darker shades indicate an increasing number of COVID-19 cases per million in the population. These graphs also contain additional information and surface-level features that make it difficult to identify the main point. In the current study, a sample of approximately 662 Qualtrics panelists attempted to identify the main point conveyed by complex graphs about COVID-19. Baseline data collection (2021) involved an online educational intervention targeting health-related math problems. Participants reported their confidence (i.e., monitoring judgments) after solving each of five health-related math problems (e.g., comparing the case-fatality rates of COVID-19 vs. flu). One year later (2022), participants reported their perceived risk, COVID-19 preventative behaviors, math anxiety and completed an assessment of their interpretation of COVID-19 graphs. In the current study, we will conduct a linear regression to identify which predictors (e.g., gender, educational attainment, political orientation, objective graph literacy, math anxiety, math attitudes, and math performance operationalized as magnitude understanding of fractions, large whole numbers, and non-symbolic ratio comparisons) are associated with graph interpretation accuracy. We will investigate the relation between monitoring judgments and graph interpretation accuracy using a hierarchical regression analysis while controlling for math performance, math anxiety, and experimental condition (educational intervention vs. control). Findings from this project can guide additional support for participants to comprehend complex health information communicated via graphs accurately.

36. Does introducing perceptually rich manipulatives in different ways influence how 4-5-year-old children perceive and use them to complete mathematical tasks?

Megan Foulkes[1], Francesco Sella[1], & Camilla Gilmore[1]
[1]Loughborough University

Children and educators use tangible objects (manipulatives) to represent mathematical concepts. An important consideration when selecting manipulatives to use with children is the features of the objects, and how these might influence mathematics learning. Researchers tend to suggest that educators should minimise the use of manipulatives with perceptually rich details (e.g., different colours, patterns, shapes) as these features are often considered to be extraneous and can distract children. However, the extent to which children pay attention to extraneous details may depend on a range of factors. For instance, evidence has indicated that the way a manipulative is initially introduced (e.g., for maths or as a toy to play with) has implications for children's later perceptions of the manipulative and how readily they use it to represent mathematical ideas (Donovan & Alibali, 2021; Osana et al., 2018).In this study we investigated how introducing perceptually rich manipulatives (i.e., brightly coloured, patterned, different shapes) as 'tools for maths' or as 'toys for play' influences children's perceptions and use of the manipulatives as representations to think about mathematics. In a pre-registered (https://osf.io/8sxvz) between-groups design, 4–5-year-old children were first introduced to manipulatives in different ways. We then measured children's performance, strategies, and reasoning on mathematical tasks in a separate session. Preliminary results indicate that children show similar performance when using perceptually rich manipulatives as mathematical representations, regardless of how they were introduced. This provides novel insights into the extent to which different instructional approaches may influence learning when using mathematical representations.

37. Associations between young children's flexible attention to numerical and spatial magnitudes and early math skills

Mary Wagner[1], Marissa Brown[1], Molly Griffin[1], Mitchell Hanson[1], Danielle Barrett[1], Julia Fabian[1], & Madelyn Hales[1]
[1]University of Dayton

Children's ability to flexibly switch between attending to different dimensions of magnitude (FAM ability) predicts math achievement (Fuhs et al., 2021). The current study uses a modified version of an existing FAM task to test the relationship between FAM ability and math achievement, extending prior research by controlling for related EF and math skills. It also extends previous studies by implementing check trials to explore whether some children may use a single-dimension strategy to succeed on the FAM task (e.g., switching from bigger to smaller items rather than from size to numerical magnitude). We assessed 226 children (51% female; Mage = 55 months; SDage = 8 months) on FAM ability, EF, general academic skills, and several specific math skills. We intentionally assessed children within local preschool classrooms to obtain a heterogeneous sample and account for the diversity of the community. We did not find evidence that children used a single-dimension strategy on the FAM task. We then used multiple regression analyses to test the relationship between math achievement and FAM ability while controlling for related skills. We found FAM ability to be a significant predictor of math achievement

above and beyond other early math skills. These results were consistent with our hypotheses and suggest that FAM ability could be a valuable target for future early math interventions. Fuhs, M. W., Tavassolie, N., Wang, Y., Bartek, V., Sheeks, N. A., & Gunderson, E. A. (2021). Children's Flexible Attention to Numerical and Spatial Magnitudes in Early Childhood. Journal of Cognition and Development.

38. Lessening the gap: Worked examples, self-explanation, and metacognition across levels of expertise in math learning

Melanie Prieto[1] & Hannah Hausman[1]
[1]University of California, Santa Cruz

One of the most recommended math teaching strategies is worked examples (WEs)–step-by-step solutions to problems. However, compared to problem-solving, WEs may cause learners to be overconfident in their understanding, especially among students with little prior knowledge (Hausman, Rhodes, & Prieto, 2021). In STEM, experts focus on the conceptual structure of problems, whereas novices focus on superficial, irrelevant, features. I aimed to improve college students' statistics learning. I am collecting data from 125 novice undergraduate students with no college-level statistics experience who are randomly assigned to one of three learning conditions (WE, SE, or SSE). Participants watch a lesson on conditional probability, practice 12 problems through one of three methods, predict their test performance, and take a 20-problem transfer test. WE practice entails studying problems' step-by-step solutions. Self-explanation (SE) involves an open-ended prompt to explain the WE solution. Structured SE (SSE) practice requires explanations about key WE solution steps. I expect one-way ANOVAs of performance on the transfer test and metacognitive monitoring accuracy to reveal a significant effect of practice conditions, with poorest performance with WEs, moderate performance with SEs, and strongest performance with SSEs. I predict that SSE practice will lead to the highest test performance and most accurate test predictions by shifting attention to deep problem structure, making connections to prior knowledge, and generating information. Follow-up research will compare the relative effectiveness of SSEs versus SEs and WEs for novice and expert students with at least 1 course of college statistics experience.

Poster Session 2 (Wednesday, 5:00-6:00 PM)

1. **What strategy does the development of ordinality in kindergarteners rely on: Cardinality or sequential knowledge?**

Christian Peake[1], Felipe Sepúlveda[2], M. Inés Susperreguy[3], Laura Espinoza[4], Yovanna Galaz[2], Richard Merino[1], & Antonia Varas[2]
[1]Universidad Diego Portales; [2]Universidad Católica de la Santísima Concepción; [3]Universidad Católica de Chile; [4]Universidad de Los Lagos

It is debated whether the development of ordinal processing relies on cardinal-based or sequential-based cognitive strategies. After studying reversed distance effects (due to the greater difficulty when verifying non-adjacent digits, as 3-5-7) in the triplets verification task in adults, it would be expected that young learners use sequential knowledge at early stages that transit to cardinal-based strategies when solving ordering verifications. We tested this hypothesis in 164 kindergarteners (5 years old) in Chile by applying an ordering task where participants must set the order of three digits, an order verification task, where they must verify the order of triplets of digits, as well as a standardized mathematical task, and a cardinality task and sequential knowledge task. Results from a series of regression analyses showed that young children rely in both cardinal-based and sequential-based strategies when solving ordinal tasks depending on the demand of the task. The ordering task did not show any distance effect, while the order verification task showed a canonical distance effect in the reaction time measure but a reversed distance effect in the accuracy measure. Participants relied more in sequential knowledge to solve the ordering task while the order-verification task showed an unexpected pattern. Children are trying to verify adjacent trials (3-4-5) based on their cardinality knowledge than on their sequential knowledge while the opposite pattern emerges when verifying non-adjacent trials (3-5-7). Task demands determines how kindergarteners solve ordinal processing tasks, showing the opposite pattern found in adults when verifying triplets as a result of numerical development.

2. **Validation of a novel toddlerhood self-regulation measure and examining its relations to preacademic outcomes**

Jorge Carvalho Pereira[1], Leanne Elliott[2], Portia Miller[1], Heather Bachman[1], Elizabeth Votruba-Drzal[1], & Melissa Libertus[1]
[1]University of Pittsburgh; [2]American Institutes for Research

Self-regulation skills often predict academic (Blair et al., 2016) and developmental (Robson et al., 2020) outcomes throughout early and middle childhood. However, evidence suggests these skills begin developing much earlier, specifically during toddlerhood (Gagne, 2017; Kopp, 1982). Direct measurement of toddlers' self-regulation skills is challenging and infrequent. Numerous early self-regulation measures exist, but most are suited only for preschool ages and above (Raikes et al., 2007). The proposed study introduces the Find Bear task, a novel direct assessment of toddlers' self-regulation, which can be completed quickly and remotely. In this task, toddlers see six different images and asked to "find the bear" within a two-minute time limit, where a cartoon bear is hidden in all but the last image. Toddlers' self-regulation during the last image (i.e., the impossible trial) will be indexed by the total time spent persisting on finding the (nonexistent) bear in the final image (i.e., looking at the image) (Mulder et al., 2019; Prykanowski et al., 2018; Wang et al., 2017). To test our new measure's validity, we will examine correlations between self-regulation indices on the Find Bear task and established parent-report (ECBQ-S; Putnam et al., 2006) and researcher-ratings of self-regulation (PSRA; Smith-Donald et al., 2007). We will also examine concurrent relations between toddlers' self-regulation and their number knowledge and expressive vocabulary, measured via an adapted Give-N task (Wynn, 1992) and parent report on the Developmental Vocabulary Assessment for Parents (DVAP; Libertus et al., 2015), respectively. Given our measure's novelty, we do not include a priori hypotheses.

3. **Metacognitive control in arithmetic: A longitudinal exploration of post-error adjustments in 7-9-year-olds**

Eveline Jacobs[1], Elien Bellon[1], & Bert De Smedt[1]
[1]KU Leuven

Monitoring and controlling one's performance are essential skills for children's cognitive development and academic success. Metacognitive control, operationalized as post-error adjustments, is, however, often measured in conflict tasks, and the findings of such studies may not be readily generalizable to academic domains, such as arithmetic. Yet, investigating how children control their performance in arithmetic is crucial in understanding the large individual differences within this specific educational domain. This longitudinal study investigated how

children control their performance through post-error slowing and accuracy improvement in arithmetic. We additionally examined this development of control in a working memory task, to further unravel its domain-specificity or the lack thereof. A cohort of 127 typically-developing children, followed up longitudinally from 7-8 years old (second grade of primary school) to 8-9 years old (third grade of primary school), completed a computerized arithmetic and working memory task at two time points. Meticulous comparison of response times and accuracy rates following errors with those following correct answers revealed the presence of metacognitive control at each time point. We observed significant positive correlations between children's metacognitive control and their monitoring skills as well as their arithmetic accuracy at 7-8 years old, while no such correlations were found at 8-9 years old. This underscores a possible adaptive role of metacognitive control in the learning phase of arithmetic. No correlations were found between the post-error adjustments in the arithmetic task and those in the working memory task, suggesting domain-specificity of metacognitive control in the age range under study.

4. **Math word problem solving: Relation to spatial skill, working memory, and problem type**

Dania Carr[1] & Susan Levine[1]
[1]University of Chicago

Past research has found that verbal working memory (e.g. Swanson & Beebe-Frankenberger, 2004), visual-spatial working memory (e.g. Zheng et al., 2011), and spatial visualization (e.g. Mix et al., 2016) skills are related to math word problem solving in elementary aged students. This study extends previous work by examining the combined influence of these spatial and working memory skills on overall word problem-solving performance as well as comparing the impact of these skills across different types of word problems. As part of a larger study, 230 2nd-grade students completed a set of math word problems in addition to a battery of cognitive tasks. Data has been collected but not yet analyzed. Analysis will be conducted to examine the variance in overall word problem solving performance that spatial visualization, spatial working memory, and verbal working memory explain after controlling for language skills, student gender, and school attended. Further analysis will also be conducted to examine if the type of word problem being solved influences the impact of spatial and working memory skills on performance. Understanding how specific cognitive skills relate to solving various types of word problems will help inform the creation of interventions and curricula that are more effective at improving math word problem solving.

5. **Exploring cognitive foundations of children's numerical development**

Anna Karlsson[1], Kenny Skagerlund[1], Mikael Skagenholt[1], & Ulf Träff[1]
[1]Linköping University

Basic numerical skills in kindergarten serve as predictors for the future arithmetic development. Understanding the variations in children's numerical abilities at school entry is essential [1], particularly in determining why some children are more mathematically prepared than others [2]. Research has explored cognitive factors influencing early differences, revealing contributions from Phonological Verbal Fluency, Rapid Automatized Naming, Nonverbal Logical Reasoning, Verbal Working Memory, General Processing Speed, and Phonological Awareness to young children's numerical abilities (Counting Knowledge/CK; Digit Comparison/DC; Number Line Estimation/NLE).This three-year longitudinal study aimed to investigate changes of the contribution of domain-general (DG) cognitive abilities on children's basic domain-specific numerical skills over time using several regression analyses. The study used von Aster and Shalev's [3] developmental model of numerical cognition and Ackerman's [4] general theory of skill acquisition as theoretical frameworks. Preliminary results: DG accounted for 37%, and 23% variance in CK in Y1 and 2.DG accounted for 33%, and 28% variance in DC in Y1 and 3.DG accounted for 31%, and 22% variance in NLE in Y1 and 3.Conclusion: During development (time), the amount of explained variance decreased and the predictor patterns changed indicating that for the DG cognitive functions Ackerman's theory aligns best with our results.[1] Manolitsis et al. (2013). Early Childhood Research Quarterly, 28(4).[2] Duncan et al. (2007). Developmental Psychology, 43(6).[3] von Aster, M. G., & Shalev, R. S. (2007). Developmental Medicine & Child Neurology, 49(11).[4] Ackerman, P. L. (1988). Journal of Experimental Psychology: General, 117(3).

6. **Exploring the impact of a portfolio of co-designed mathematics interventions that leverage executive functions**

Megan Brunner[1], Karen Douglas[1], Rebecca Merkley,2 Michelle Tiu[1], & Aubrey Francisco[1]
[1]EF + Math Program; [2]Carleton University

Meta-analyses have shown that interventions targeting executive functions (EFs) do not reliably lead to improvements on mathematics (Melby-Lervåg et al., 2016), despite the strong relationship between EFs and math achievement. Mathematics and EFs have reciprocal influences on each other over development

and the causal nature of the relationship remains unclear (Miller-Cotto & Byrnes, 2020; Niebaum & Munakata, 2023; Scerif et al., 2023). Moreover, there have also been recent calls to take a more strengths-based approach to measuring executive functions in diverse populations, in contrast with the deficit-framing that has dominated prior research (Miller-Cotto et al., 2022). Interventions targeting mathematics by leveraging executive functions may be more effective if they are embedded in math instruction and mindful of the individual differences of participating students. The EF+Math program is directly testing this hypothesis by supporting several related, but unique multidisciplinary teams of researchers, developers, and educators to co-create math learning approaches to improve the outcomes of students who have been historically underserved (EF+Math, 2021). While the EF+Math program holds a shared core hypothesis, each R&D team has conceptualized their approach uniquely and have taken different pathways to both development and research. Here we assess what we've learned about the relationship between EFs and mathematics by looking across the unique projects' findings. We will reflect on the process of synthesizing insights across teams, while also honoring individual hypotheses and mechanisms.

7. **Cognitive-linguistic skills and preschool children's development of story problem solving: The sequential mediation roles of three levels of numeracy skills**

Catrina Cuina Liu[1], Xiao Zhang[2], & Wai Ming Cheung[2]
[1]The Hong Kong Polytechnic University; [2]The University of Hong Kong

This study examined the extent to which receptive vocabulary, phonological processing skills, and spatial skills predicted preschool children's development of story problem solving, and whether three levels of numeracy skills sequentially mediated these associations. Using a multi-wave longitudinal design, 210 Chinese children (106 boys; mean age: 41.08 ± 3.43 months at Time 1) in Hong Kong were followed for six time points from the first year of kindergarten (K1) to the third year (K3). Children were assessed on a wide range of cognitive-linguistic skills including receptive vocabulary, phonological processing skills (phonological awareness [PA], verbal short-term memory [STM], and rapid naming), and spatial visualization. Three numeracy skills including basic numeracy skills, quantity to number mapping skills, number relations, and story problem solving were also assessed. Latent growth curve modeling showed that PA, verbal STM, and spatial visualization uniquely predicted the level of story problem solving, and spatial visualization was the only significant predictor of the growth of story problem solving. Furthermore, the three levels of numeracy skills were found to sequentially mediate the associations between cognitive-linguistic skills and story problem solving. The findings have important implications for early numeracy learning and the teaching of story problem solving.

8. **Working with numbers: Does task content influence the measurement of executive functions and their relation to math ability?**

Alexa D. Mogan[1], Nathan T.T. Lau[2], Amelia Murray[1], Monica Bashir[1], & Eric D. Wilkey[1]
[1]Vanderbilt University; [2]Western University

Individual differences in executive functions (EFs), such as working memory, inhibitory control, and shifting behaviors, are associated with math achievement and growth in math skills across development. Though this relation has been documented among multiple EF behaviors and math skills, basic questions remain about the underlying cognitive structure of EF and the context-dependent nature of EF processing. Current models present EFs as a group of "domain-general" constructs and downplay their interaction with lower-level cognition and task-specific processing. However, it is critical to develop a more nuanced understanding of this interaction to understand the relation between EF and math. In this study, we will investigate whether stimulus type (i.e., numerical vs lexical) influences measurement of individual differences in EF, and further, whether stimulus type influences the tasks' relation to math performance. Five-hundred U.S. adults will complete a battery of tasks: EF tasks with numbers and letters (3 EF domains x 2 stimulus types, 6 tasks total), 3 math ability tasks, and numerical magnitude and word recognition control tasks. We will use confirmatory factor analysis to test the hypothesis that lower-level task features provide unique measurement variance to form separable EF factors. We will then use a structural equation model to test whether each factor of the two-factor model (i.e. EF of numbers and EF of letters) differentially relates to math ability as measured by tests of arithmetic retrieval fluency, calculation fluency, and procedural knowledge.

9. **College students' strategy choice in fraction comparison and its relation to math achievement and executive functions**

Ao Fan[1], Roberto Abreu-Mendoza[2], Jo Van Hoof[3], Wim Van Dooran[3], & Miriam Rosenberg-Lee[1]
[1]Rutgers University - Newark; [2]Indiana University; [3]University of Leuven

Fractions pose a significant challenge for many students, and several flawed fraction comparison strategies have been identified. Whole-number-bias-strategy, choosing larger numerals as the larger

fractions, works for congruent comparisons (7/9 vs. 2/3), but not incongruent ones (4/5 vs. 7/9). Reverse-bias-strategy, choosing the smaller numerals, has the opposite outcomes. Another flawed but more sophisticated approach is the gap strategy, choosing the smaller difference between numerator and denominator as the larger fraction (4/5 vs. 7/9). This approach works for all incongruent comparisons but fails for some congruent ones (7/9 vs. 2/3). The prevalence of these strategies among college students is unknown. In the current study, we used a specially designed stimuli set, include a condition where the gap strategy fails, to identify strategy-use among 90 college students. We also assessed overall math achievement, inhibitory control, and working memory, to explore relations between these factors and students' strategy choice. Our cluster analysis revealed three profiles: Whole-Number-Bias group (14%), who always selected the fraction with larger numerals; Partial-Reverse-Bias group (30%), who selected the fraction with smaller numerals when there were no common components; and Gap-Tendency group (56%), who performed well in all conditions, except when the gap strategy fails. Regarding math achievement, inhibitory control, and working memory, the Gap-Tendency group performed better than the Whole-Number-Bias group, but did not differ from the Partial-Reverse-Bias group. Thus, although most college students overcome whole number bias, they still lack a full understanding of fractions, and cognitive factors do not differentiate between users of more sophisticated strategies.

10. Investigating the link between Chinese students' ratio processing system and symbolic fraction comparison

Xiaotong Yi[1], Connie Barroso[1], & Percival Matthews[2]
[1]Texas A&M University; [2]University of Wisconsin Madison

Introduction. Fractions can be challenging to compare, primarily because of a whole number bias interference. Recent research suggests that a ratio-processing system (RPS) might be useful in overcoming this bias (Matthews et al., 2016). However, RPS may be more helpful for solving complex symbolic fraction problems that may be more likely to be impacted by a whole number bias than simpler ones. Here, we test the role of RPS in increasingly complex symbolic fraction comparisons, above and beyond inhibitory control. Method In this in-progress study, we are collecting data from a sample of 60 10-13-year-old Chinese students. Participants are completing nonsymbolic ratio comparisons (RPS), a flanker task (inhibitory control), simple symbolic fraction comparisons (congruent, e.g., ¾ vs ½), and complex ones (incongruent, e.g., ⅙ vs ⅓; ambiguous, e.g., ¾ vs ⅕). Analytic PlanWe propose to run 3 hierarchical linear regression models to separately predict congruent, incongruent, and ambiguous symbolic fraction comparisons. Each model will start with inhibitory control as the independent variable and then include nonsymbolic ratio comparison performance. We hypothesize that inhibitory control will significantly predict each type of symbolic fraction comparison. We expect nonsymbolic ratio comparison performance to significantly predict and explain significantly more variance for complex symbolic comparisons (i.e., ambiguous and incongruent fraction comparisons) beyond inhibitory control, but not predict simpler symbolic fraction comparisons (i.e., congruent fraction comparisons). References Matthews, P. G., Lewis, M. R., & Hubbard, E. M. (2016). Individual differences in nonsymbolic ratio processing predict symbolic math performance. Psychological science, 27(2), 191-202.

11. Numerical activities of daily living in aging adults

Olivia Ewing[1], Sarah Pope[1], & Kerry Jordan[1]
[1]Utah State University

Human numerical cognition is essential for basic activities such as counting and comparing quantities, to more functional aspects such as measuring, remembering important numbers, estimating time, and using money. The processes that contribute to numerical cognition develop in childhood, mature in adulthood, and appear to be impacted by both healthy and non-normative aging. This study aimed to elucidate the impact of aging on both numerical and metacognitive abilities. It was hypothesized in this study that those who exhibit less effective general cognitive abilities (as measured by the Montreal Cognitive Assessment, or MoCA) would also perform worse on the Numerical Activities of Daily Living (NADL-Short version). A second hypothesis of this study was that those with lower MoCA scores would overestimate their performance on the NADL-Short. The current sample of this study is 34 individuals, aged 65 and above, with no clinical diagnosis of dementia. Alongside the MoCA and NADL-Short, participants filled out a broad health history questionnaire, a depression survey, and a subjective measure of memory complaints. The two hypotheses of study were somewhat supported, depending on interpretation of different statistical analyses. Overall, results indicate that those with declining cognitive abilities also scored lower on numerical abilities but did not inaccurately overestimate their abilities.

12. Differential magnitude estimation of big and small ratios

Nicola Morton[1], Sheena Henderson[1], Jacinta Cording[1], & Randolph Grace[1]
[1]University of Canterbury

Depending on the order two quantities are operated on, their ratio can take one of two values: the 'big ratio' of the larger to the smaller magnitude, or the 'small ratio' of the smaller to the larger. Although they are multiplicative inverses, big and small ratios have different metric properties, with the latter being bounded below and above, and the former bounded below only. We hypothesised that due to this distinction, adult human observers may judge the relative sizes of big and small ratios differently. In an online survey we asked 350 participants to evaluate two statements by judging how much more or less likely some event was than another on a 7-point Likert scale. In the first statement, the relative likelihood was expressed as a big ratio, and in the second it was expressed as the corresponding small ratio (with this order counterbalanced). Likelihoods expressed as a big ratio were ranked significantly greater than the equivalent small ratio, though effect size varied with the overall ratio magnitude. Participants were subsequently asked to place 7 small and 7 big ratios corresponding to the relative sizes of U.S. states on an analogue scale. While average scaling of small ratios was linear, scaling of big ratios was best modelled by a logarithmic function. This suggests that participants compared small ratios with differences, but big ratios with ratios. The compressed nature of the subjective big ratio scale may account for the discrepancy found between judgments of equivalent big and small ratios.

13. Examining the role of math talk tips during parent-child shared reading

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Parent-child shared reading can provide valuable chances to promote mathematical language skills in young children (e.g., Purpura et al., 2021), even with storybooks that are not explicitly designed for math learning (e.g., Uscianowski et al., 2020). Intervention studies providing math talk tips have suggested increased parental engagement in math talk during shared reading (Hojnoski et al., 2014). However, there is limited evidence on whether parents can generalize from tips provided for a specific storybook to other learning contexts. The current study employs an experimental design to examine 1) parents' use of math talk tips while reading a storybook for which the tips were specifically designed, and 2) whether parents will extend their use of these tips while reading a wordless storybook with their child one week later. Parent-child dyads (data collection ongoing for n = 80) are randomly assigned to either an experimental condition, in which dyads receive two storybooks along with a bookmark with math talk tips designed specifically for one of the books, or a control condition, in which dyads receive the two storybooks without math talk tips. Dyads complete two reading sessions which will be transcribed and coded for the quantity and diversity of spatial and numerical talk. Repeated-measure regressions will be conducted to compare level and change in math talk for the experimental and control groups. We hypothesize that parents in the experimental group will generate a greater quantity and more diverse math talk compared to the control group, even when reading the wordless book.

14. Is math part of a complete breakfast?: Content analysis of math-based activities on breakfast cereal boxes

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Unlike research on environmental print, less is known about mathematical elements found in everyday environments and how they might support children's math learning. We know from studies on Learning Landscapes that implementing playful STEM-based learning activities in public spaces can foster learning opportunities between caregivers and children, especially those in under-resourced communities (Hassinger-Das et al., 2018; Neumann et al., 2012). One potential source of environmental math that many families interact with is breakfast cereal boxes. For many families in the United States, breakfast cereal is part of their morning routines. Cereal boxes often include activities aimed at children and these activities present opportunities to engage with educational content in a fun and playful manner. Little is known about the current landscape of cereal box activities, so the goal of this study is to assess that landscape by conducting a content analysis of the activities on cereal boxes. We did an exhaustive analysis of 174 cereal boxes in the aisle of a major local grocery store. Initial analysis indicated that approximately 14% of the cereal boxes contained math-based activities and 25% contained reading-based activities. Nearly half of the cereal boxes contained no activities at all. Subsequent rounds of coding will assess the math-based activities for alignment with current math standards and developmental appropriateness. Results from this study will help us better understand the utility of existing math-based activities on cereal boxes and inform future studies on how to leverage cereal box activities as part

of the home math environment.

15. Associations among quantitative and qualitative dimensions of the home math environment and young children's math skills

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The Home Math Environment (HME), defined as caregiver-child math interactions in the home (Hornburg et al., 2021), is associated with children's math achievement (Daucourt et al., 2021) and has quantitative and qualitative dimensions. The former has a large body of literature compared to the latter and research is scarce on how each dimension is uniquely associated with children's math skills. By surveying caregivers of 3- to 5-year-olds (N = 109), we examined the associations among the HME's quantitative and qualitative dimensions and children's math skills. Caregivers reported on children's math skills (Hart et al., 2016) and frequency of direct numeracy, indirect numeracy, and spatial activities (Purpura et al., 2020). Caregivers also were shown four pictures (train station, weather report, recipes, produce stand) and asked what they would talk about with their children (Carrazza, 2021). Qualitative data will be coded for the frequency with which caregivers mention concepts of basic math (counting, written numerals, spatial language) and advanced math (operations, comparing quantities). We hypothesize that frequency of direct numeracy, indirect numeracy, and spatial activities, as well as caregivers' mentions of math will be positively associated with children's math skills. A series of regression analyses will be conducted examining the contribution of each predictor to children's numeracy skills, spatial skills, and math language skills, controlling for parent education, child gender, and child age. Understanding how variables associated with the HME quantitative and qualitative dimensions are related to children's math skills could contribute valuable information on how parents can best support math skills.

16. Fathers' and mothers' reports of their attitudes to and experiences of the home mathematical environment

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This study is for parents of children aged 4-8 years and will examine if individual differences including gender and math anxiety predict differences in parental reports of HME practices. Responding to calls for more research into fathers' roles in the HME, this study aims to redress the imbalance in levels of maternal response reported in previous parental surveys and to deepen understanding of the factors which contribute to variability within the HME and inconsistent findings in pupils' outcomes. Using innovative recruitment to increase fathers' participation, it seeks to enable a more equitable comparison of parental perspectives, how they relate to and differ from each other in frequency and types of activities and the math language used. In keeping with the literature, we hypothesize that mothers and fathers will report differently on their expectation of children's ability and potential and the activities they provide, related to their own and their children's gender. We further hypothesize that there will be gender differences in levels of parental anxiety, engagement, and use of math language. Following survey data collection, multivariate methods will be used to examine the impact of gender and parental anxiety on reports of parental math goals, use of math language and math activities. After initial t-tests and correlations, regression analyses will be carried out to determine which of the independent variables of age and gender of child, gender of parent reporting and parental math anxiety, predict parental reports of types of activities, parental goals and frequency and type of language use.

17. Does parent math anxiety and performance relate to math talk with toddlers?

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The psychological distress when confronted with mathematical tasks or situations can be overwhelming for many adults. For parents, this math anxiety can potentially impact their involvement in their children's math education (Maloney et al., 2015). Parent engagement in Xmath significantly impacts children's academic achievement, such that parents who engage more frequently in math with their children have children who tend to perform better in math (Daucourt et al., 2021). However, most previous work has focused on mothers of preschool- and school-aged children. The current study aims to investigate whether mothers' and fathers' math anxiety correlates with their math performance, and if their math anxiety and math performance relate to their math talk to toddlers. A sample of 388 mothers and fathers from English- and Spanish-speaking families were video-recorded completing remote "picture book" tasks via Zoom. Parent math anxiety levels were assessed through questionnaires, parent math performance was assessed through timed simple arithmetic problems, and parent math talk during the "picture book" task that was coded.

We plan to analyze math anxiety, math performance, and their correlations with math talk separately by parent gender. Additionally, we will run a regression model to observe if they predict math talk uniquely. Altogether, the study will examine how mothers' and fathers' math anxiety and math performance may jointly and uniquely influence parental math talk to toddlers.

18. Enhancing e-book interactions for Latine families and children

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Mathematical knowledge and technology literacy (i.e., e-books) have recently been at the forefront of research and early learning (Rosenfield et al., 2019). Notably, Latine families, an important demographic group understand the importance of technology, but have not been included in research designs to identify key features of what they prefer (Noguerón-Liu, 2017; Casas et al., 2014). Therefore, it is crucial to design interventions for Latine families. The current study sheds light on crucial considerations for optimizing e-book features to support Latine mothers in reading interactions with their children. Data were collected from a pilot study conducted as part of an ongoing intervention study on e-book reading for Latine mothers and their children. The study included (N = 26) dyads with children aged 2-5 (M = 3.8 years, 50% female). A qualitative design was used to identify the e-book features that best support mother-child interaction. A thematic analysis was conducted to analyze the semi-structured questions. Some are the questions that were asked were "What did you like most about the e-book? and Describe your impressions of browsing the e-book." Findings revealed that mothers often perceive technology as challenging to understand, contrasting their familiarity with physical books. This aligns with previous research, indicating that Latine families may view technology as complex (Noguerón-Liu, 2017). Additionally, qualitative data revealed the importance of bilingualism, issues related to text size and story length, and the ease of navigation within the e-book interface, emphasizing the need for tailored interventions to optimize the e-book experience for Latine families.

19. Implementing a tier 2 early numeracy intervention for students with mathematics difficulties

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The goal of this study was to conduct an initial evaluation of an early numeracy intervention for students with MD in first grade. In addition, this study provided support to educators in local school districts to teach mathematics to small groups of students identified as needing intervention due to MD. The purpose of this study was to answer the following research questions: Does the implementation of an early numeracy intervention improve mathematics outcomes for first-grade students identified as students with MD compared to students receiving business-as-usual instruction? Does teacher fidelity mediate the relationship of the impact of early numeracy intervention on student mathematics outcomes? This study implemented a randomized control trial design at the student level, where individuals were randomly assigned to either the treatment or the control group (Spybrook et al., 2011). For student-level effects, standard effect sizes from paired t-tests were calculated to assess standardized intra-individual change from pretest to posttest. The measures that identified changes from pre- to posttest included (a) mathematics achievement tests and (b) progress monitoring data. The analysis included multiple tests using the Benjamini-Hochberg (BH) correction (What Works Clearinghouse, 2020) to identify the efficacy of the early numeracy intervention on student mathematics outcome measures. This study highlighted the positive effect of our Tier 2 early numeracy intervention for first-grade students with MD. This early numeracy intervention incorporated six key instructional practices and three mathematical skills.

20. Embodied-cognition intervention for numerical deficits after a stroke/brain-injury (acalculia)

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Background: Acalculia is an acquired deficit in numerical skills affecting 30-65% of stroke/brain injury survivors. The condition negatively impacts independence (e.g. traveling, managing money, counting medications) and wellbeing. Despite the availability of several assessments, acalculia is not routinely screened for, and a recent systematic review identified only 16 English-language published interventions for acalculia, with a total of N=31 patients. These interventions were all delivered individually (i.e., none utilised group settings), most were tailored to individual patients' deficits (e.g., specific multiplication facts), and interventions largely relied on old-fashioned 'drill' strategies. Methods: A mixed-methods pilot study examining the feasibility of a group-based acalculia intervention designed using the principles of embodied-

cognition (i.e., combining congruent physical engagement with cognitive concepts). Patients (N=4) took part in six-weekly 45-minute group sessions involving playful activities with numbers designed to encourage congruent movements. Following a 4-week break, N=3 took part in three further sessions. Performance on number skills (theoretical and functional) was collected before the intervention (T0), after six weeks (T1) and after further three weeks (T2). Qualitative data were collected 3-months post-intervention using semi-structured interviews with two patients. Results: Substantial improvements were observed on all measures at both T1 and T2. Qualitative findings emphasized the importance of group-settings, and the impact of playful learning on cognition, engagement, and wellbeing. Discussion and conclusions: Playful group therapy integrating modern educational theories is feasible and provides early efficacy data showing improving numerical skills and wellbeing. Future work should evaluate more accurately the relation between changes in movement, cognition and wellbeing.

21. Manipulating money in math: (Whom) does it help?

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Math manipulatives are suggested to enhance learning outcomes (Carbonneau et al., 2013), and bridge abstract concepts with real-world scenarios (Moch, 2008). Their effect appears to vary across student's prior language and math achievement levels (Bresser, 2009, Moyer-Packenham, & Suh, 2012). Our study aimed to further investigate these effects using real money during math problem-solving and considering potential gender effects known to influence performance in measurement related math problems (e.g., Vasilyeva et al. 2009; National Center for Educational Statistics, 2004). Participants included 97 3rd graders (59 girls, age: M = 9.45, SD = 0.54) who had previously taken a national standardized achievement test (prior achievement in math and in language). Students solved money-related math problems with and without money (condition) in a between-subject design. After the initial assessment, students participated in a 45-minute training session on money decomposition and interactive coin activities (day 1), followed by a repeated assessment the next day (day 2). Repeated Measures Anova controlling for socioeconomic status revealed no effect of condition on students' problem-solving performance, but a significant day × condition interaction ($p = .047$). Condition did not interact with prior achievement, but we observed a marginal triple interaction of day × condition × gender ($p = .052$). The manipulation of money generally interfered with performance before the training and training improved performance in both gender groups. However, boys profited more from the training, such that the detrimental effect of manipulating money tended to disappear in boys on day 2.

22. The impact of an adaptive math learning tool focused on improving number sense a longitudinal study on NY District grade 1-3 students

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The successful acquisition of mathematical competencies is a complex and multifactorial process. A large body of evidence suggests that the acuity of a non-symbolic, approximate number system (ANS) is an important precursor of more formal math achievement. Other studies highlight the importance of a good mastery of number and other mathematical symbols. While the jury is still out on which of these factors represents the most pivotal factor, most researchers converge on the idea that the mental representation of numerical magnitude is spatial and hence suggest harnessing this knowledge in the way mathematical education is presented. In this study, we wish to examine the effectiveness of an adaptive math-learning tool, which is based on five notions that have emerged from the literature. (1) Visualizing numerical information in space; (2) Refinement of the approximate number sense (ANS) by training with non-symbolic quantities; (3) Explicitly associating numerals with the corresponding set size; (4) Reinforcing the notion of abstractness of numerical information; (5) Reinforcing the relational characters of mathematical symbols. Thirty classes from the New York district (approximately 900 students in grade 1 to 3) will use this learning tool for 6 weeks with a minimum of 1h30 per week while another 30 classes will use the programming application Scratch (Scratch - Imagine, Program, Share (mit.edu)). We expect students having trained using the adaptive math-learning tool to improve on both symbolic and non-symbolic number abilities compared to the control group.

23. Failure attributions and the development of math anxiety

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Math anxiety (MA) is a prevalent negative emotion with serious negative consequences for math learners

(Ramirez et al., 2018). Research shows that learners' attributions of their academic failures can induce certain state emotions (Graham, 2020). However, minimal research has examined the role of failure attributions in the development of MA. In the present study, we explored the developmental associations between MA and failure attributions in math, particularly among low achievers who are more likely to develop MA. MA, four sources of failure attributions (lack of effort, lack of ability, having a bad teacher, and task difficulty), and math achievement data were collected from a sample of 96 5th – 7th graders in the U.S. at T1. MA was assessed at T2 between 7-25 months after T1 (varied due to pandemic). Multiple regression was used to predict MA at T2 using T1 failure attributions, math achievement, and their interactions while controlling for grade level, gender, and T1 MA. Failure attributions to difficult math tasks predicted later MA. The interaction between effort attribution and math achievement was also significant, with low math achievement more strongly predicting the development of MA at low levels of effort attribution. Therefore, modifying the ways in which students view their math struggles has important implications for MA development. Graham, S. (2020). An attributional theory of motivation. Contemporary Educational Psychology, 61, 101861.Ramirez, G., Shaw, S. T., & Maloney, E. A. (2018). Math anxiety: Past research, promising interventions, and a new interpretation framework. Educational psychologist, 53(3), 145-164.

24. Examining the role of spatial, affective, and mathematical processes and gender in postsecondary precalculus

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The introductory calculus sequence is a barrier for many undergraduate students aiming to pursue a STEM major program, with women showing greater attrition from the sequence than their men counterparts. Research indicates that both cognitive and affective factors play a role in STEM learning and achievement (Atit et al., 2020), however, the relations between these factors pertaining to undergraduate mathematics achievement are not well understood. This study examines the relations between three factors found to influence mathematics learning and achievement (i.e., spatial skills, spatial anxiety, and math anxiety; Delage et al., 2021), and identifies how they vary by gender using data collected on 820 undergraduates enrolled in precalculus. T-tests reveal gender differences in spatial skills, spatial anxiety, math anxiety, and precalculus achievement with women showing higher spatial and math anxiety, and lower spatial skills and precalculus achievement. Regression analyses indicate that after controlling for general anxiety and gender, spatial skills and spatial anxiety contribute to math anxiety, but only math anxiety is significantly associated with precalculus achievement. Additionally, spatial anxiety mediates the relation between gender and math anxiety, and math anxiety mediates the relation between gender and precalculus achievement suggesting that differences in spatial anxiety help explain why women exhibit higher math anxiety, and that differences in math anxiety help explain women's underperformance in postsecondary precalculus. These results enhance our understanding of the factors contributing to gender differences in postsecondary mathematics outcomes and will inform efforts aimed at bolstering the retention of women in STEM major programs.

25. Can a workshop for high school teachers influence their attitudes and beliefs, ultimately impacting both teachers' and students' classroom nervousness about maths?

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Teachers' attitudes toward maths, such as growth or fixed mindset and gender stereotypes, can potentially impact students' maths anxiety and achievement, particularly among female students. This study aims to: 1) to scrutinise the association between secondary school teachers' beliefs about maths and students' maths anxiety and achievement, and 2) to assess the efficacy of a maths anxiety workshop in influencing teachers' beliefs about maths and students' maths anxiety and maths achievement. We will recruit a sample of 300 students and their teachers in mathematics and related fields, such as physics and chemistry. At the baseline, students and teachers will respond to measures assessing socio demographic information, maths anxiety, maths achievement, and teachers' awareness of maths anxiety. Then, teachers will participate in a single session of the "Teachers' Maths Anxiety Classroom Management Programme" (Santos, 2022). Following a four-month interval, participants will respond to the same measures employed at the baseline. As for the first research question, regression models analysing baseline data will be employed, with students' maths anxiety and achievement as dependent variables and teachers' maths beliefs as independent variables. These analyses will account for factors such as gender, age, teaching

experience, workload, and other relevant variables. To explore the second research question, we will conduct a comparative analysis of the performance of both students and teachers at baseline and post-test, employing ANOVA models to assess variations across the variables of interest. The findings plausibly will highlight the influence of teachers' attitudes on students' mathematical experiences and effectiveness of target interventions.

26. The development and pilot testing of Math Lions: a math anxiety intervention for children

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Math anxiety is prevalent even among children in early elementary school (Ramirez et al., 2013). In this study, we developed and pilot tested a math anxiety intervention for children based on materials from Passolunghi et al. (2020) and cognitive behavioral therapy principles. The intervention includes discussions of emotions and anxiety, physiological responses to anxiety, strategies for addressing anxiety, helpful and unhelpful thoughts, and exposure to anxiety-producing math situations. Thirteen children aged 7-9 were screened in for moderate-to-high math anxiety on a 3-item screener. They were administered the intervention in the lab individually. We assessed math anxiety (Ganley & McGraw, 2016) before and after the intervention and gave a survey to the children after each of four visits. Our results showed an average decrease in math anxiety of -.10 on a 1-4 scale, which was not statistically significantly different from 0 (d=.17, p=.56). However, some children had fairly low math anxiety on the full scale at pretest and, when excluded, the average decrease in math anxiety was -.28 (d=.40, p=.32), however, there was a lot of variability across children. Children felt the intervention activities were fun (3.86 on 1-4 scale), not difficult (1.63 on 1-4 scale), and that they made them somewhat less nervous (2.96 on 1-4 scale). These findings suggest that children felt positively about the intervention and that it was potentially effective for higher math-anxious children. We are currently developing a better screener and revising to the intervention to be appropriate for small groups and to address child feedback.

27. The influence of anxiety on the intersecting perception of space and time

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Significant evidence supports that our perception of number, time, and space are closely intertwined (Walsh, 2003). A separate body of research has demonstrated that anxiety can independently influence our temporal (Sarigiannidis et al., 2020) and spatial perceptions (Graydon et al., 2012). This study aims to examine how anxiety influences the relationship between spatial and temporal perception. We plan to recruit 62 participants, half of whom will meet the criteria for an anxiety disorder. While in a virtual reality environment, participants will judge the physical displacement of a stimulus or the temporal duration over which said stimulus moved. Participants will undergo 162 trials. In 81 trials, participants will be shown a photo intended to induce anxiety before observing the stimulus and making their subsequent judgments. The remaining 81 trials will be neutral, preceded by a black screen. Ratio scores will be calculated to compare reproduced and actual values of spatial displacement and temporal duration. These data will be analyzed using a linear mixed effects model with a 2x2x2 factorial design, including factor type (time vs. distance), group (anxiety vs. control), and experimental condition (anxiety induction vs. neutral). A within-between ANOVA will be used to analyze the strength of this relationship in both conditions. We anticipate that the anxiety group will demonstrate more significant distortions in temporal and spatial perceptions in both conditions compared to the control group and that the distortions observed in the control group in the anxiety condition will resemble those of the anxiety group in the neutral condition.

28. Does math confidence mean math ability in school-aged girls?

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The present study explored relationships between students' math self-efficacy (SE) scores, performance, and error types made. This study aimed to answer the following: 1) Is there a relationship between children's math SE and math performance? 2) What error types were consistently made? 3) What is the relationship between grade levels and error types made? Participants (N=20) completed a Math SE questionnaire, a Math Computation measure (MCOMP), and a Math Problem-Solving measure (MCAP) corresponding to grade level. Students were asked to read each statement and write the number corresponding with

their confidence about the statement. A correlational analysis found that children's math SE did not correlate with MCOMP scores, r(18)=.060, p=.802, or MCAP scores, r(18)=-.063, p=.792. Descriptive statistics found that the most common errors were overgeneralization (N=19, M=9.42, SD=8.002), not knowing basic number facts (N=17, M=4.18, SD=4.187), and not knowing math terms (N=16, M=1.62, SD=.885). An ANOVA found that sixth-graders made more overspecialization errors, F(3,9)= 8.699, p=.005.This study found no correlation between math SE and math performance. The findings suggest that students made more conceptual and factual errors. This analysis will aid in determining resources to help math teachers track errors and ensure students understand mathematical concepts. Future research should employ a longitudinal design to examine changes in math errors, SE, their relationship over time, as well as communalism in the home and classroom environment.

29. The role of gesture that accompanies instruction of a statistical concept: Computational versus conceptual approaches

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Standard Deviation (SD) is fundamental for understanding data distributions (Chan & Ismail, 2013) but presents significant learning challenges (Huey et al., 2018). This research explores the influence of instructor gestures in web-based mathematics education for adults learning about SD. SD can be taught computationally (focusing on a formula) or conceptually (focusing on the underlying relationship between the mean, the shape of the distribution, and the frequency of data points). These approaches engage different types of representations, resulting in different learning outcomes, with students often excelling in computational tasks but struggling with conceptual questions (Papaphotis & Tsaparlis, 2008; Nurrenbern and Pickering, 1987). Research has shown that adults gesture when explaining statistical concepts (Parrill, et al., 2019; Son et al., 2018), and that instructor gesture can influence math learning (Alibali & Nathan, 2008). This study explores the impact of instructors' gestures while explaining SD. We ask whether 1) conceptual versus computational instruction improves SD understanding; 2) the impact of gesture has differential effects for the two kinds of instruction. This is a work in progress. Adults complete a pretest-instruction-posttest protocol. The pretest and posttest ask whether means and SD change as a function of altering data distributions. The participants are randomly assigned to 4 conditions: computational instruction with/without pointing gesture and conceptual instruction with/without spatial gesture. We expect participants to benefit more (1) from instruction with gesture than without gesture and (2) from conceptual than computational instruction, with (3) the highest level of learning occurring after conceptual instruction with gesture.

30. Cognitive and academic profiles of students with and without math learning difficulties

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The purpose of this research was to compare the cognitive and academic profiles of seventh-grade students with and without mathematics learning difficulties (MD). The data were collected as part of larger study identifying key mechanisms that underlie pre-algebra competence (R324A220268). The participants were 134 seventh-grade students from four middle schools in a midwestern state and one middle school from a southern state. Of the those, 78 students were identified with MD (<25th %tile) and 56 students (35th-75th %tile) without MD were identified based on their performance on an on-grade level screener. Students were assessed on working memory, cognitive flexibility, inhibition, processing speed, language, and foundational mathematics skills. Their parents completed a behavioral rating form of attention. Data analysis is ongoing with no preliminary findings to report at this time, but findings will be presented and discussed in terms of cognitive strengths and weaknesses of students with MD compared to those without MD and implications for instruction/intervention.

31. Strategy choices and common errors in fraction and decimal number line estimation tasks among upper elementary students

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Background and Aim: The study aimed to identify the sources of difficulty in understanding rational numbers by analyzing students' strategy choices and the accuracy of their marks in the number line. Sample and Method: Fifth and sixth graders(n=96) completed the three versions of number line estimation (NLE) task with natural numbers, fractions, and decimals on a computer. For fractions and decimals, students estimated their locations on the 0-1 number line by choosing one strategy among three options: 1) benchmark, 2) transformation, and 3) segmentation (only fractions) or rounding (only decimals) strategy. The

physical locations of 24 target numbers in each version corresponded to each other on the 0-1000 or 0-1 number lines (e.g., natural number=650, fraction=13/20, decimal=0.65). Fraction target numbers comprised 12 problems with one-digit and two-digit denominators each, and decimal target numbers comprised 21 three-digit decimals (e.g., 0.286) and 3 two-digit decimals (e.g., 0.85). Results: Students were least precise at estimating decimals, fractions, and natural numbers on the number line (PAEs: 8.31, 5.82, 4.34). The item analysis revealed that the lowest precision in estimating decimals was mainly derived from errors in interpreting the magnitudes of two-digit decimals. The most frequently selected strategy was the rounding strategy (35.4%) for decimals and the segmentation strategy (38.0%) for fractions. Interestingly, Students were more likely to adopt the transformation strategy when estimating two-digit denominator fractions vs. one-digit denominator fractions (34.8% vs. 29.3%). Conclusions: The findings indicate the critical role of place-value in understanding decimals. They also suggest that students make adaptive strategy choices based on problem features.

32. Inhibition of the "add zero(s)" heuristic is needed to multiply by 10, 100, 1000 decimal numbers: A developmental conflict adaptation paradigm study

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Introduction: Growing evidence shows that mathematical learning relies not only on mastering the appropriate rules, but also on inhibiting heuristics that might prevent students from applying these rules. We investigate whether the process of multiplying by 10, 100 or 1000 decimal numbers requires to inhibit the “adding zero(s) after the last digit” heuristic. Methods: 49 adults (aged 18-40 years, Mage = 32.5±6.6 years) and 34 adolescents (7th to 9th grade, Mage = 14.2±0.9 years) were included. We designed a conflict adaptation (CA) paradigm task involving 72 prime-probe trials. Primes and probes consisted of multiplications by 10, 100 or 1000 of integers or decimals. Results: Analyses on the probes show that participants were faster and more accurate to multiply by 10, 100 or 1000 integers than decimal numbers. Also, the difference in RTs between the two types of probes was larger following primes that required to multiply integers by 10, 100, 1000 than following primes that required to perform similar operations on decimal numbers; reflecting the CA effect. Finally, this CA effect was more pronounced in adolescents than adults. Conclusions: Adolescents, and to a lesser extent adults, should inhibit the “adding zero(s) after the last digit” heuristic when multiplying decimals by 10, 100, 1000, which could explain why such multiplications are more difficult than similar ones on integers. This finding suggests that to avoid errors, students need to be aware that such errors stem from the “adding zero(s) after the last digit” heuristic and that this heuristic needs to be inhibited.

33. Towards a cognitive archaeology of mathematics in the American southwest

Alma McKown[1,2]
[1]Albuquerque Public Schools; [2]Central New Mexico Community College

The mathematical practices of the Ancestral Pueblo people, who inhabited the American Southwest from 500 BCE to 1350 CE, are understudied in scholarship. Mathematical cognition and practices have been extensively analyzed in the material culture of many other prehistoric societies notably. This interdisciplinary study aims to fill this gap by examining units of measurement in Southwestern archaeological sites and comparing local results to cross-cultural anthropology literature on the cognition and history of measurement. Using archaeological site maps, I will incrementally divide the lengths of exterior walls in communal architecture, a process known as 'quantum coupling.' Whole number divisions may indicate potential units of measure if statistically significant. Results will be compared with cross-cultural literature, using the Human Area Relation Files as ethnographic sources to explore units of measurement across temporal and geographic spaces. Investigating non-perishables, such as architecture, in the archaeological record is crucial for understanding prehistoric cognitive processes, often called cognitive archaeology. Inspired by ethnomathematics praxis and mathematics education literature, this project advocates for new interdisciplinary research into Indigenous mathematical practices, particularly in the American Southwest. Such research is essential for achieving curricular equity in math classrooms and examining the legacy of colonialism within mathematics history and education.

34. Understanding the complexity of preschool teachers' math knowledge: Insights from decontextualized versus scenario-based assessments

Jiwon Ban[1] & Elida V. Laski[1]
[1]Boston College

Teachers’ knowledge, especially relating to pedagogy and early mathematical content knowledge, has shown to be positively associated with students’ outcomes (Campbell et al., 2014; Hill et al., 2005; McCray & Chen, 2012). This current study examined preschool teachers’ knowledge early math development (i.e., ability to

recognize concepts that are considered appropriate milestones of math learning). Pre- and in-service teachers (n = 83) completed a survey in which they were asked to identify whether particular math skills can be observed in typically-developing four-year-old students in the US. Specifically, teachers were presented with two scales: one, a decontextualized list of learning trajectories (adopted from Douglas, 2023), and two, a situated, scenario-based instrument with the milestones embedded in the context of children's learning (adapted from Torbeyns et al., 2020). Analysis of accuracy scores highlighted differences in teachers' knowledge of early math development—their performance across the two measures varied, depending on the domains of mathematical thinking (i.e., numeracy, patterning, and geometry) and teacher characteristics (e.g., amount of professional development (PD), years of experience, student perceptions, etc.). As predicted, teachers with higher levels of PD were more accurate on the decontextualized measure; however, and surprisingly, the pattern was reversed for vignettes. Furthermore, this relation was more apparent when accounting for just in-service teachers. In line with prior work, the current study suggests that while teacher characteristics predict teachers' knowledge, there are significant differences when context is considered. Implications for pre-service teacher education and in-service professional development are discussed.

Poster Session 3 (Thursday, 1:00-2:00 PM)

1. **Instructional framing and math performance: The relevance of state and trait math anxiety**

Thomas Hunt[1] & Eric Steiner[2]
[1]University of Derby; [2]National University

The negative correlation between math anxiety and math performance is well established. Instructional framing, i.e., how instructions are worded, can also affect math performance. The current online study examined instructional framing and math anxiety on math performance simultaneously. State and trait math anxiety were measured via a one-item visual-analogue scale and the Mathematics Anxiety Scale–UK (MAS-UK; Hunt et al., 2011) respectively. Math performance was assessed using the Brief Mathematics Assessment-3 (BMA-3; Steiner & Ashcraft, 2012). Across three countries (UK, USA, Romania), 503 participants (358 women, 139 men, 6 nonbinary/undisclosed) were randomly assigned to one of three instructional framing conditions: challenge (encouraging), threat (anxiety inducing), and control (neutral). No significant interaction between trait math anxiety and instructional framing was found. Higher trait math anxiety and an increase in state anxiety were significantly negatively related to performance. However, the latter result was only present for the low trait math anxious group and appears to be driven by the threat-based instructions. The findings highlight the complex interplay between state and trait math anxiety and the negative impact of threat-based instructional framing on math performance.

2. **Time pressure predicts negative cognitive and affective outcomes in mathematics**

Raeanne N. Martell, Alexander Avdellas, Ava Cobarrubias, Vincent Miller[1], Howard Tai[1], & Ian M. Lyons[1]
[1]Georgetown University

The use of time pressure in the classroom, especially in mathematical contexts, has long been a source of debate among researchers and practitioners. To date, the research this debate has sparked has tended to focus on time pressure's relationship with cognitive performance. Very little of this research, however, has investigated how time pressure might affect other important outcomes, such as in-the-moment feelings of anxiety or self-efficacy. The current study examines the relationship between time pressure and 3 primary outcomes: (1) performance on a mental-arithmetic task, (2) state anxiety ratings, and (3) post-task self-efficacy ratings. Participants completed mental arithmetic under both time-pressure (TP) and non-time-pressure (NTP) conditions. (1) Results revealed that performance on the mental-arithmetic task was worse in the TP condition, even after adjusting for guessing and speed-accuracy trade-offs. (2) Results also showed that participants reported feeling more anxious after the TP relative to the NTP condition. (3) Results provided evidence that participants reported lower self-efficacy in the TP condition. When exploring these same outcomes for a verbal working memory task, a similar pattern of results was identified. Overall, these results indicate that exposure to time pressure may have negative effects with respect to cognition and affect. These results also suggest that the effects of time pressure may not be domain-specific, but may in fact be more widespread. This implies that, in addition to performance, we should also consider how time pressure relates to other constructs, such as state-level anxiety and self-efficacy across a variety of domains.

3. **Tactile bilateral stimulation for math anxiety: A pilot study**

Leyla Karami Isheqlou[1], Tori Dehlin[1], Cassey Ivie[1], & Kerry Jordan[1]
[1]Utah State University

Abstract Tactile Bilateral Stimulation (TBS), a non-invasive intervention to manage stress and anxiety, reduces brain activity in the salience network (SN) [1]. A pattern of increased activity during emotional processing in SN structures like the amygdala has been shown in individuals with high trait anxiety [2] and high math anxiety (HMA) [3], a negative reaction to math-related situations. Tactile stimulation effectively reduced anxiety on a mathematics test in a healthy/typical population [4]. This pilot study will investigate the effectiveness of TBS on math anxiety by recruiting thirty college students with HMA, with half receiving the mind-body TBS (Brainsculpt) for 15 minutes prior to performing a two-digit addition task. Pretest and posttest stress levels will be measured. Group differences in stress and task performance will be analyzed. This research ultimately aims to identify effective interventions for HMA individuals, reducing stress and improving math performance. References [1] Serin, A., Hageman, N. S. & Kade, E. The Therapeutic Effect of Bilateral Alternating Stimulation Tactile Form Technology on the Stress Response. J. Biotechnol. Biomed. Sci. 1, 42–47 (2018). [2] Stein, M. B., Simmons, A. N., Feinstein, J. S. & Paulus, M. P. Increased Amygdala and Insula Activation During Emotion Processing in Anxiety-Prone Subjects. Am. J. Psychiatry 164, 318–327 (2007). [3]

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4. **MotivUP: An innovative application to assess students' motivation for mathematics**

Kamila Schulz[1], Christian Peake[1], Yovanna Galaz[1], Matias Rojas[1], Diego Esperidion[1], & Sara Caviola[2]
[1]Universidad Diego Portales; [2] University of Padova

The following research aims to develop an application to measure motivation for mathematics. This application is intended to be an easy-to-use and feasible tool for teachers: MotivUP. It is based on the Expectancy-Value-Cost Model of Motivation (Barron & Hulleman, 2014). This model allows for understanding and improving student motivation. By taking into consideration the beliefs that students have about their ability to succeed (expectancy), the desire to participate in the task (value), and the perceived effort (cost), will allow a better understanding of motivated cognitions and behaviors to promote math learning. Furthermore, measures of motivation are often not validated in different academic contexts or are not always practical to be applied in classrooms and immediately (Kosovich et al., 2014). The objective of this study is to validate this theoretical proposal in children from kindergarten through 6th grade (expected N = 630, N = 90 in each cohort). In MotivUP, students are asked to rate how much they agree or disagree with the statements presented, on a continuous scale (from 0 to 100). Their scores will serve to compute a motivational factor to inform teachers about the motivation their students show for mathematics, for better decision-making to impact the mathematics learning context positively.

5. **Investigating the effects of classroom-based mindfulness on math anxiety: Does improving emotional regulation enhance math performance?**

Anna George[1], Nadine Yildiz[1], & Darcy Hallett[1]
[1]Memorial University of Newfoundland

Pre-registration: Evidence suggests that up to 25% of children experience moderate to high levels of math anxiety (MA) which typically persists into adulthood. Previous studies have addressed situational and external factors contributing to MA; however, a gap exists regarding emotional aspects and interventions targeting MA. Mindfulness, a technique focusing on non-judgmental awareness of present-moment experiences, has shown promise in reducing anxiety and improving emotional regulation, potentially benefiting individuals with MA. Classroom-based mindfulness programs have demonstrated positive outcomes in emotional control and math grades among students. However, the specific mechanisms through which mindfulness affects MA and math performance remain unclear. The study aims to explore the mediating role of emotional regulation in a mindfulness program designed to alleviate MA and enhance math performance among fifth-grade students. It hypothesizes that mindfulness training will enhance emotional regulation, either through reappraisal or extinction mechanisms, leading to improvements in MA and/or performance. Method: A randomized controlled trial will be administered with classes assigned to either a MindUp mindfulness program or a Relaxation control condition. Math performance, MA, emotional regulation, and general anxiety will be assessed at 4 time points during the course of a school year. Statistical approach: Using a time-lagged analysis, changes in emotion regulation in between earlier time points will be used to predict changes in math anxiety and math performance between later time points in a proposed mediation model where emotion regulation changes predict changes in MA and math performance.

6. **Mathematics anxiety and number processing: The link between executive functions, cardinality, and ordinality**

Kenny Skagerlund[1]
[1]Linköping University

One important factor that hampers children’s learning of mathematics is math anxiety (MA). Still, the mechanisms by which MA affects performance remain debated. The current study investigated the relationship between MA, basic number processing abilities (i.e., cardinality and ordinality processing), and executive functions in school children enrolled in grade 4-7 (N = 127). Children were divided into a high math anxiety group (HMA; N = 29) and a low math anxiety group (LMA; N = 31) based on the lowest quartile and the highest quartile. Using a series of ANOVAs, we find that highly math anxious students do not perform worse on cardinality processing tasks (i.e., digit comparison and non-symbolic number sense), but that they perform worse on numerical and non-numerical ordinality processing tasks. We demonstrate that children with high MA show poorer performance on a specific aspect of executive functions – shifting ability. Our models indicate that shifting ability is tied to performance on both the numerical and non-numerical ordinality processing tasks. A central factor seems to be the involvement of executive processes during ordinality judgments, and executive functions may constitute the driving force behind these delays in numerical competence in math anxious children.

7. **How do metacognitive experiences and math anxiety predict mathematical problem solving?**
Daniel Scheibe[1], Alissa McGill[1], Sharon Jaramillo[1], & Clarissa Thompson[1]
[1]Kent State University

When people solve math problems, their accuracy may be affected by their metacognitive processes and math anxiety. Recent research proposed that these constructs interact to predict problem solving accuracy. The current preregistered study is the first step to experimentally test components of the regulated attention in mathematical problem solving framework (RAMPS; Scheibe et al., 2023). Informed by a preregistered power analysis, we are currently collecting a sample of 340 adults in the United States through the online service Prolific. Participants are randomly assigned to one of four conditions in a fully-crossed design: 2 [metacognitive judgments or no metacognitive judgments] X 2 [math anxiety probes or no math anxiety probes]. Participants either complete math–fraction arithmetic and word problems–either paired with or without metacognitive judgments. Additionally, participants either are interrupted by four math anxiety probes during the math tasks or complete the math without probes. Our preregistered predictions are that (a) participants who complete the math problems paired with metacognitive judgments will be more accurate on the math problems, report less math anxiety at posttest, and report higher math self concept at posttest compared to participants who do not make metacognitive judgments, and (b) math anxiety probes will not affect math performance, posttest math anxiety, or posttest math self-concept. The aims of the current study are to elucidate the relations between metacognitive experiences, math anxiety, and math performance and to provide quantitative data on possible effects of administering math anxiety probes throughout a research design.

8. **The gender gap in math anxiety (and in a link between math anxiety and math performance too) is not so salient when other anxieties are controlled for**
Monika Szczygieł[1] & Mateusz Hohol[1]
[1]Jagiellonian University

Math anxiety (MA) is considered to affect math performance and choosing math-related education paths, contributing to a gender gap in STEM careers. Despite decades of research, the mechanisms driving associations between MA, gender, and math performance remain largely unknown. This is mainly because different kinds of anxiety are rarely controlled in MA-related studies. To fill this research gap, we collected assessments of MA, spatial anxiety, emotional stability, state anxiety, test anxiety, and math performance from 269 adults. We replicated the findings that spatial anxiety in areas of navigation and mental manipulation, but not imagery, mediates the relationship between gender and MA. What is important in light of previous contradictory findings is that we found that math performance significantly mediates this relationship. Most crucially, we found that gender, spatial anxiety, emotional stability, state anxiety, test anxiety, and math performance explain 70% of the variation in MA. We conclude that the gender gap in MA, frequently reported in the literature, is not so salient when other anxieties are controlled for. The same holds regarding the link between MA and math performance.

9. **Analysis of errors in student work on elementary fraction assessments**
Gabriella Lyth Donofrio[1], Emily Singell[1], Allison Dennis McClure[1], & Megyn Martin[1]
[1]University of Missouri at Columbia

A key component of data-based individualization is diagnostic assessment. A gap exists in the research and resources available to conduct diagnostics, particularly those that can be used by practitioners to inform instruction. The purpose of this study is to code a set of fraction measures for error patterns to inform a future study. Findings will serve to guide future work analyzing teachers' ability to diagnose errors in fraction problems and subsequently identify corresponding appropriately targeted instruction, modeled after a 2005 study by Riccomini (Riccomini, 2005). Fraction items from measures gathered as a part of Project SCALE (Scalability, Capacity, and Learning Engagement for Fraction Face-Off) will be analyzed. Problems that fit the criteria for demonstrating written student work will be grouped by type. Analyses of error patterns by type will first be conducted to identify solution pathways (or how individuals choose to solve problems that have more than one approach). Next errors will be coded by their stages (the steps within a solution pathway), followed by the stage wherein the error occurred. Results for each problem type will indicate 1) the identified solution pathways and frequency, 2) the frequency of error within each stage of a given solution pathway (Hwang and Riccomini, 2021), and 3) the most common error patterns within each problem type. Data will be analyzed during the Spring semester of 2024. Results will include the types of error patterns identified, as well as implications for future research and practice as they relate to practitioner utility.

10. **Math instruction that includes gesture improves learning for deaf and hearing children when gesture is simultaneously produced with language**
Zena Levan[1], Nina Semushina[1], Ruth B. Church[2], Naureen Hemani-Lopez[1], & Susan Goldin-Meadow[1]
[1]University of Chicago; [2]Northeastern Illinois University

Math instruction with gesture has been shown to improve mathematics learning and reduce gaps in math understanding between children with few vs. many resources, promoting math learning for all. Deaf children are minoritized students who show underperformance in mathematics. Two questions have not been asked in previous research: (1) Would instructional gesture influence learning in the same way when accompanying a manual language, like ASL? (2) Does gesture have to be temporally synced with language to impact learning? This research determined whether gesture in math instruction: (1) improves learning for both deaf and hearing individuals, and (2) enhances learning when it is temporally synchronized with accompanying language (English or ASL). The concept taught was mathematical equivalence: understanding what the equal sign means. Deaf (49) and hearing children (134) aged 6-11 years old participated. Each child was randomly assigned to watch one of 4 video instructions expressing correct ways solve problems (e.g., 3+4+5=__+5): (1) language simultaneously occurred with gesture, (2) language occurred before gesture, (3) language occurred after gesture, and (4) language occurred without gesture. Children participated in a pretest-instruction-posttest design. Instruction significantly improved learning from pretest to posttest: (CI = 0.05 – 0.18, $p < 0.001$, mixed effect binomial regression). Language instruction with simultaneous gesture conferred the greatest learning advantage (CI = 1.11 – 163.12, $p < 0.05$) and the effect was significant for both deaf and hearing children. Gesture improves learning across diverse groups of children, particularly when it is simultaneously produced with either speech or sign.

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11. Kindergarten students' motivation: Linked to general mathematical knowledge but not to their performance on a tablet-based math game

Felipe Sepulveda[1,2], Antonia Varas[1], & Christian Peake[3,4]
[1]Universidad Católica de la Santísima Concepción; [2]Núcleo Milenio para la Ciencia del Aprendizaje (MiNSoL), Chile; [3]Universidad Diego Portales; [4]Núcleo Milenio para el Estudio del Desarrollo de las Habilidades Matemáticas Tempranas (MEMAT)

Deci and Ryan's Basic Psychological Needs Theory posits that fulfilling students' intrinsic needs for autonomy, competence, and relatedness is essential for academic motivation and success. This study aimed to evaluate the link between these psychological needs and kindergarten students' mathematical knowledge and their performance on a tablet-based numeracy game. Data from 292 students across 11 Chilean schools were analyzed using adapted scales for psychological need satisfaction and the Woodcock-Muñoz IV Achievement Tests for mathematical understanding. A beta version of a tablet-based software designed for practicing early numeracy skills was employed to evaluate students' proficiency in number identification and cardinality. The results demonstrated that students' levels of autonomy and competence were significantly positively correlated with their overall mathematical knowledge ($r = .410$). However, these levels did not significantly correlate with achievement in number identification and cardinality tasks. When considering general mathematical knowledge as a categorical variable, it was observed that students with higher levels of autonomy and competence markedly outperformed those with medium and low levels on a general mathematical knowledge test ($p < .001$, $\eta^2 = .054$). Nonetheless, no variations were noted in the performance of early numeracy skills when categorized by levels of autonomy and competence, with general mathematical knowledge controlled as a covariate. These findings offer new insights into the application of Basic Psychological Needs Theory at this educational level and its potential to explain student achievement. Yet, the evidence regarding the association between autonomy, competence, and performance on a technology-based platform for mathematics learning remains inconclusive.

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12. Multiplying student success in early mathematics: Sharing insights from research-practice partnerships

Liza Kahwaji[1], Ayushi Chitranshi[1], Abbey Gandhi[1], Stephen Hurley[2], Jo-Anne LeFevre[1], Erin Maloney[3], Sheri-Lynn Skwarchuk[4], Madison Young, Chy Zhang[4], & Rebecca Merkley[1]
[1]Carleton University; [2]voicEd Radio, Canada; [3]University of Ottawa; [4]University of Winnipeg

Building connections between researchers and educators is critical for supporting the uptake of evidence-based assessments and instructions in math education. The AIM (Assessment and Instruction for Mathematics) Collective is a Canadian partnership initiative linking researchers and educators across Canada to co-develop and test math assessment and instructional strategies. With 23 researchers and educators as partners, over 11 school districts and across 4 provinces, our goal is to share evidence-informed math education tools and resources. This poster shares the communication strategy formed in May 2023 titled ‘Collective Voices’. The underlying principle of Collective Voices is to strengthen communication and collaboration between researchers and K-6 math educators who teach students aged 4-12. The strategy progresses beyond disseminating research as it includes educators’ voices in the conversation. In a working group at the AIM Summit in May 2023, we discussed how communication with educators needs to be highly interactive and bi-directional to ensure that educator voices are included, and research addresses the needs of classroom educators. Our method reflects these

principles by bringing together expertise from diverse professionals using multi-media formats including newsletters, podcasts, videos, and a website. The strategy highlights the needs of both researchers and educators by using direct feedback about the content produced. To date, this strategy has led to 1390 website sessions with 891 unique visits, over 70 podcast listeners, and an average 74.6% newsletter interaction rate. The poster aims to further the discussion around effective research-education collaborations.

13. Understanding arithmetic principles correlates with approximate computation ability

Mingxin Yu[1], Bowen Xu[1], Shaungyu Zhang[1], & Xinlin Zhou[1]
[1]Beijing Normal University

Previous studies have revealed that the neural mechanism of approximate computation may be brain semantic network, but there is no research to verify the cognitive correlation between semantic processing and approximate computation from the perspective of cognitive mechanism. Therefore, this study aims to explore the cognitive correlation between mathematical semantic processing and approximate computation in children of different grades through two experiments. Experiment 1 recruited 342 sixth-grade primary school students (mean age: 12.15 ± 0.68 years) in three different cities in China. All students completed nine test tasks: non-verbal matrix reasoning, Choice reaction time, color ball tracking, mental rotation, paper folding, word analogy, approximate computation, exact computation, and arithmetic principles. The results showed that mathematical semantic processing was highly correlated with approximate computational ability. Experiment 2 recruited 344 students in grades four to six to take the test, including 120 in grade four (mean age 116.3±4.1 months), 112 in grade five (mean age 128.7±3.8 months), and 112 in grade six (mean age 140.1±4.3 months). All students completed five test tasks: non-verbal matrix reasoning, approximate computation, exact computation, arithmetic principles, sentence completion. The results showed that after controlling for age, gender and non-verbal matrix reasoning, the relationship between mathematical semantic processing and approximate computation ability increased with grade increase. This finding might change people's understanding of approximate computational ability and has implications for classroom teaching of computation, reaffirming the importance of mathematical language.

14. Bridging the gap: A professional development program to enhance preschool teachers' confidence in stem education with a focus on early math skills

Hannah Smith[1], Madison Berube[2], & Paul Reimer[2]
[1]Assumption University; [2]AIMS Center for Math and Science

The importance of early STEM has been echoed across contexts (Clements & Sarama, 2016; National Research Council, 2011). However, teachers' low confidence and negative attitudes toward STEM teaching, combined with few opportunities for professional development, have resulted in an avoidance of STEM and math teaching (Timur, 2012). The current study presents findings from a qualitative analysis of teacher interviews, surveys, reflections, and classroom logs from a larger professional development partnership aimed to fill gaps in preschool teachers' STEM engagement and training, as well as how teachers implemented and adapted activities from the program in their classrooms. The study included 26 central California Head Start preschool teachers and teacher assistants who taught 131 children across eight classrooms. Each month of the six-month program included a professional learning session that introduced research-based activities designed by the research team, coaching sessions led by researchers to support teachers in the classroom, and take-home kits for children to engage in a math activity at home with their families. We focus specifically on teachers' attitudes and confidence related to math teaching and learning and describe teachers' implementation and adaptation of the activities designed to promote math learning among preschool students. Activities specifically focused on patterns, spatial communication, and early numeracy skills; teachers adapted these activities to fit their children's needs. Results from teacher reflections indicate an increased focus on math content, newly formed confidence and positive attitudes towards math, and a newfound appreciation for math and its importance for their children.

15. Examining math word-problem solving in 3rd-graders with math difficulty using a worked examples measure

Vishakha Agrawal[1], Anna H. Miller[1], Hailey Kepiro[1], Marcia A. Barnes[1], & Sarah R. Powell[2]
[1]Vanderbilt University; [2]The University of Texas at Austin

Introduction: Worked examples (WEs) show a problem's set-up and solution, reducing cognitive load while learning. Although using WEs to examine student approaches to math word-problem solving can inform instruction, research on WEs in elementary-age students with math difficulty (MD) is limited. Using performance trends on a researcher-made WE word-problem measure from a large-scale RCT with Grade 3 students with MD, we make recommendations for using WEs to examine approaches to word-problem solving. Methods: 154 3rd graders with MD were randomized to receive either

schema-based instruction or not and were shown nine additive-schema WE word problems at both pre- and posttest. Students were asked to identify if the WE was correct or incorrect and then probed on the reasoning behind their answer. The analyses examine associations between response accuracy and schema understanding across the WEs and a descriptive error analysis. Results & Discussion: There is evidence of construct validity at posttest for students who received schema-based instruction. Response accuracy is lowest when the arithmetic was correct but the problem set-up/schema was incorrect. A descriptive analysis of student reasoning included a high proportion of "I don't know," and arithmetic-focused responses with few references to the word-problem set-up. Taken together, this lack of mathematical talk, especially concerning schema, and reliance on arithmetic accuracy even in the intervention group, suggests that our sample (3rd graders with MD; 66% ELLs) had difficulty with understanding and articulating answers to a WE task. We discuss recommendations for measure improvement based on psychometric and descriptive data.

16. Visualize and operate with multi-dimensional data

Minzhi Liu[1] & Matthew Lira[1]
[1]University of Iowa

In fields related to mathematics and statistics, reducing dimensions is a common method to analyze data. However, as a human being, it's "impossible" for us to directly imagine a structure higher than three dimensions. When people start to deal with multidimensional problems, it's important to build a "mental model" in mind and analyze the model to see the performance in different planes. For current products working on multi-dimensional data analysis, all of them just can show a result of the completed process. However, sometimes students have a hard time understanding how to interpret the results. To help students better understand the shrinking of dimensions, I refer to Grounded Cognition Theory as the theoretical framework to design a project to display each step on how to gradually shrink the dimensions. Grounded Cognition reflects the assumption that cognition is typically grounded in multiple ways, including simulations, situated action, and, on occasion, bodily states (Barsalou, 2008). Reflecting upon Grounded Cognition Theory, I developed a design principle to help students better understand how multi-dimensional problems work. The design is based on Mixed Reality (MR) carried out by Meta Quest 3, to allow students to use gestures to operate with a visualized multi-dimensional dataset. This design provides the opportunity to visualize and operate the steps in shrinking a dataset in high-dimensional problem space, especially graduate-level multi-dimensional problems and applications.

17. Investigating multimodal fusion of structural and functional brain imaging components supporting the development of number processing and mathematics ability in children

Mikael Skagenholt[1], Kenny Skagerlund[1], & Ulf Träff[1]
[1]Linköping University

Despite interrelations between structural and functional properties of the brain, these modalities are often analyzed separately. To capture the richness of neuroimaging data, multimodal fusion is a promising method for joint analysis of several modalities. This approach has successfully been applied to (e.g.) schizophrenia, leading to the discovery of correlated functional and structural neural biomarkers [1]. In a novel application, we investigated the structural and functional interrelationships of brain development in numerical cognition. Using a publicly available longitudinal neuroimaging dataset [2], sixty-two children (27 boys) were included from two sessions spaced approximately 2.3 years apart (mean age session 1/SD = 11.07/1.44; mean age session 2/SD = 13.40/1.52). Data were subject to multiple canonical correlation and joint independent component analysis. This allows differentiating developmental effects due to modality-specific structural and functional changes as well as joint-modality effects. Both types of effects were identified for structural and task-based (numerosity judgment, subtraction) functional components and successfully distinguished the two sessions. Joint-modality mixing coefficients correlated with standardized math ability measures. Results highlight the gains of multimodal analyses, providing interrelated structural and functional neural biomarkers for the development of numerical cognition. References:1. Calhoun, V. D., & Sui, J. (2017). Multimodal fusion of brain imaging data: A key to finding the missing link(s) in complex mental illness. Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 1(3), 230–244.2. Suárez-Pellicioni, M., Lytle, M., Younger, J. W., & Booth, J. R. (2019). Data Descriptor: A longitudinal neuroimaging dataset on arithmetic processing in school children. Scientific Data, 6, 190040.

18. Investigating the neural underpinnings of math and reading across the lifespan

Hillary Mastarciyan[1], Devin Sodums[2], Ju-Chi Yu[3], & H. Moriah Sokolowski[1]
[1]Toronto Metropolitan University; [2]Rotman Research Institute, Baycrest Health Sciences; [3]Campbell Family Mental Health Research Institute, Centre for Addiction and Mental Health

Math and reading are fundamental skills typically learned during childhood; a crucial period characterized by changes in large-scale brain organization and cognitive development. Previous studies exploring the neural basis of academic skills focus on how activation within individual brain regions relate to math or reading ability (Abreu-Mendoza et al., 2021; Chaddock-Heyman et al., 2018). While this approach provides significant insights into the neural underpinnings of early academic skills, it may underestimate the influence of whole brain network organization. The current study investigates the association between network level functional organization of the whole brain and individual differences in math and reading ability across the lifespan. Participants include 403 adults and 85 children (6-85 years) from the enhanced Nathan Kline Institute-Rockland Data Sample (NKI-RS) (Nooner et al., 2012). Reading and math ability were measured using the Wechsler Individual Achievement Test (WIAT-IIA). Whole-brain network organization was calculated using functional connectivity matrices from resting-state functional magnetic resonance imaging (fMRI) scans. Multivariate analyses were used to investigate the association between network segregation, across 7 brain networks (Yeo et al., 2018), and individual differences in math and reading ability, controlling for age. Results revealed that reading ability correlates with greater network segregation in visual, default and frontoparietal networks. Furthermore, math ability correlates with greater network segregation of the limbic system from the rest of the brain. Additional analyses unravel age-specific associations between academic achievement and network segregation. These findings highlight that functional brain organization contributes to individual differences in academic learning and cognition across the lifespan.

19. Functional activation patterns in developmental dyscalculia across arithmetic, magnitude processing, and visuospatial working memory tasks

Eric D. Wilkey[1], Isabella Starling Alves[1], Lien Peters[2], Fu Yu Kwok[3], & Daniel Ansari[4]
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Imaging of brain mechanisms underlying mathematical cognition may serve as a tool to better understand the developmental profiles associated with persistent, severe math learning difficulty (developmental dyscalculia; DD). Recent meta-analyses suggest some consistency across fMRI studies, whereby children with DD exhibit less parietal activity and more insular activity than control groups across tasks. However, sample sizes are small (DD n < 24), characterization of DD varies substantially, and tasks are often examined in isolation. We recently published fMRI analyses comparing a group of 30 children with DD to 38 children with typical achievement (TA) in mathematics (8-10 years old) and reported largely null results for any group differences across arithmetic, magnitude processing, and visuospatial working memory tasks [1]. Here, we build on these univariate analyses by investigating multivariate patterns in fMRI data using machine learning classifiers. Further, we explored whether providing data from multiple tasks to a single multivariate classifier would increase the predictive power of the algorithm to classify DD and TA groups. DD and TA groups were classified at above-chance accuracy (62% correct) during the magnitude processing task, but neither the arithmetic nor the visuospatial working memory task increased the classification accuracy. These results suggest that task-specific patterns exist that characterize neural differences between math achievement groups, but that these patterns may not be as simple as increased or decreased activation in a single brain structure.[1] Kwok, F. Y., et al. (2023). Human Brain Mapping, 44(18), 6308–6325.

20. EEG measurement of specific number representation in the human brain

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Throughout the early stages of development, humans acquire many numerical skills that serve as stepping stones for future success. These skills include estimation, counting, and arithmetic, which are fundamental for everyday life. For educators to effectively improve children's numerical cognitive ability at various levels of understanding, it is essential for researchers to accurately assess their level of numerical comprehension (i.e., Cardinal Principle knower-level (Wynn, 1990)). In this study, we use neuroimaging measurements like electroencephalograph (EEG) to test adults' brain waves for specific numbers. Our current research aims to advance our knowledge of the neural representations of specific numerical values in the adult brain, to provide a solid foundation to elucidate the developmental processes that underlie numerical cognition in children so that can better determine children's numerical knower-level. The study involves participants wearing a suitable EEG cap and watching sets of tasks that involve estimating specific numbers in both symbolic (i.e., Arabic numbers and number words) and nonsymbolic versions (i.e., visual dots stimuli and auditory sound stimuli). The goals of this study are twofold: (1) to access the brain waves for specific numbers from adults' brains to show that the brain wave can represent humans' math knowledge status, and (2) to provide a reference for determining children's number knower-level. In conclusion, this study

has the potential to significantly advance our understanding of how the brain processes numerical information and can inform the development of effective educational strategies for children at different knower-levels.

21. Two sides of a similar coin? Exploring the distinct and shared neural correlates of early precursors to math and reading

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There is some evidence that reading and math are related. Most of this research comes from studies on the co-occurrence of dyslexia and dyscalculia; however, it remains unclear how these associations arise early in development prior to receiving formal instruction in both domains. We plan to explore the co-development of reading and math by investigating the relationships between precursors skills - namely phonological and cardinal processing in 3-to-5-year-old children. Specifically, this study uses event related potentials (ERPs) to investigate the shared and distinct neural processes elicited during similar matching tasks within each domain. Children will complete two picture-word matching tasks, one with phonological manipulation (e.g., see a beach and hear either “peach” or “beach”) and the other with a quantity-number word manipulation (e.g., see three things and hear either “two” or “three”) Children are asked to indicate if what they hear matches what is visually presented. Within each domain, greater N400 amplitude for mismatch relative to match conditions will indicate sensitivity to phonological and number word mapping cues. Therefore, if there are shared neural processes, we hypothesize that the neural congruity across both domains will be positively correlated. This study has implications for understanding how early precursors for math and reading related, which may inform the early identification of children at risk for dyscalculia and dyslexia.

22. Resting state functional connectivity in 1st graders identified for math support in the classroom

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Developmental dyscalculia (DD) is the persistent difficulty in mathematics learning, which affects 5-10% of school-age children. However, approximately 25% of school-age children experience mathematics difficulties (MD) with a broader etiological basis. There is evidence that children with DD present increased resting state functional connectivity (rsFC) between frontal and parietal brain regions relative to typically-achieving peers. However, the relationship between rsFC and MD remains less clear. In this study, we address this gap by investigating the rsFC of 46 1-st graders with MD (mean age = 6.79, sd = .34) identified in a classroom setting. Additionally, 60 first-graders (mean age = 6.86, sd = 0.38) not identified as at-risk for mathematics difficulties composed a typically-achieving group (TA). We conducted a seed-to-voxel analysis contrasting the rsFC profiles of MD and TA children in subregions of the intraparietal sulcus (hIP1, hIP2, and hIP3) and the angular gyrus (PGa, and PGp), bilaterally. However, results yielded no significant difference between groups (all p>.542, cluster-size p-FDR corrected). Subsequently, we performed a multivariate classification of the groups based on their rsFC maps, using a support-vector machine classifier. The classifier performed above chance in all subregions, with the lowest accuracy in the r-PGp (61%), and peak accuracies in the l-hIP2 (69%), the r-PGa (68%), and the l-PGp (68%). These findings suggest that atypical rsFC in the intraparietal sulcus and the angular gyrus serves as a marker of MD, even in ecologically defined samples.

23. Math achievement and functional connectivity differences in young adults with and without autism

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Introduction: Autism has been associated with altered patterns of brain connectivity. Resting state connectivity studies have found the development of overconnectivity in children and underconnectivity in adults as a unique feature of autism, compared to neurotypical individuals. Task-based studies have uncovered that the intraparietal sulcus (IPS) is involved in arithmetic processing and numerical magnitude comparison. Greater IPS connectivity in neurotypical (NT) adults is associated with high math achievement, but in children, greater connectivity is related to worse math achievement. However, few studies have examined IPS resting state connectivity and math achievement in autism spectrum disorder (ASD). Methods: Here, we utilized seed-based correlation analysis to determine the relationship between math ability and IPS functional connectivity in 17 young adults with ASD and 21 NT peers. Results: We found that greater IPS connectivity in the frontal pole was related to higher math achievement in the NT sample, consistent with prior studies of adults. In contrast, we found that higher IPS connectivity was related to lower math achievement in the autism sample in the posterior cingulate cortex and superior frontal gyrus, as found in NT children. In the direct comparison between the groups,

there were stronger correlations of functional connectivity of the IPS within the frontal-parietal cortex in NT than in ASD. Conclusion: These results suggest that reduced connectivity is a feature of greater math achievement in autism and that different brain organization may relate to strengths in math achievement in ASD.

24. Does childhood experience with the abacus influence mathematics performance in adulthood?

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Past research suggests that children who are trained in using the abacus use a "mental abacus" when performing mental calculations. Specifically, children who have had abacus training are less accurate at performing mental calculations when they are asked to tap a finger on the table concurrently with performing mental calculations (Brooks et al., 2018; Frank & Barner, 2012). This interference from concurrent motor movements suggests that they use a "mental abacus" to perform mental calculations. In this study, we plan to explore the long-term impact of childhood abacus training on mental calculation. Specifically, we will test whether adults who received extensive training in the abacus as children will demonstrate evidence of using the mental abacus for calculation in adulthood. Participants will perform mental calculations under two conditions: when free to move their hands, and when asked to tap a finger on the table while performing calculations. If participants continue to use a mental abacus in adulthood, they should display degraded performance when asked to tap a finger on the table concurrently with mental calculations. Control participants who did not receive abacus training as children should not display this pattern. We will also examine whether early experience with the abacus is associated with enhancements in participants' spatial ability and flexibility in representing quantities. If abacus training does have long-term effects, we expect abacus users to score higher than non-users on spatial reasoning and representational flexibility tasks. Our outcomes could guide researchers' and educators' decisions to use abacus for promoting math learning.

25. Arithmetic in two languages: Localizing simple multiplication processing in the bilingual brain

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Bilinguals are typically faster and more accurate in the language they learned math in (LA+) than their other language (LA-). It remains unknown whether this effect is driven by the recruitment of different brain areas across languages. The current study used multiplication problem size as a tool for investigating language differences in the brain. Small problems (2x3) are thought to engage verbal memory to a greater extent than less practiced, large problems (8x9). Spanish-English bilingual adults verified multiplication problems in each language while functional magnetic resonance imaging (fMRI) was acquired. Two questions were investigated: 1a) Does LA+ engage areas associated with verbal representations of arithmetic facts (left superior and middle temporal gyri; STG/MTG) to a greater extent than LA-? 1b) Does LA- engage areas associated with more effortful retrieval (left Inferior frontal gyrus; IFG) or quantity areas (bilateral intraparietal sulcus; IPS) to a greater extent than LA+? 2) Is there a language by problem size interaction, where language differences are greater for large problems? No cluster reached significance for planned analyses comparing languages or examining a problem size by language interaction. An exploratory analysis found a main effect of problem size, where STG/MTG and IFG were engaged to a greater extent for small than large problems, suggesting greater verbal involvement. Additionally, right IPS was recruited to a greater extent for large than small problems, suggesting reliance on quantity processes. Our results suggest that proficient, early bilingual adults engage similar brain regions in both languages, even for more difficult, large problems.

26. Numerical processing in the parietal cortex, through the lens of acalculia cases

Erin Duricy[1], Corrine Durisko[1], & Julie Fiez[1]
[1]University of Pittsburgh

Introduction: Prominent theories of numeracy link the intraparietal sulcus (IPS) to approximate representations of quantity that underlie basic math abilities. In this review, we identify numeracy-focused single case studies with parietal damage and test for causal relationships between numeracy impairments and damage to IPS and surrounding parietal cortex. Methods: We identified 27 single case studies with left parietal lesions and categorized tasks across four numeracy domains: Approximation, Calculation, Transcoding, and Ordinality/Cardinality. To assess IPS damage, we compared published lesion images by drawing spheres at the estimated center of mass for each case. Cases were grouped based on sphere overlap with a left IPS region-of-interest and original anatomical description: IPS or Other Parietal damage. We performed Fisher's Exact Test to compare behavioral performance on each numeracy domain between the two groups. Then, we used Activation Likelihood Estimation (ALE) to identify sites of damage within parietal cortex preferentially associated with impairments in each domain. Results: We found that

Approximation impairments were significantly more frequent in the IPS group (p = .008). The ALE analysis revealed that only Approximation impairment cases significantly overlapped with the IPS, while impairments in the other domains were localized to different parietal lobe regions. Conclusions: Based on the pattern of impairments shown across these cases, we conclude that damage to left IPS is sufficient to impair approximation ability, but not other components of numeracy. Our findings support theoretical claims linking IPS to approximate quantity, but do not provide evidence that IPS critically underpins performance across all numeracy tasks.

27. Teaching mathematics in early childhood education - the role of spatial reasoning in children's mathematics learning

Rachel Politt[1]
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Young children are innately mathematical and explore mathematical concepts through play. Children's demonstrated understandings of mathematics take many forms that are often interrelated, enacted during everyday activities, and encompass multiple modes of mathematical thinking across many curriculum areas. Children do not necessarily explore mathematics ideas separately or in isolation. Such educator beliefs about and attitudes towards mathematics can impact the identification and inclusion of mathematics in early childhood education (ECE). Further challenges arise when educators are unsure of what to look and listen for to assess children's demonstrated mathematics knowledge. The development of children's mathematics skills requires explicit teaching strategies. Opportunities for children's mathematics learning can be missed when there are gaps in initial teacher training, impacting educators' mathematics content knowledge, confidence, and teaching proficiencies. This research investigated how to promote teaching mathematics in play-based settings, by focusing on key concepts children need to know and supporting early childhood educators when assessing, teaching, and planning for children's ongoing learning. Recent research has suggested spatial reasoning forms the foundations of mathematics learning. The theoretical argument underpinning this research is that young children benefit from intentional teaching focused on supporting the development of spatial reasoning skills during play, which is foundational for ongoing mathematics learning. The objectives include discussing what constitutes mathematics learning in the early years, defining and evaluating research methodologies contributing to sustained professional learning outcomes, the uptake of research findings in practice, play-based spatial reasoning teaching and assessment strategies and a focus on spatial reasoning in early childhood curricula.

28. Intrinsic rather than extrinsic spatial skills predict planar geometric proof performance

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[1]Beijing Normal University

Spatial ability comprises intrinsic spatial ability and extrinsic spatial ability. Previous studies have demonstrated a close relationship between intrinsic spatial ability and mathematical ability. However, the association between extrinsic spatial ability and mathematical ability remains uncertain. This study involved 397 high school students who completed three intrinsic and two extrinsic spatial tasks along with planar geometric proofs. After controlling for gender, age, and non-verbal inductive reasoning, intrinsic spatial ability rather than extrinsic spatial ability can independently predict geometric proof performance. This result suggests that developing intrinsic spatial ability rather than extrinsic spatial ability can be more beneficial for acquiring geometry knowledge.

29. Transfer of gains from spatial training to math performance: The role of training delivery and working memory

Chloe Oi Ying Leung[1], Marian Hickendorff[1], Christine Espin[1], & Dietsje Jolles[1]
[1]Leiden University

A recent meta-analysis found that concrete training materials were more effective than computerized training in transferring the effect to math (Hawes et al., 2022). It has been argued that physical materials are effective because they provide a concrete basis for abstract spatial representations. Yet, it remains unclear whether digital manipulatives are equally beneficial in this respect. Furthermore, children's working memory (WM) capacity might interact with training manipulatives. Therefore, in this study, we will explore whether training delivery (with manipulatives vs. without manipulatives and concrete materials vs. non-concrete materials) and individual differences in WM ability moderate the transfer of gains from spatial training to math within a pretest-training-posttest-followup design. A sample of 200 fifth- to sixth-graders will be recruited in the Netherlands, of which 160 have been recruited so far. Participants are stratified randomly based on their WM capacity and gender into one of the four training conditions: 1) with physical manipulatives, 2) with digital manipulatives, 3) with video demonstration, and 4) without additional materials. Children's spatial abilities and mathematical performance are assessed in the pre-test, post-test, and follow-up

tests. In all four training conditions, near-transfer gains are expected. Only training paradigms using manipulatives can result in far-transfer gains since participants conceptualize ideas based on sensory-motor encoding through embodied action derived from interaction with manipulatives. Moreover, we expect that WM capacity moderates the training effect. Children with lower WM capacity are more likely to benefit from the additional sensory input and exhibit greater improvements in the training condition with concrete manipulatives.

30. Examining kids' intuitive understanding of mechanical system through gears task

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Background: Early science education is crucial for children's development of scientific and spatial reasoning skills (Eshach & Fried, 2005). In this study, we adapted a "gears task" to assess children's understanding of mechanics (Legare & Lombrozo, 2014). Successful performance on this task would reflect a child's understanding of how each part should connect and function together. Previous studies of preschool-age children have not measured at what age children overcome naive concepts and learn mechanical systems through use of gears. Our research aims to test and chart this across ages. Research Question: At what age do children demonstrate adult-like mastery of understanding of mechanical principles, based on successful performance on the gears task? Do children acquire proficiency on the gear task slowly with maturation and learning, or does it suddenly emerge, like transitioning from naivety to insight? Methods: We will examine gear task performance in cross-sectional samples 2 to 6 year olds (N = 20 per age group). Parent-report language background surveys are included to assess a child's home-language exposure. The DAYC-2 will be used to control for IQ differences. Predicted Results: We will establish normative values in a large sample, and provide reliability and validity estimates. In the future, we will examine whether exposure to gears or guided exploratory play can lead children to overcome their naive concepts and perform better on the gears task.

31. Symbolic and non-symbolic number representations: Leveraging language variation

Clifton Langdon[1] & Marie Coppola[2]
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Question. Is the development of the non-symbolic number magnitude representation (approximate number system, ANS) constrained by the developmental trajectory of symbolic number magnitude representation (number words)? The extent of the influence of symbolic representations on non-symbolic representations is occluded by the fact that most children are exposed to language from birth. This pilot project seeks to further clarify this co-development by examining the directionality of correlation between non-symbolic and symbolic representation in children with later onset of language exposure: deaf children. Hypothesis. The development of non-symbolic number magnitude skills will be hindered by the delayed development of symbolic number magnitude representation. Thus, the ANS acuity in later exposed children would trend lower than that of early exposed children. Methods. Participants. Deaf children (4;0-6;0 with ≥70dB hearing thresholds) with early (≤0;6) or (later exposure (≥2;0) to their first language (ASL or English). Task. Dot quantity comparison. 64 trials with eight trials for each of four ratio ranges, (≤ 0.5, =0.5, 0.5-0.7, ≥0.7). T-tests comparing larger ratios of ANS should find no significant difference between groups, whereas smaller ratios for dot quantity comparison will reveal differences between groups. Discussion. Should there be a difference between groups for smaller, but not larger ratios, then it would support the view that symbolic numerical magnitude representations impacts the development of non-symbolic numerical magnitude representation. Additionally, it would serve as a preliminary result for a larger project in which the symbolic, non-symbolic, and arithmetic development is tracked longitudinally in children with later exposure to language.

32. Whole-number magnitudes interfere with decimal processing in children across strategies, and high performers additionally process rational magnitudes

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Rational numbers are challenging due to interference from whole-number knowledge. In decimal comparison, adults and children are less accurate on Inconsistent comparisons, where whole-number knowledge contradicts rational magnitude (0.26<0.8, but 26>8), than Consistent comparisons (0.86>0.2, 86>2). Adults display distance effects for rational distance between pairs: greater accuracy on far pairs (0.8 vs. 0.26) than near (0.9 vs. 0.81). Recently, we showed that adults also experience whole-number magnitude interference (based on the distance between numbers ignoring the decimal), demonstrating less accuracy on far (0.9 vs. 0.81, 9<<81) than near pairs (0.3 vs. 0.21, 3<21), despite equivalent rational distance (0.09). Here, we examined whether children also show these distance effects. Given children's heterogeneous strategy performance, we first

used cluster analyses to group them by rational number strategy. 178 6th-8th graders completed a decimal comparison task online from their classrooms. Cluster analysis identified 61% Whole-Number Biased (WNB) children who performed above chance for Consistent pairs and below chance for Inconsistent, 4% Reverse Biased (RB) children with the opposite pattern, and 35% High Performers (HP) who were above chance in both comparison types, but more accurate for Consistent than Inconsistent pairs. Among the most prevalent strategy groups (WNB and HP), students displayed whole-number interference effects for Inconsistent comparisons, specifically worse performance for far (0.9 vs. 0.81) than near (0.3 vs. 0.21) distances (RB model did not converge). However, only HP participants showed rational distance effects as seen in adults. These findings indicate that whole-number magnitude interference is pervasive in children across strategies.

33. Impact of inhibitory control and continuous magnitude on dot comparison performance in children with mathematical difficulties

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The precision of the Approximate Number System (ANS) is commonly measured using dot comparison tasks. However, the accuracy of these tasks seems to be influenced by the stimuli's continuous magnitudes and the participants' inhibitory control skills. The impact of these factors on the performance of children with mathematical difficulties (MD) has been scarcely studied. This study investigated the effects of inhibitory control, non-numerical continuous features, and numerical ratios on dot comparison performance among second graders with MD (N=53) and typically developing (TD) peers (N=297). Among others, we employed the Grass-Snow and dot comparison tasks to assess inhibitory control and ANS acuity, respectively. We followed Gebuis and Reynvoet's (2011) method for creating the dot arrays. Logistic mixed-effects model analysis revealed significant main effects of group, ratio, continuous magnitude, and inhibitory control on dot comparison accuracy. A notable double interaction of continuous magnitude x Group was observed, indicating that the impact of continuous magnitude on dot comparison accuracy varies between groups. Both groups relied more on continuous magnitudes than on numerosity; however, MD children notably underperformed in surface area-incongruent trials compared to TD children, albeit not in fully-congruent or fully-incongruent trials. The study underscores the complex interplay of task continuous features and individual differences in inhibitory control in shaping ANS task performance. It highlights the need for careful analysis of ANS results for children with MD, mindful of non-numerical task influences and cognitive factors.
References Gebuis, T., & Reynvoet, B. (2011). Generating nonsymbolic number stimuli. Behavior Research Methods, 43(4), 981–986. https://doi.org/10.3758/s13428-011-0097-5

34. The differential developmental trajectory for symbolic and situational mathematics abilities

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Symbolic ability and situational ability are two important mathematical skills. Within the realm of mathematical education theory, symbolic ability is often regarded as a more advanced mathematical skill compared to situational ability. However, empirical research to unveil the developmental trajectories of these two abilities is still lacking. This study employed arithmetic calculation tasks to measure students' symbolic ability and word problem composition tasks to measure their situational ability. The developmental trajectories of symbolic and situational abilities were explored among sixth-grade to eighth-grade students. The results revealed that students' symbolic ability remained unchanged with grade levels, whereas situational ability showed a significant decline. This study uncovers relatively independent developmental trajectories for situational and symbolic abilities. The findings of this study suggest that mathematics education should equally emphasize the cultivation of both symbolic and situational abilities in students, rather than focusing solely on the development of symbolic ability.

35. Mental strategies for estimating the relative magnitude of exponential expressions

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[1]University of Minnesota; [2]Georgia Institute of Technology

Math cognition research using speeded magnitude comparison tasks has found that individuals can quickly discern the relative magnitudes of different natural numbers, decimal proportions, integers, fractions, and more. However, little research has examined how people compare more complex expressions like exponentials. Exponentials are important in real-world mathematics, but they are challenging due to their complexity, nonlinearity, and infrequency in school mathematics. In this project, our goal is to uncover the underlying mental strategies people use to estimate the relative magnitude of exponential expressions. We expand on prior work (Varma & Bye, MCLS 2019) to examine how people compare the relative magnitudes of exponential expressions composed

of single-digit natural numbers. For example, to quickly estimate which of 3^9 and 5^6 is greater, one might use componential strategies, such as choosing the expression that has the larger base (e.g., 3 < 5) or larger exponent (e.g., 9 > 6). Attending more to the base versus exponent would produce different accuracy and reaction time (RT) profiles across trials. Alternatively, one may use arithmetic strategies, such as computing and comparing each base-exponent pair's sum (3+9 > 5+6) or product (3·9 < 5·6). These shortcuts are computationally tractable but not always accurate. We investigated the accuracy and RTs of U.S. undergraduates as they estimated the relative magnitudes of 96 pairs of exponential expressions (each presented twice). We report analyses of accuracy and RT to examine individual differences predicted by strategy use as well as the log-ratios of base and exponent magnitudes.

36. Situational mathematical ability lags far behind symbolic mathematical ability among middle school students

Jianing Lyu[1], Yi Liu[1], Chenye Bao[2], & Xinlin Zhou[1]
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According to the Three-Component Theory proposed by Zhou and Zeng (2022), both symbolic and situational mathematics are forms of mathematical representations throughout the entire process of mathematical learning. It remains unclear whether students exhibit advantages in either symbolic or situational mathematics as the proportion of abstract symbolic learning content increases. The present study aimed to address this gap by recruiting 375 seventh-grade middle school students to solve symbolic and situational mathematical problems in fraction division. The findings revealed that 81.60% of students successfully solved the symbolic fraction division problem, but only 13.90% of students provided reasonable answers for the situational fraction division problem. Notably, a considerable proportion of students who solved symbolic mathematics experienced challenges in situational mathematics. This discrepancy highlights a substantial lag in the performance of situational mathematics compared to symbolic mathematics among middle school students, which imply the need for a reconsideration of the instructional approach employed for situational mathematics in schools.

37. Finger-based and verbal cardinal representations in young children born pre-term

Laurence Rousselle[1], Auriane Leclercq[1], Line Vossius[1], & Maëlle Neveu[1]
[1]University of Liège

Children born prematurely are at increased risk of developing learning difficulties in mathematics (McBryde et al., 2020; Lee et al., 2017). These learning difficulties may stem from the well-documented sensorimotor impairments in these children (Moreira et al., 2014). Indeed, numerous studies suggest a link between sensorimotor abilities and the development of numerical and arithmetic skills in preschool-aged children (Barrocas et al., 2020). This study examines the effect of prematurity on the development of verbal and finger-based cardinal representations. Thirty 3 to 5 years-old prematurely born children (<37 weeks of gestation), were compared to 30 full-term control children (> 37 weeks of gestation) matched for chronological age. Children were administered a series of sensorimotor tasks (finger gnosia, fine motor skills) as well as various tasks assessing the development of verbal and finger-based cardinal representations (Give-N and Show-N tasks with verbal number words or cardinal number gestures either as inputs or outputs). Preliminary statistical analyses showed that preterm children, which exhibited lower manual dexterity index than their peers, performed lower in producing cardinal finger gestures based on verbal input but not in understanding the cardinal meaning of number words or finger gestures. The analyses are still in progress.

Poster Session 4 (Friday, 1:00-2:00 PM)

1. **Math meets science: Enhancing children's interpretations of 2x2 data tables**

Rui Meng[1] & Martha Alibali[1]
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Interpreting data is a pivotal skill in STEM education and modern society. However, mastering this skill poses challenges, especially for young learners. This study investigated middle-school students' data interpretation with two-way tables. Previous research has revealed that students tend to employ a frequency-based approach, comparing absolute numbers, leading to frequent misinterpretations. To address this problem, we developed interventions to support students in using the normative strategy of comparing ratios or probabilities, aiming to enhance students' data interpretation abilities. We tested the effectiveness of these interventions in a randomized experiment, in which 109 seventh-grade students were randomly assigned into one of three experimental conditions: a control group receiving no instruction, a group receiving conceptual instruction only, and a group receiving both conceptual and procedural instruction. The conceptual instruction addressed students' misconceptions about the frequency strategy and also emphasized the importance of proportional thinking. The group that received both conceptual and procedural instruction received the conceptual instruction followed by a presentation of a step-by-step implementation of the conditional probability strategy. Both interventions were effective in enhancing participants' data interpretation performance. Specifically, participants who received instruction significantly increased the likelihood of correctly interpreting data tables and using the conditional probability strategy, compared to the control group that did not receive instruction. This intervention can serve as a first step toward developing instructional practices to support data interpretation.

2. **Diagnosing fraction misconceptions: Illustrating the development of a concept inventory for use with diagnostic cognitive assessment**

Katherine Rhodes[1], Lourdes Acevedo-Farag[1], Kreshnik Begolli[1], Drew Bailey[1], Siling Guo[1], Andres Bustamante[1], June Ahn[1], & Lindsey Richland[1]
[1]University of California, Irvine

Mastery of fractions is foundational to subsequent mathematical learning, and fraction misconceptions are tied to difficulty with advanced math and science concepts (Bailey et al., 2012; Booth & Newton, 2012; Siegler et al., 2012). Yet the field of research on fractions is vast, and fraction assessments focus on a wide variety of different skills and potential misconceptions. We highlight the importance of developing a theoretically and empirically derived conceptual inventory of skills and misconceptions to support the development of a comprehensive diagnostic assessment. The psychometric framework: an approach to measurement that involves not only specifying students' continuous abilities but also allows for characterizing categorical misconceptions, has been described in extant literature (Bradshaw & Templin, 2014). However, this psychometric framework generally assumes that the theoretical groundwork of specifying the assessment framework is already accomplished (i.e., multiple-choice assessment data, based on an existing conceptual inventory of skills and misconceptions; Bradshaw & Templin, 2014; Sadler, 1998; Smith & Tanner, 2000).The current study (1) discusses the critical first step of specifying a conceptual inventory for diagnosing students' fraction misconceptions, (2) illustrates this process with a concept inventory for the skill of fraction addition, and (3) uses data from an experimental, open-response assessment of 241 4th- and 5th-grade students (Bustamante et al, 2022) to provide empirical evidence of common misconceptions in this skill domain and their frequencies of occurrence. Taken together, these misconceptions and their corresponding miscued answer selections form the theoretical basis for the next stages of assessment design and evaluation.

3. **It's me, hi, I'm in the problem, it's me**

Cheryll Fitzpatrick[1] & Matthew Rideout[1]
[1]Memorial University of Newfoundland

Realistic word problems (WPs) (i.e., requiring one's real-world knowledge to solve) are more challenging than standard WPs (i.e., those found in textbooks). Using the theoretical frameworks of mathematical modelling (Verschaffel et al., 2000) and situation model dimensions (Zwaan & Radvanksy, 1998), the current study aimed to improve the rate of realistic responses (RR) to realistic math WPs. In theory, manipulating the personalization dimension should contribute to developing a richer situation model and facilitate realistic problem solving. Research examining personalized information in textbook WPs show improved performance in fifth graders (Davis-Dorsey et al., 1991); however, researchers have not applied this manipulation to realistic WPs or with university students. Undergraduate students were

randomly assigned to receive a mix of 10 word problems (5-standard and 5-realistic) with either generic names (i.e., names in the WPs used in the literature) or their own name. Participants also completed measures on test, state/trait, and math anxiety and a measure of general math ability. Personalizing the realistic WP did not show an improvement in the number of RR. The RR rate was around 30%, which is higher than has been shown in child samples, but is still low. As hypothesized, performance was better on the standard WPs than realistic WPs. Moreover, performance on standard WPs was not as high as expected (60%) for this age/grade level. Together the variables accounted for roughly 25% of variability in RRs, suggesting other non-academic skills are also important contributors to success in realistic WP solving.

4. **Undergraduates' evaluations of arguments about dividing by zero**

Lauren Sprague[1], Addie Mitchell[1], & David W. Braithwaite[1]
[1]Florida State University

In this modified replication of Tsamir & Sheffer (2000), we will investigate undergraduates' knowledge about the indivisibility of zero and their evaluations of arguments on the topic. In Part 1, Participants will solve a series of division problems, including some with zero as the divisor. In Part 2, they will rate the convincingness of various formal and concrete arguments for why dividing by zero gives an undefined solution. In Part 3, they will complete a measure of logical reasoning and the Cognitive Reflection Test (CRT; Frederick, 2005). We hypothesize that students who initially give numerical solutions to "divide by zero" problems will find concrete arguments more convincing than formal arguments. We expect positive correlations with CRT and reasoning scores for formal argument convincingness ratings, but the opposite pattern for concrete argument convincingness ratings. Finally, we predict that the number of math classes a student has taken will be positively correlated with both their knowledge of indivisibility by zero and their ratings of formal arguments.

5. **A review of recently developed numeracy assessment, instruction and intervention resources from Canada**

Jessica Shapiro[1], Sarah Melo[2], & Sheri-Lynn Skwarchuk[1]
[1]University of Winnipeg; [2]Louis Riel School Division

As a result of the culminating Canadian and International numeracy research evidence since the turn of the 21st century, Canadian educators and researchers have been developing numeracy materials to supplement existing school curricula. In the recent past, numeracy interventions and the identification of mathematics learning disabilities were often based on commercialized standardized tests with limited Canadian content and sampling. Alternatively, large-scale population-developed assessment measures could be used to understand overall patterns, but are limited in the number of numeracy versus literacy items; and/or contain limited content grounded in the most recent Canadian research. A goal of this presentation is to describe and juxtapose seven recently-developed Canadian resources: Numeracy Screener, Early Math Assessment, Little Counters, TOYBOX, NyKK-5, MeloMath4Kids, and Jump Math as they pertain to current developmental numeracy trajectories and the existing Canadian (Manitoban) mathematics curricula. Based on our review to date, these seven measures support developmental models and early years curriculum coverage. However, depending on the specific area of numeracy intervention, or developmental age of the child, certain tools are better suited than others for classroom instruction, home use, clinical intervention, and/or research. We hope that this review serves as a reference on how the different assessment materials converge with emerging developmental numeracy trajectories, recommended school curricula and pedagogical practices, and response-to-intervention approaches. We plan to share our content analysis via a take home bookmark and/or QR code, containing an easy-reference synopsis on how these Canadian materials converge to support evidence-based numeracy assessment, instruction, and intervention practices.

6. **SPecialized Instruction to Reach All Learners (SPIRAL) Professional Learning-Coaching Model**

Katie MacLean[1] & Alison Hardy[1]
[1]The University of Texas at Austin

Coaching is a form of professional learning intended to support teachers in improving their instructional knowledge and practice. Coaching has demonstrated effectiveness in increasing positive outcomes for K–12 teachers' mathematical content knowledge, self-efficacy, and the identification and use of evidence-based practices (Anthony et al., 2011; Garet et al., 2016; Kretlow et al., 2012). These increased teacher outcomes have demonstrated an impact on student achievement within mathematics as well (Campbell & Malkus, 2011; Campbell & Malkus, 2014; Harbour et al., 2018). In this poster presentation, we discuss a teacher-focused coaching intervention (SPIRAL: SPecialized Instruction to Reach All Learners) in which we worked with teachers of students with mathematics difficulty in Grades 4 and 5. SPIRAL teachers participated in four professional learning sessions, each followed by two differentiated coaching sessions. SPIRAL professional learning sessions focused on an instructional platform comprised of five components: (a) modeling and practice; (b) vocabulary;

(c) multiple representations; (d) fluency; and (e) problem solving. Following each professional learning session, teachers participated in coaching sessions tailored to their own schedules and students' needs. Coaching sessions included goal setting, modeling, elbow coaching, co-teaching, lesson planning, inter-visitation, and focused observations. This equitable approach provided teachers with the opportunity to receive individual support and feedback while engaging in dialogue related to evidence-based mathematics practices. In this poster presentation, we will (1) present our professional development and coaching model, (2) outline coach training, and (3) discuss practical implications for the field.

7. **Mitigating the effect of computer programming anxiety on college level and early career computer scientists**

Alissa McGill[1], Susan Fisk[1], Audrey Rorrer[1], Tom McKlin[1], Veronica Catete[1], Tiffany Barnes[1], Jamie Payton[1], & Clarissa Thompson[1]
[1]Kent State University

Broadening participation in computing careers is of the utmost importance as we find that technology and mathematics are becoming increasingly relevant in the careers of tomorrow. Programming anxiety, defined as a situation-specific psychological state caused by negative experiences or expectations in a computer programming situation, has been found to be a significant predictor of achievement in programming. Additionally, women are underrepresented in computing careers and majors and have higher programming anxiety compared to men. This two-part study will first analyze data previously collected by the STARS Computing Corps about college-level computing students and their persistence intentions. STARS aims to broaden participation in computing for those who are typically underrepresented in the field by reinforcing computing knowledge and developing a community among students. The previously collected data will be analyzed using a regression model or path model to investigate relations among factors such as self-efficacy, programming anxiety (e.g., "I get tense or nervous about my ability to do computing."), belonging, and persistence. The findings from this secondary data analysis will be used to develop an experimental intervention aimed at increasing women's persistence in computing careers and lowering their programming anxiety via a learning intervention about stereotype threat. The results of this pretest-posttest experimental design will be analyzed by conducting a between-within ANOVA. This intervention can be used as a tool for early-career and college-level computer scientists to decrease their anxiety and increase the persistence of these women in computing careers.

8. **Math playtime: A playful approach to socializing children's math skills at home**

Michele Stites[1], Susan Sonnenschein[1], & Besjane Krasniqi[1]
[1]University of Maryland Baltimore County

Playful learning at home is gaining increasing attention from researchers. However, most of the research focuses on children's literacy development. A playful approach to fostering children's literacy development is positively associated with the types of activities children engage in, their interest in literacy, and their literacy development. This study considers a playful approach to children's math development. We document the frequency with which 4-9 year olds engage in play-oriented math activities (e.g, playing board games) at home versus skills-oriented ones (e.g., using flash cards). Much of the research on math development comes from North America and, to a degree, Europe. We consider here similarities/differences in math engagement in the US (N = 357), Kosovo (N = 162), Turkey (N = 422), thus extending work to Southeastern Europe and the Middle East. Parents of children between 4 and 9 years from the US, Kosovo, and Turkey completed an online survey indicating the frequency with which children participated in the two types of activities. In the US and Turkey, but not Kosovo, children more frequently participated in play or daily living math activities than skill-oriented ones. There were no differences in any country in patterns of participation for boys versus girls. In contrast, younger children (ages 4-5) were significantly more likely to engage in play-oriented activities in each country whereas older children (6-9) participated more in skills-fostering activities. These data confirm the importance of understanding the types of math activities children from different countries and different ages engage in at home.

9. **Is teaching mathematics hard? Is it harder to teach inclusive mathematics, computational thinking, and engineering?**

Michele Stites[1], Susan Sonnenschein[1], Jonathan Singer[1], Hsiu-wen Yang[2], Chih-Ing Lim[2], Megan Vinh[2], Hatice Gursoy[1], Freya Kaur[1], & Besjane Krasniqi[1]
[1]University of Maryland Baltimore County; [2]University of North Carolina Chapel Hill

Children with disabilities are often denied opportunities to engage in STEM activities including mathematics, computational thinking, and engineering (Clements et al., 2021). It is widely accepted that literacy opportunities in preschool are more frequent than mathematics ones, however, little is known about the frequency at which computational thinking and engineering occur in preschool. This presentation compares 10 Maryland Head Start Teachers' ability to implement inclusive mathematics with their skills for implementing inclusive

computational thinking and engineering activities strategies following a four-day professional development focused on inclusive STEM and follow-up Networked Improvement Community (NIC) meetings. We address the following research question: Do Head Start teachers increase the number of inclusive mathematics, computational thinking, and engineering opportunities following targeted professional development (PD) and on-going support using Networked Improvement Community (NIC) meetings? Prior to the professional development, participating teachers indicated needing support and lacking the confidence to engage students in activities addressing mathematics, computational thinking, and engineering. Following four days of intensive professional development, teachers reported higher confidence levels in teaching mathematics but not computational thinking or engineering. Teachers were observed implementing mathematics activities more frequently than computational thinking or engineering. Teachers indicated they would benefit from additional support about computational thinking and engineering. Further recommendations regarding professional development needs and support to enhance their competence in implementing more computational thinking and engineering activities will be included. Clements, D. H., Vinh, M., Lim, C. I., & Sarama, J. (2021). STEM for inclusive excellence and equity. Early Education and Development, 32(1), 148-171.

10. **Structural brain correlates of subtraction and multiplication performance and their interaction with age in children**

Reyhan Shorbi[1], Macarena Suarez-Pellicioni[1], & Firat Soylu[1]
[1]The University of Alabama

Functional neuroimaging studies on children's arithmetic skills show dispersed brain networks that shift and converge during development. While most neuroimaging studies focus on functional networks, we know less about structural correlates of arithmetic skills and how developmental changes in brain structures relate to arithmetic performance. To this aim, we investigated the association between age-related changes in gray matter volume (GMV) and white matter volume (WMV) and multiplication and subtraction performance in a group of 132 3rd to 8th graders. We defined regions of interest (ROIs) in left MTG/STG, bilateral IPL/SPL, and left IFG, as they have been associated with math processing, and in the cerebellum, as cerebellar activation is often reported in literature. We found age-related changes across all ROIs, with negative correlations between age and GMV, and positive correlations between age and WMV. There was a positive correlation between GMV in bilateral SPL and right IFG and subtraction performance. A positive correlation emerged between GMV in right IFG and multiplication performance. For both subtraction and multiplication, there were multiple dispersed regions showing an interaction between performance and age. The results showed differential structural correlates for subtraction and multiplication performance and informed how developmental processes of gray matter pruning interact with the specialization of the arithmetic networks with age.

11. **Neural representation of discrete and continuous ratios: An fMRI study**

Rebekka Lagacé-Cusiac[1], Jessica Grahn[1], & Daniel Ansari[1]
[1]Western University

We often rely on relative magnitudes (ratios and proportions) to make decisions. For example, we can tell from battery icons how much charge is left by comparing the length of the filled bar to the length of the full battery icon, regardless of the overall size of the icon. This leaves the question of how humans process ratios across different formats. Some of have proposed that all ratios are processed by a perceptually based "ratio processing system" (RPS). Though some neuroimaging studies have shown a spatial overlap in brain areas processing ratios across different formats, the assumption that all non-symbolic ratios (e.g., ratios depicted using length or numerosity) have a common representation via the RPS is currently untested. Therefore, the aim of this study was to investigate the neural representation of discrete and continuous ratios using fMRI. Thirty participants completed a ratio match-to-sample task on discrete (sets of dots) and continuous (line lengths) magnitudes while in the MRI scanner. Using representational similarity analysis, we tested a series of models representing low- and high-level features on a range of areas from primary visual cortex to parietal and frontal cortex. This poster presents results from a preregistered report and tests a fundamental assumption composing the RPS theory. Results have implications for theories of ratio processing and how these can be leveraged to improve teaching of fractions.

12. **Tracking the magnitude discrimination of two-digit number symbols with frequency-tagging EEG: A feasibility study [WITHDRAWN]**

Amandine Van Rinsveld[1] & Christine Schiltz[2]
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Previous evidence highlighted that it is not possible to ignore the numerical magnitude when looking at number symbols, at least for adults. However, the neural

mechanism behind this automatization of symbol processing remains largely unknown, because these kinds of cognitive processes are difficult to isolate with explicit tasks. We recently developed a novel electrophysiological experimental paradigm, which aims to assess automatic numerical representations and access magnitude information conveyed by number symbols in an incidental manner. The current study extends this paradigm to two-digit numbers. Concretely, we used frequency-tagging EEG to measure the spontaneous processing of magnitude from one and two-digit numbers across three groups of participants: preschoolers (5-6 year-olds), 4th graders (9-10 year-olds), and adults (undergraduate students). Automatic magnitude processing was assessed by presenting a stream of frequent small digit numbers mixed with deviant large digits (and the reverse) presented every eight stimuli. Stimuli were displayed with a sinusoidal contrast modulation at the frequency of 10 Hz and Steady-State Visual Evoked Potentials were recorded. These electrophysiological measurements showed a neural synchronization at the frequency of the fluctuating change and its harmonics, recorded on electrodes encompassing right occipitoparietal regions for the one-digit numbers already in preschoolers, and for two-digit numbers in the 4th grade and adult groups. Our findings show that magnitude can be processed automatically both from one- and two-digit symbolic numbers. This indicates that magnitude is a salient semantic feature, which is deeply associated to digit symbols in long-term memory across development.

13. **The neural basis of number processing and its relation to individual differences in 4th graders' math competence**

Xueying Ren[1], Marc N. Coutanche[1], Julie A. Fiez[1], & Melissa E. Libertus[1]
[1]University of Pittsburgh

Number processing is an essential skill for math competence in children, laying the groundwork for acquiring advanced quantitative abilities later in life. This study examines the relations between brain activity in various brain regions, particularly those that have been less examined in number processing, and children's math abilities. To achieve this, we used functional magnetic resonance imaging (fMRI) to 1) identify a set of brain regions involved in number processing, and 2) examine the relations between brain activation in various brain regions and children's math abilities. We collected fMRI data from 88 4th graders with an average age of 9 years and 8 months. During the imaging session, participants performed two tasks: a number comparison task and a phonological comparison task, using two types of stimuli - Arabic digits and images of hands. Children's math abilities were assessed using the math subtests of the Woodcock-Johnson Tests of Achievement in a separate behavioral session. Univariate analyses contrasting tasks involving the two types of stimuli revealed various brain regions that support number processing. In addition to well-researched areas such as the intraparietal sulcus, our study has also identified a set of brain regions that have not been thoroughly investigated in previous work (e.g., the left fusiform gyrus). We will investigate the important functions of these less-examined brain regions in children's math abilities by examining the relations between brain activation in these areas and children's math skills.

14. **Financial abilities: Is there more to it than mathematics? A VLSM study on stroke patients**

Laura Danesin[1], Maria Grazia Ranzini[2], Arianna Menardi[2], Giorgia Baron[1], Gabriella Bottini[3], Antonino Vallesi[2], Carlo Semenza[2], & Francesca Burgio[1]
[1]IRCCS San Camillo Hospital, Venice; [2]University of Padua; [3]University of Pavia

Financial abilities (FAs) are classified into basic skills, relying on arithmetic, and advanced ones, involving higher-order cognitive functions (Marson et al., 2000). Numerical difficulties, including managing financial assets, are common post-stroke sequelae (Robert et al., 2021), and their investigation constitutes a unique opportunity toward the understanding of the neurocognitive mechanisms of numerical and mathematical processing. Scarce neuroimaging studies have explored the neural mechanisms behind these abilities (Benavides-Varela et al., 2021). Furthermore, how lesions in brain areas related to calculation may affect basic or advanced FAs is still unclear. Therefore, we aim to investigate post-stroke behavioral and neuroanatomical dissociations between numerical and financial deficits using voxel-lesion-symptom-mapping analyses. 100 stroke patients will undergo neuropsychological evaluation and structural MRI. Performances will be converted into z-scores and averaged into composite variables for each cognitive domain. Correlations between cognitive, numerical, and financial competencies and co-occurrence of deficits will be explored (Pearson's coefficients and Chi-square tests, respectively). Lesion mapping will be analyzed through voxel-lesion-symptom-mapping (Nonparametric Mapping Toolset). Liebermeister test will be applied to identify injured voxels that may predict numerical and/or financial deficits. Analyses will include voxels damaged in >5% of patients, with statistical maps adjusted for multiple comparisons (False Discovery Rate correction, $p<.05$). Lesional patterns involving regions crucial for numerical functions (e.g., parietal cortex, Dehaene et al., 2005) are expected to affect

calculation and basic FAs but not advanced FAs that may involve more strategic areas like prefrontal cortices. Overall, this study will contribute to shed light on the link between numerical and financial abilities.

15. **How the association between behavior and event-related potential in numerical symbol acquisition develops with grade and exercise**

Shuangrao Qi[1], Yuhan Zhang[1], Naiqian Luan[1], & Xinlin Zhou[1]
[1]Beijing Normal University

This study investigated the neural mechanisms involved in children's acquisition of numerical symbols during early mathematical education. Children in grades 1-6 were trained to associate novel symbols with non-symbolic numerical magnitudes. They then performed matching and comparison tasks. Event-related potential (ERP) analysis was used to examine the developmental trend of children's numerical symbol acquisition ability. Results revealed an age-dependent early N2 component in the occipitoparietal cortex during the comparison task. Behavior-related potential (BRP) analysis showed the emergence and development of the BRP-P1 component across different grade levels and exercises. These findings highlight the value of using BRP to uncover developmental trends in the association between behavioral performance and ERP during numerical symbol acquisition, which vary based on grade and exercise.

16. **Decoding fraction magnitude from EEG signals using machine learning**

Brian Rivera[1]
[1]University of Nebraska Lincoln

Multivariate pattern analysis (decoding) methods provide alternative ways to analyze EEG data that allow the study of numerical representations in wider temporal and spatial scales, and with higher sensitivity. Decoding analysis can provide insights into processing outside of the specified time windows of selected ERP components. In the present analysis, decoding was performed on EEG data collected during a fraction magnitude validation task. The task required participants to validate whether one of 15 different fractions, the first 5 multiples of 1/2, 1/3, and 1/4, matched target fractions (i.e., 1/2, 1/3, or 1/4). The results of the original study highlight the presence of a P300 component for trials with matching fraction magnitudes and an N270 component for mismatching trials. However, this analysis did not allow to test two key questions: 1) Can information about which fraction is being processed be identified from EEG signals, for example, can we identify whether a participant looked at 2/4 or 3/9 or 4/12? and 2) Can the numerical magnitude of the fractions being processed be identified from their EEG signatures, for example, can the multiples of 1/2 be distinguished from those of 1/3? The present analysis sets out to answer these two questions applying decoding methods to this dataset. Results to these questions have implications for our understanding of how EEG signals encode numerical representations and numerical magnitudes.

17. **A study on playing cards to disentangle order and magnitude in the SNARC effect**

Mauro Murgia[1], Valter Prpic[2], Serena Mingolo[1], & Krzysztof Cipora[3]
[1]University of Trieste; [2]University of Bologna; [3]Loughborough University

The SNARC effect is believed to reflect a left-to-right mapping of numbers resembling a mental number line (MNL). However, disentangling the roles played by numbers' magnitude and order in the SNARC effect remains a challenge due to their inherent correlation. This study focused into the impact of order and magnitude on the SNARC effect, utilizing playing cards as stimuli. While most people hold cards in ascending order (AO), we observed that a subset of individuals holds them in descending order (DO). Notably, DO individuals stably dispose low-magnitude cards (e.g., 2) to the right and high-magnitude cards (e.g., 6) to the left, i.e., the order opposite to the MNL. In our first experiment, AO and DO participants engaged in a magnitude classification task involving both simple numerals and playing cards as stimuli. AO participants showed regular SNARC effects in both conditions. Differently, DO participants showed SNARC only with numerals, but not with cards. In a second experiment, AO and DO participants engaged in a parity judgement task on simple numerals and playing cards. The same pattern of results emerged, with regular SNARC effects in every condition except for the DO participants in the parity judgement with cards. Overall, these results seem to indicate that the order in which DO participants arrange cards affects the shape of a regular SNARC effect.
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18. **The relation between number line performance and mathematics outcomes: Two meta-analyses**

Zehra Unal[1], Züleyha Terzi[2], Beyzanur Yalvaç[2], & David Geary[1]
[1]University of Missouri; [2]Boğaziçi University

Understanding the magnitudes represented by numerals is a core component of early mathematical development and is often assessed by accuracy in situating numerals and fractions on a number line. Performance on these

measures is consistently related to performance in other mathematics domains, but the strength of these relations may be overestimated because general cognitive ability has not been fully controlled in prior studies. The first of two meta-analyses (162 studies, 33,101 participants) confirmed a relation between performance on whole number (r = 0.33) and fractions number (r = 0.41) lines and overall mathematics performance. These relations were generally consistent across content domains (e.g., algebra and computation) and other moderators. The second (71 studies, 14,543 participants) used meta-analytic structural equation modeling to confirm these relations while controlling general cognitive ability (defined by IQ and working memory measures) and, in one analysis, general mathematics competence. The relation between number line performance and general mathematics competence remained significant but reduced (b = 0.13). Controlling general cognitive ability, whole number line performance predicted competence with fractions but not performance on numeracy or computations measures. The results suggest an understanding of the magnitudes represented by whole numbers might be particularly important for students' fractions learning. Keywords: Number line, mathematics, math performance, general cognitive ability.

19. Re-examining differences and ratios in perceptual comparisons: Dual-operational control across restricted stimulus ranges

Cameron Hooson-Smith[1], Nicola J. Morton[1], Simon Kemp[1], & Randolph C. Grace[1]
[1]University of Canterbury

Grace et al. (2018) developed a non-symbolic 'artificial algebra' task where participants learned by feedback to respond to differences or ratios of magnitude pairs by feedback and without specific instruction. Multiple regressions showed that responses were often jointly determined by both operations even though only one was trained. However, differences and ratios were highly correlated, raising the possibility that multicollinearity could have influenced results. The current study addressed this concern by restricting the range of the stimulus set following the initial acquisition of the task. Across three experiments, participants performed comparison tasks with either pairs of lines (n = 27), circle radii (n = 30), or circle areas (n = 26); receiving feedback based on either differences or ratios. The full stimulus set was used in the initial two blocks (rdiff-ratio = ~.90), with 20-80% of the original range then used across the final two blocks (rdiff-ratio = ~.50). Results showed that in 84% of participants across all experiments, the trained operation continued to significantly predict responses within the restricted blocks. Significant coefficients for the untrained operation were found in 54% of individual participants, showing that control by two operations is not an artifact of multicollinearity. Findings demonstrate robust control by both differences and ratios, even though feedback was based on one operation. This suggests that the perceptual system automatically encodes both differences and ratios in magnitude comparison.

20. Contrasting ANS performance and sensitivity to numerical and non-numerical information for stimuli presented in a separate or intermixed manner

David Gomez[1,2], Felipe Leiva[1,2], & Valentina Giaconi[1,3]
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The Approximate Number System (ANS) represents large numerosities of objects approximately and quickly, and it has been related to mathematics achievement across the lifespan. However, our knowledge of how this system works and its dependency on non-numerical information is still insufficient. Here, we compared performance across two types of stimulus presentation (separate or intermixed sets of dots) with different stimulus durations to study the time course of numerosity judgments. We used numerosity comparison tasks. Participants selected the larger of two sets of dots along four sessions (2048 items in total). Total set area and convex hull size varied orthogonally to numerosity. Stimulus presentation varied from 100ms to 800ms. Here, we present data from 8 participants who compared separate sets and six who compared intermixed sets (they all obtained an overall accuracy of 55% or higher). Response accuracies showed a distinct pattern of results. Separate sets induced lower accuracy for 100ms of stimulus duration and stabilized from 200ms onwards. Intermixed sets, instead, showed increasing accuracy from 100 to 800ms. We analyzed sensitivity to numerosity and the effect of non-numerical dimensions by using logistic mixed-effect regression models (DeWind et al., Cognition, 2015). Sensitivity to numerosity followed a similar pattern to accuracy data. The total set area had overall small effects, whereas the convex hull was mostly irrelevant for separate sets but showed negative effects for longer stimulus duration (600-800ms). Altogether, these findings show how the presentation format of dot stimuli and their duration affect the role of numerical and non-numerical information.

21. Pupillometry as a measure of error detection in mathematics

Maria Brandao[1] & Darko Odic[1]
[1]University of British Columbia

Mathematics poses a special challenge as people are frequently faced with a lack of cues to decide whether an answer is right or wrong. Recent work has suggested that individual differences in the Approximate Number System (ANS) may provide a very coarse error detection signal in symbolic math problems, and children and adults with a sharper ANS are better at detecting even relatively small errors in math. In two studies, we aim to replicate this effect and further examine how pupillometric measures of surprise correlate with the ANS and error detection. In Experiment 1, 7- and 8-year-old children listen to a puppet and decide whether its answers to different problems are correct or incorrect while their eyes are tracked by a remote eye tracker. In Experiment 2, adults are asked to listen to math problems being wrongly solved by either small or large magnitudes, and then decide whether the answers were too high or too low. The errors are presented at different ratios in relation to the correct answers (e.g., 1.2, 1.5, and 2.0). We examine how pupil dilation changes for incorrect vs. correct answers (in Experiment 1), and for larger vs. smaller errors (in Experiment 2). We further investigate if individual differences in the ANS are related to the magnitude of pupillary dilation when detecting mistakes in symbolic math problems. We anticipate revealing useful insights on the mechanisms of error detection and its relationship to predictive cognitive processes.

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22. Exploring groupitizing behaviors in first graders: A study on counting strategies and finger representations

Céline Poletti[1] & Catherine Thevenot[1]
[1]University of Lausanne

In this study, ninety-one first graders aged between 6 ½ to 7 ½ years were observed in a counting task. The dots could be organized randomly and ungrouped on a paper card or arranged according to two different regular configurations. In one regular configuration, the dots were presented by groups with the same numerosity by 2 (e.g., 4 groups of 2 dots or 2 groups of 4 for a total of 8) and in the other configuration, the dots were grouped one the basis of different numerosities (e.g., one isolated dot, one group of 2 dots and one group of 3 dots for a total of 6). Our goal was to investigate the potential groupitizing behaviors of children (i.e., counting dots by groups instead of one by one) and relate them to their finger counting strategies. The hypothesis is that children who can groupitize are able to grasp some numerosities at a glance, and consequently, to represent these numerosities directly on their fingers without having to raise their fingers one by one.

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23. Does eight equal eight? The role of counting knowledge in children's understanding of exact equality

Khuyen Le[1], Rafael Núñez[1], & David Barner[1]
[1]University of California, San Diego

Equinumerosity – the understanding that two sets in 1-to-1 correspondence share the same quantity of items – underpins adult-like understanding of numbers, moral judgments of fairness, and mathematical reasoning. It is an open question how children gain understanding of equinumerosity and whether proficiency in counting knowledge (measured by understanding of the Cardinal Principle, or CP) is critical to this development. Previous research regarding this line of question has reported mixed results. In a novel task, we showed English-speaking 2- to 5-year-olds two containers with the same number of items (e.g., 8 orange and 8 purple fish). The items were taken out of their containers and placed in 1-to-1 correspondence in a row. Then all items except one was concealed (e.g., all 8 orange fish and 7 purple fish were hidden in the respective containers, with a purple fish remaining visible). Children were then asked to identify the container with 'more' items. If children understand equinumerosity, they should use 1-to-1 correspondence to reason that the containers initially have the same quantity of items. Therefore, when one item is left out, the other container should have more items. We found that CP-knowers generally succeeded in this task, while subset-knowers performed at chance. Interestingly, however, we found variability in CP-knowers' performance. Our findings suggest that counting knowledge is implicated in, but not sufficient for, the ability to reason about 1-to-1 correspondence and exact equality. Future research should investigate sources of this variability and explore mechanisms beyond counting critical to equinumerosity development.

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24. Individual differences in human clustering

[1]Shubh Goyal, Vijay Marupudi[2], Sashank Varma[2], & V.N. Vimal Rao[1]
[1]University of Illinois at Urbana-Champaign; [2]Georgia Tech

Visual clustering is an important part of human behavior that is likely implicated in graph comprehension. Despite research on the general principles of clustering in the Gestalt tradition (Wagemans et al., 2012), we do not fully understand the variability present in people's clusterings. This may be due to differences in people's perception (Bimler et al., 2004), the strategies they employ, or personality traits associated with math and statistics anxiety. In this study, we investigate individual and group differences in people's clustering of dot clouds. Marupudi et al. (2022) have shown that people are reliable when clustering groups of points with even a slight degree of

grouping (compared to random dispersion). We conduct a secondary analysis on data collected by Marupudi et al. (2022) to quantify the similarity in response patterns between individuals across clustered stimuli. Results indicate that there are group differences in participants' response patterns, with some stimuli generating larger individual differences than others. In this ongoing study, we analyze stimulus characteristics and participant responses to identify perceptual features and strategies that may be driving these differences. Additionally, we analyze data from new participants completing the clustering task as well as a survey measuring their academic achievement, arithmetic fluency, and personality traits associated with statistics anxiety (O'Keefe et al., 2012; Chew & Dillon, 2014). We analyze the relationship between these factors and participants' clustering patterns. These results shed light on the variability of human clustering and perceptual processes that may play a role in how people understand graphs.

25. Might visual clustering underlie numerosity estimation?

Vijay Marupudi[1], Shubh Goyal[2], & Vimal Rao[2]
[1]Georgia Tech; [2]University of Illinois

In this study, we investigate whether people's ensemble perception processes, specifically visual clustering, might underlie numerosity estimation. Despite the approximate number system (ANS) being considered foundational for symbolic mathematics, the processes involved in a common measure of ANS acuity, the numerosity estimation task, are unknown (Dowker, 2023). The importance of visual processes, such as subitizing (Mandler & Shebo, 1982) and groupitizing (Starkey & McCandliss, 2014) for arithmetic abilities, and ensemble perception processes (Haberman & Whitney, 2012) for vision in general hint at the importance of visual clustering. Chakravarthi and colleagues (2023) have shown that manipulating the perceptual properties of points in space (point clouds) likely impacts numerosity estimation by changing how participants perceive clusters of points. Here, we investigate precisely how the clusters of points participants perceive in point cloud stimuli are associated with their numerosity estimations. In this ongoing study, participants will complete 3 different tasks in counterbalanced order: (1) clustering a set of point clouds using their mouse, (2) estimating the numerosities of these stimuli, and (3) completing a magnitude comparison task comparing pairs of the same stimuli. If visual clustering underlies numerosity estimation, we expect properties of the clusters participants perceive to predict their estimated numerosity of a stimulus. We also predict a ratio effect in the magnitude comparison task, controlling for differences in the actual numerosity of the stimulus. These results complement research investigating the nature of perceptual clustering processes and provide insight into the component processes underlying numerosity estimation.

26. Numerical values modulate size perception

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The link between various codes of magnitude and their interactions has been studied extensively for many years. In the current study, we examined how the physical and numerical magnitudes of digits are mapped into a combined mental representation. In three psychophysical experiments, participants reported the physically larger digit among two digits. In the identical condition, participants compared digits of an identical value (e.g., "2" and "2"); in the different condition, participants compared digits of distinct numerical values (i.e., "2" and "5"). As anticipated, participants overestimated the physical size of a numerically larger digit and underestimated the physical size of a numerically smaller digit. Our results extend the shared-representation account of physical and numerical magnitudes.

27. Maternal education and motor skills: Predictors of early precursor math skills in three-and-four-year-old Mexican children

Elia Verónica Benavides Pando[1], Carolina Jiménez Lira[1], Daniela Susana Paz García[1], Martha Ornelas Contreras[1], & María Inés Susperreguy[1]
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Developing early numeracy skills involves a diversity of factors, both intrinsic, including prior skills acquired by the child, and extrinsic, which are contextual factors such as maternal education (Peake et al., 2021). In a prior study, Jimenez-Lira et al. (2024) found that motor skills and early precursor numeracy skills (i.e., verbal counting, cardinal knowledge, and number identification) were predictors of symbolic number comparison and problem-solving skills, which are considered to be more complex math outcomes. In the present study, we ask whether motor skills predict early precursor numeracy skills in young three-and-four-year-old Mexican children while also including maternal education as a predictor variable. A total of 49 children (Mean age = 50.04, SD = 6.26) completed four precursor math tasks (i.e., verbal counting, verbal and written cardinal knowledge, and number identification) and the gross, fine and perceptual-motor subscales from the Battelle Developmental Inventory, Second Edition (Newborg, 2005). Parents reported on their highest level of education (62% of the mothers reported having completed highschool education

or less). Results from regression analyses predicting each of the precursor skills showed that maternal education, but not motor skills, predicted children's verbal counting and written cardinal knowledge skills, while verbal cardinal knowledge was predicted by children's perceptual-motor skills. These results highlight the importance of analyzing extrinsic factors at younger ages, especially given that prior research has provided evidence that more highly educated, higher SES mothers tend to be more resourceful and helpful in strengthening their children's math skills (del Rio et al., 2022).

28. Examining the developmental trajectories of basic numerical skills and the contribution of domain-general cognitive factors

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Many studies have investigated domain-specific and domain-general cognitive factors explaining individual differences in early numeracy. However, many have used variable-centred analyses, focussing on average trends, suggesting that associations among variables apply to all learners in the same way. Instead, we need more person-centred approaches to identify factors associated with differences in growth in early numeracy and determine different developmental trajectories. In this study, we will apply a series of pre-registered statistical analyses to examine the developmental trajectories of a variety of basic numerical and domain-general skills by following 552 children longitudinally, testing them approximately every three months over the course of one year, starting at 3 years of age. Once data collection is completed, we will observe how children's performance changes across multiple numerical tasks between the age of three and four. Moreover, we will run a latent growth model to determine how growth in domain-specific and domain-general skills relates to mathematics achievement when children are four years of age. With a cross-lagged panel design we will determine clusters of children and reveal potentially different developmental trajectories over time. We are currently running a test-retest study (N=100 3- to 4-year-olds) to validate the numerical tasks we will be using. So far, results indicate that the tasks are reliable (r=.6 to .9) and easy to administer.

29. Nonsymbolic proportional estimation profiles are not associated with better magnitude understanding at the early stages of fraction instruction

Roberto A. Abreu-Mendoza[1] & Elizabeth A. Gunderson[1]
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Nonsymbolic proportional reasoning skills are theorized to form an early building block of children's understanding of fractions magnitudes, yet surprisingly little work has empirically tested this relationship. Only one study has found that better performance on a nonsymbolic proportion estimation task is related to stronger general fraction knowledge (Möhring et al. 2016). To further test this relationship, we adopted a person-oriented approach: we grouped children based on their proportion estimation profiles and then asked whether the groups differed in fraction comparison skills. From a larger longitudinal study, 177 third- and fourth-graders completed a nonsymbolic proportional reasoning task and a fraction comparison task. In the proportional reasoning task, children placed proportional quantities (bicolored bars) on a horizontal line. Bars were presented in four sizes, and proportional quantities had a negative relation with size--small proportions were presented with large bars and large proportions with small ones. Additionally, larger bars required less scaling as the larger the bars were closer to the horizontal line size. Latent profile analyses on the proportional reasoning task revealed three profiles: an absolute-size biased group (n=10, mean percent absolute error (PAE)=0.38), whose estimations were worse for larger bars. The second group (n=46, mean PAE=0.17) showed a scaling effect; estimations were worse for bars that required more scaling. The third group had high estimation skills (n=121, mean PAE=0.10). Remarkably, these groups showed similar fraction comparison skills. These results suggest that better nonsymbolic estimation skills are not associated with better fraction magnitude understanding at the early stages of fraction learning.

30. Correlation between symbolic and non-symbolic matemathical skills in 4-year-old children measured through a digital tool

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In pre-schoolers, symbolic and non-symbolic mathematical processing skills are not integrated; however, they are correlated (Libertus et al., 2011; Marinova et al., 2021). The purpose of this study was to assess symbolic and non-symbolic mathematical skills in 4-year-old children, together with early mathematical skills, through a digital screening tool in an Argentinian Spanish-speaking population. A total of 138 4-year-old children (M=59.5 months, SD=3.3 months; 57.2% female) who attended private schools in CABA, Argentina were assessed. Participants completed tasks of numbering (verbal and object-counting, dot enumeration) and magnitude understanding (symbolic comparison, numeral

identification, operations) using tablets. The factorial analysis identified three main factors ($p < .05$): (1) symbolic representation, (2) non-symbolic representation, (3) arithmetic operations. The assessed mathematical skills showed moderate to strong correlations among themselves (Cohen, 1988). Symbolic and non-symbolic mathematical skills are associated with different systems; however, they are interrelated. Early assessment is substantial to detect children at risk of mathematical learning disabilities. References Libertus, M. E., Feigenson, L., Halberda, J. (2011). Preschool Acuity of the Appoximate Number System Correlates with School Math Ability. Dev Sci, 14(6), 1292-1300. Marinova, M., Sasanguie, D., & Reynvoet, B. (2021). Numerals do not need numerosities: robust evidence for distinct numerical representations for symbolic and non-symbolic numbers. Psychological Research, 85(2), 764–776.

31. Building fraction magnitude understanding through perceptual cues: A Stroop fraction number line task

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Introduction. Fraction knowledge appears to be crucial for success in algebra and future mathematical success (Jordan et al., 2017). In particular, fraction magnitude knowledge is especially important for mathematical and algebraic proficiency (Siegler et al., 2011). Despite this finding, children and adults still tend to struggle with these key mathematical concepts (Lortie-Forgues et al., 2015). However, researchers have found that perceptual cues can direct student's attention to important aspects of mathematical concepts and problems. Following this approach, these experiments will explore whether perceptual cues influence real-time fraction magnitude estimations. Current proposed study. This experiment will modify the font size of a target number in a standard 0-1 fraction number line estimation task to explore whether magnitude judgments are influenced by modifications to the font sizes of the target number. The congruent conditions will modify the font sizes of the numerator and denominator to match the symbolic fraction shown. For example, if the target fraction is 1/3, the font size of the 1 will be one third the size of the 3 on the screen. In incongruent trials, the ratio created nonsymbolically with the font sizes will not match the symbolic fraction. Previous research has found congruency effects when making fraction comparisons when the nonsymbolic ratios are the irrelevant dimension (Matthews & Lewis, 2017). This study aims to build on previous findings and quantify the potential influence of nonsymbolic ratios on fraction magnitude judgments.

32. Boundary effects in graduate students' memory of the numerical magnitude of p-values

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Recently, statisticians have challenged the conventional $p < .05$ boundary for inducing dichotomous statistical thinking, instead arguing for treating p-values continuously. Mathematical cognition research has demonstrated that people map numbers onto a continuous mental number line (MNL), including decimals (Varma & Karl, 2013). However, place-value units create MNL discontinuities (Nuerk et al., 2001; Lai et al., 2018). We recently demonstrated a discontinuity in similarity judgments for decimals expressed as p-values when they cross the conventional .05 boundary; this context-dependent 'boundary effect' appeared for statistically-trained graduate students but not undergraduates (Rao et al., under revision). Here, we test whether this discontinuity appears on a longer timescale, affecting people's memory for the numerical magnitude of p-values recalled from mock scientific abstracts. Graduate students read 16 abstracts in four blocks. After each block, they were asked to recall key information from each abstract (i.e., the research question, design, sample size, p-value, and conclusion). We then assess for each participant whether their recall is biased away from the .05 boundary, i.e., misremembering p-values as being smaller when below .05 but larger when above .05. We found this pattern in a pilot study ($d = -1.1$). We will report the results for a full study of 60 participants. These results set up experiments to test mechanistic hypotheses of categorical effects on statistical cognition as well as the efficacy of teaching interventions to address and ameliorate these categorical biases affecting statistical cognition.

33. Is 16/9 more than 13/8? Fraction comparison performance depends on symbolic format, problem features, and attitudes

Jennifer Murray[1], Megan Smitz[1], & Martha Alibali[1]
[1]University of Wisconsin – Madison

Knowledge of fraction magnitudes—that is, understanding of the relative size of a fraction compared to other numbers—is related to success in algebra and other advanced math courses. However, many learners struggle to grasp fraction magnitudes. Most previous work on fraction magnitude understanding has focused on fractions less than one (i.e., proper fractions), and has used magnitude comparison tasks, which involve judging which of two fractions is larger. The current study extends prior work to investigate adult college students' ($N = 48$) performance on magnitude comparisons of fractions greater than one, including both improper fractions (e.g., 16/9) and mixed numbers (e.g., 1 7/9). We consider

whether performance in comparing fractions greater than one is dependent on (a) symbolic format (i.e., improper fractions vs. mixed numbers), (b) features of the numbers being compared, specifically, whether they have the same whole number component (e.g., 1 2/5 to 1 3/4) or different whole number components (e.g., 1 2/5 to 2 3/4), and (c) the solvers' attitudes towards mathematics. Preliminary results indicate that adults were more accurate at magnitude judgements (i.e., which is larger?) for pairs of mixed numbers than for pairs of improper fractions, and they were also more accurate when the two numbers in a pair had different whole number components (e.g., 1 2/5 to 2 3/4) than when they had the same whole number component (e.g., 1 2/5 to 1 3/4). Participants with higher mathematics self-confidence were also more accurate. Analyses of participants' strategy use are ongoing.

34. Do people rely on symbolic number strategies in discrete proportional reasoning?

Paige Dadika[1] & Michelle Hurst[1]
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Proportional reasoning is an integral part of mathematical understanding; however, people often struggle to understand ratios, particularly when presented in discrete formats (Hurst et al., 2022). Prior research suggests that these difficulties stem from specific errors, such as numerical interference, where children make judgements using the value of the numerator rather than considering the entire fraction. This is more common in discrete formats, where information is presented in units and numerical values can be estimated or counted, emphasizing the role that symbolic numbers have in these errors (Boyer et al., 2008). Our project will test whether this error is in fact driven by symbolic number interference. Children and adults will be shown stimuli of either discrete or continuous proportions and asked to judge which of the two contains a higher percentage of a target color. To limit people's ability to count, a subset of participants will continuously repeat nonsense syllables, a verbal interference task that has been shown to prevent the use of inner speech (Nedergaard et al., 2022). We will compare performance when evaluating each representation type with the presence and absence of verbal interference. We have two specific hypotheses: 1) The verbal interference task will prevent the use of a symbolic counting strategy and result in improved performance on discrete proportional reasoning and 2) This performance improvement will be unique to discrete ratio representations and will not be evident with continuous representations.

35. Processing speed links approximate number system and arithmetic abilities

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Mechanisms underlying the correlation between approximate number system (ANS) and arithmetic abilities remain unclear. We hypothesized that processing speed can explain this correlation. This correlation was significant only when the dot arrays were displayed for 200 ms, but not when they were presented until response, implying the importance of processing speed (Study 1). To examine the role of processing speed, 120 adults completed dot comparison (display time, 200 ms), arithmetic, two processing speed (inspection time and choice reaction time), and control tasks (Study 2). We observed a significant correlation between ANS and arithmetic performance. However, it disappeared after controlling for processing speed. Inspection time accounted for the correlation between the accuracies of the dot comparison and arithmetic tasks, while choice reaction time accounted for the correlation between the reaction times of the two tasks. Overall, processing speed can be an alternative mechanism for the correlation between ANS and arithmetic abilities.

36. Do fine motor skills and finger gnosia predict the development of arithmetic through finger-use? A longitudinal study to investigate the functionalist hypothesis

Maëlle Neveu[1] & Laurence Rousselle[1]
[1]University of Liège

Fine motor skills (FMS) and finger gnosia have been shown to be a key component of arithmetic development, but the processes underlying this relationship are still poorly understood. The aim of this study was to test whether FMS and finger gnosia would support arithmetic development through the use of finger-based calculation strategies. The predictive value of FMS and finger gnosia on arithmetic development was explored, as well as the possible mediating role of finger-use on these relationships. Seventy-four 6-year-old children were assessed on four occasions, between the beginning of grade 1 and the end of grade 2. At each measurement time, they were asked to complete tasks assessing arithmetic skills, finger gnosia and FMS. By conducting latent growth models, the initial value of FMS and its rate of change were not found to be significant predictors of the development of arithmetic skills. Conversely, the initial value and rate of change of finger gnosia were shown to be a key predictor of arithmetic development. Taken together, they explained 43% of arithmetic development between the beginning of grade 1 and the end of grade 2. Latent growth models failed to show that finger gnosia predicted the development of arithmetic skills through finger-use, suggesting that at this stage of development, the origin of

the finger gnosia/arithmetic relationship failed to be functional.

37. Seeing the whole picture: Fraction magnitude processing using non-symbolic fractions

Saranya Kumary[1], Amanda George[1], & Darcy Hallett[1]
[1]Memorial University of Newfoundland

Introduction: Many people still struggle with understanding fractions. When attempting to process fractions, individuals often focus on the individual components (numerator and denominator) as opposed to the magnitude of the fraction. In support of this componential approach, Bonato and colleagues (2007) found that, when asked to compare fractions ranging from 1/1 to 1/9 to 1/5, both the distance effect and the SNARC effect was consistent with perceiving the quantity of the fractions in terms of the denominator rather than the fraction. Other researchers have subsequentially found that using more complicated fractions will make responses more sensitive to the quantity of the fraction. We propose to replicate these studies using non-symbolic representations of fractions (that do not have components). As the non-symbolic fractions should reflect the quantity of the fraction, we can compare how symbolic fractions are processed compared to their non-symbolic counterparts: Method: Participants will complete a measure of fraction understanding, a fraction comparison test (with both symbolic and non-symbolic fraction representations), and a number line task. In the fractions will consist of two sets, the simple set used by Bonato et al (2007) (i.e., 1/9, 1/8, 1/7, etc.) and a more complex set used by Schneider and Siegler (2010) (i.e., 2/9, 2/7, 3/8, etc.). These fractions will be presented both symbolically and as partially filled horizontal rectangles. Statistical Approach: We will measure the distance effect and SNARC effect for each set of fractions and compare the non-symbolic and symbolic fractions to each other.

LIGHTNING TALKS

L1/S4D: Session 1 (Wednesday, 3:45-5:00 PM)

1. **The influence of reasoning ability, processing speed and domain-general divergent thinking on mathematical creativity**

Michaela A. Meier[1], David Z. Hambrick[2], Alexander P. Burgoyne[3], & Roland H. Grabner[1]
[1]University of Graz; [2]Michigan State University; [3]Georgia Institute of Technology

Creativity has been recognized as one of the most important skills for success in the 21st century, especially creativity in the domain of mathematics. Despite this, our knowledge of constructs contributing to performance in mathematical creativity is still limited. Most commonly, creativity is assessed using divergent thinking tasks (i.e., generating a variety of creative ideas by exploring different possible solutions to a problem in a limited amount of time). Responses are then scored for fluency (number of correct answers), flexibility (number of categorically different answers), and originality (usually judged by raters). Especially when a composite score is used, a fluency confound occurs. This raises the question of how much variance in mathematical creativity scores can be explained by processing speed, in contrast to what can be explained by general creative thinking processes, reasoning, and experience in the specific domain. To this end, this study assesses creativity, reasoning ability, processing speed, and learning experiences in the verbal, numerical, and figural domains. Data will be collected online at Michigan State University and Georgia Tech (planned N ≈ 500), and collection will be completed no later than May 2024. The data will be analyzed using structural equation modeling to determine if mathematical creativity is predicted solely by numerical reasoning ability, numerical processing speed, and mathematical experience, or if reasoning ability and processing speed in the figural and verbal domains also contribute to the prediction of mathematical creativity. Overall, this study will contribute to a better understanding of the complex field of mathematical creativity.

2. **Tackling the maths anxiety barrier: can a digital maths game help children to spontaneously decide to practise more maths at home**

Pierpaolo Dondio[1], Mauriche Gomides[2], & Flavia Santos[2]
[1]TU Dublin; [2]University College Dublin

Digital game-based learning can have a positive effect on pupils' cognitive abilities, an effect that is larger the more the games are played. In this study we investigated the profile of primary school children that spontaneously kept playing a maths digital game from home after the in-class game-based intervention was completed. We wondered what factors could have predicted the decision of a student to keep playing and whether emotional factors such as maths anxiety (MA) represented a barrier. We analysed a dataset of 814 Irish pupils (F=371, M=443, age 8-11 years old) participating in a game-based intervention under Happy Maths and Arithmos projects. After being engaged in a 6- or 5-week in-class intervention, pupils had the possibility to keep playing from home. No obligation or reward was associated with playing from home. The following predictors were considered: gender and age of players, their level of maths abilities, MA and their familiarity with videogames. 49% of pupils kept playing the game, meaning that half of the pupils spontaneously decided to practise extra mathematics. The results of zero-inflated hurdle count models showed how older children, players with higher maths abilities and players that usually do not play videogames played more from home, while MA was a significant factor preventing children playing from home, evidence that MA triggered maths avoidance even outside the classroom and in the context of educational games. Even if MA was a significant barrier, 37% of highly maths-anxious students played from home, suggesting that gameplay may mitigate maths avoidance.

3. **Overcoming the natural number bias in fraction comparison through magnitude-based reasoning: Results of an intervention study**

Michael D'Erchie[1], Johannes Rosenkranz[2], Sabrina Schwarzmeier[1], & Andreas Obersteiner[1]
[1] Technical University of Munich; [2]University of Education Freiburg, Germany

Introduction: Many students struggle with understanding fractions. Specifically, when comparing fractions, students often show a natural number bias, that is, they rely on reasoning about natural numbers (e.g., 2/4 is greater than 1/2 because 2 > 1 and 4 > 2). This bias has been documented in students and adults, suggesting it is resistant to change. The effectiveness of short-term interventions in reducing this bias is unclear. This study examines whether an intervention focusing on reasoning about fraction magnitude (i.e., the size of 1/2 and 2/4) can reduce the natural number bias. Methods: Participants were 331 students (M=11.45 years). They were randomly assigned to an intervention group or one of two control groups. The intervention group received computer-based

training to associate symbolic fractions with dynamic visual representations (to activate fraction magnitude). The first control group also received computer-based training on fractions but with a different tool that did not focus on fraction magnitude. The second control group received no training. Results: Unlike the control groups, the intervention group improved accuracy in fraction comparison. In line with previous studies, students displayed three distinct bias patterns (typical, reverse, or no bias). Substantially more students from the intervention group than the control groups shifted from typical or reverse bias in the pretest to no bias in the posttest. Conclusions: Short-term training enhanced students' ability to activate fraction magnitudes in fraction comparison and reduced the occurrence of the natural number bias. Our findings challenge previous research that suggests that the bias is rather persistent.

4. **The role of language in children's beliefs that numbers are infinite: Insights from Hindi and English learners in India**

Urvi Maheshwari[1], Jessica Sullivan[2], & David Barner[1]
[1]University of California San Diego; [2]Skidmore College

Despite experiencing the world as finite, by age six, many children believe that number, time, and space are infinite. Recent studies (Chu et al., 2020; Sullivan et al., 2023) argued that children might infer the existence of infinite magnitudes through experience with number words, which provide a system of rules for generating ever-larger numbers. In English, a finite set of unit ('one' - 'nine') and decade ('twenty' - 'ninety') labels can be combined to generate numbers between 'twenty-one' and 'ninety-nine', and even larger numbers combined with 'hundred', 'thousand', 'million', etc. Although the labels children experience are finite, they might nevertheless make an inductive inference that ever-larger numbers can be imagined. Unlike English, Hindi exhibits many morphological and phonological variations in the count routine, and numbers 1-100 need to be memorized (Comrie, 2011). We investigated whether children learning Hindi show a more protracted developmental trajectory for learning the productive rules of counting, and the belief that numbers are infinite. We tested 120 four-to-six-year-old Hindi- and English-speaking children in India on their verbal counting skills and beliefs about infinity, and found that, relative to Hindi speakers, English speakers (1) demonstrated greater counting proficiency, and (2) were more likely to believe that every number has a successor. We found no significant difference of language on the belief that numbers are therefore endless, though overall infinity beliefs were low, and children were younger than in previous studies. We conclude that language plays an important role in children's belief that numbers are infinite.

5. **Domain-general and domain-specific antecedents of pre-algebraic knowledge: Focusing on English-language learners with word-problem difficulty**

Xin Lin[1]
[1]University of Macau

As students learn how to solve word problems, they are engaged in the process of converting real-life scenarios described in word-problem statements into mathematical equations (Wong & Ho, 2017). Therefore, practicing solving word problems forms the basis for developing pre-algebraic knowledge (Geary et al., 2008). Consequently, students with word-problem difficulty (WPD) may encounter difficulties developing such pre-algebraic knowledge (Powell et al., 2021). A significant portion of students experiencing WPD in the U.S. are English language learners (ELLs; Powell et al., 2020). ELLs' difficulty in solving word problems could often be attributed to comprehending word-problem statements (Orosco, 2014). In addition, lower performance with cognitive and foundational mathematics capacities could also lead to WPD (Lin et al., 2021). Given the heterogeneity in factors contributing to WPD, it is plausible that students experiencing WPD may encounter various obstacles in their progression toward abstract pre-algebraic thinking. The present study investigated how various antecedents contributed to pre-algebra's initial level and growth rate among students who experience WPD. Furthermore, we examined if such a profile differs for ELLs (n = 75) and non-ELLs (n = 55) with WPD. We assessed 130 students at the beginning of Grade 3, end of Grade 3, and middle of Grade 4. The latent growth curve analyses revealed only word-problem solving emerged as a predictor of pre-algebraic growth across ELLs and non-ELLs. ELLs, potentially due to their stronger foundational computation skills, demonstrated more effective utilization of cognitive resources in acquiring pre-algebraic knowledge.

6. **A meta-analysis of mathematics anxiety interventions in reducing mathematics anxiety and improving mathematics performance**

Yuting Liu[1] & Peng Peng[1]
[1]University of Texas at Austin

Based on 51 studies on interventions aiming at reducing mathematics anxiety (MA interventions) involving 7,673 participants ranging from children to adults, this meta-analysis examined the effects of different types of MA interventions on mathematics anxiety reduction and mathematics performance improvement. Results showed MA interventions significantly reduced mathematics

anxiety (MA) with a strong effect size, g = -.706, 95% CI [-.933, -.480], but had a statistically weaker effect on improving mathematics performance (MP), g = .195, 95% CI [.033, .357]. Results showed that for MA reduction, the effectiveness of interventions is as follows: combined MA interventions, g = -1.120, 95% CI [-1.610, -.630], mathematics anxiety-oriented interventions, g = -.940, 95% CI [-1.600, -.277], and mathematics skills-oriented interventions, g = -.360, 95% CI [-.546, -.174]. Moderation analysis results showed that for students with high MA, mathematics anxiety-oriented interventions were more effective than mathematics skills-oriented or combined mathematics anxiety interventions; MA interventions conducted in a class setting were significantly more effective compared to those conducted individually. For mathematics performance outcomes, only mathematics skills-oriented interventions were effective, g = .256, 95% CI [.012, .501]. Taken together, to reduce MA, especially for students with high MA, it is important to directly target MA, with possible peer support from the group interventions. However, the most immediate effective and cost-effective intervention to simultaneously reduce MA and improve MP is mathematics skills-oriented interventions. Future research should further investigate the possible "sleeping effect" of mathematics anxiety-oriented interventions or combined MA interventions on the MP in the long run.

7. **Bidirectional longitudinal relations between preschool children's spatial skills and interest in spatial activities [WITHDRAWN]**

Xinzhuo Zou[1] & Xiao Zhang[1]
[1]The Univerisity of Hong Kong

Understanding the dynamic relation between interest and ability during childhood has crucial implications for educational practices. Spatial skills are essential for success in science, technology, engineering, and mathematics fields, yet little is known about how children's spatial skills affect and are affected by their spatial interest. This study aimed to investigate the reciprocal relations between preschool children's spatial skills and interest in spatial activities. One hundred and ninety-seven Hong Kong preschoolers (age at the first wave of assessment: M ± SD = 52.72 ± 3.30 months) and their mothers were followed three times from the second to the third year of preschool. At each time point, children were tested individually on their spatial skills, and their mothers rated their interest in spatial activities. Random-intercept cross-lagged panel modeling showed that children's spatial skills at Time 1 (T1) positively predicted their interest in spatial activities at Time 2 (T2). Additionally, children's interest in spatial activities at T2 positively predicted their spatial skills at Time 3 (T3). These cross-lagged relations remained statistically significant even after controlling for children's age, sex, interest in visual art activities and family income. The findings indicate a reciprocal relation between young children's spatial skills and interest in spatial activities. They also suggest that spatial training programs that combine skill-building interventions with interest enhancement may be more effective than programs focusing solely on one aspect.

8. **Is students' ability of visually comparing fraction magnitudes related to their general fraction knowledge? An eye-tracking study**

Sabrina Schwarzmeier[1] & Andreas Obersteiner[1]
[1]Technical University of Munich

Introduction. Fraction magnitudes are difficult to understand for many students. However, studies suggest that children are able to compare visually presented proportions from a very early age (Jeong et al., 2007). During fraction instruction, teachers use visualizations as well. Tape diagrams (i.e., rectangular visualizations) are thought to be especially beneficial for comparing fraction magnitudes because they draw on children's early abilities of proportional reasoning. However, the relation between these early abilities and fraction knowledge is not well understood. Specifically, it is unclear whether students' ability to solve visual comparison tasks efficiently is related to more general knowledge of fractions. We investigated this relationship and also analyzed comparison processes with eye tracking. Methods. Sixty-seven children (mean age: 12.0 years) took a paper-pencil test on fraction knowledge. After that, they solved 40 comparison tasks with tape diagrams on a computer screen. We recorded their eye movements, accuracy, and response times. Results. Students' ability of visually comparing fraction magnitudes was related to their level of general fraction knowledge. Cluster analysis identified five groups of students. Both students' general fraction knowledge and their comparison processes only partly explained their efficiency in the visual fraction comparison tasks. Instead, students' tendency to compare the absolute rather than relative magnitudes represented in the diagrams better explained their efficiency. Conclusion. There is a relationship between students' general fraction knowledge and their ability of visually comparing fraction magnitudes. However, students differ in how they use their knowledge to compare visual fraction magnitudes.

9. **Children's estimates of equivalent rational number magnitudes are not equal: Evidence from fractions, decimals, percentages, and whole numbers**

Lauren Schiller[1], Roberto Abreu-Mendoza[2], Clarissa

Thompson[3], & Miriam Rosenberg-Lee[4]
[1]Columbia University; [2]Indiana University, Bloomington; [3]Kent State University; [4]Rutgers University, Newark

Integration of rational number knowledge with prior whole number knowledge has been theorized as critical for mathematical success. It is generally assumed that magnitude knowledge for rational numbers depends on the similarity between whole numbers and the superficial features of the newly introduced rational number notations. Specifically, percentages are viewed as most similar to whole numbers with their fixed, unstated denominator of 100. Decimals are often assumed to be easier than fractions because their place-value structure is an extension of the base-ten system for whole numbers, unlike fractions, which have a bipartite structure (i.e., a/b). However, there has been no comprehensive investigation of how fraction, decimal, and percentage knowledge compares with whole number knowledge. To assess understanding of the four notations, we measured within-subjects number line estimation of equivalent fractions and decimals with shorter string-lengths (e.g., 8/10 and 0.8) and longer string-lengths (e.g., 80/100 and 0.80), percentages (e.g., 80%), and proportionally equivalent whole numbers on a 0-100 scale (e.g., 80.0). Middle school students (N = 65, 33 female) generally underestimated all formats relative to their actual values (Whole Numbers: 3% below, Percentages: 2%, Decimals: 17%, and Fractions: 5%). Shorter string-length Decimals and Fractions were estimated as smaller than equivalent longer string-length equivalents. Overall, Percentages were estimated similarly to corresponding Whole Numbers, Fractions had modest string-length effects, and Decimals were the most underestimated, especially for single-digit Decimals. These results highlight the strengths and weaknesses of children's understanding of each notation's magnitudes and challenge the assumption that decimals are easier than fractions.

L2/S8D: Session 2 (Thursday, 3:45-5:00 PM)

1. **Building fraction knowledge using real-world examples in conversation**

Karina Kling[1], Yihan Chen[1], & Susan Levine[1]
[1]University of Chicago

Fractions are challenging for many children, and little is known about how parents and children informally communicate about fractions using examples in their environment. Dyads of 6-7 year-old children and their parents (N=65) participated in an online, video-recorded study hosted on the platform Lookit (Scott & Schulz, 2017). Children completed a symbolic-to-nonsymbolic fraction mapping task (adapted from Miura et al., 1999) which was followed by a conversational period where parents and children were invited to characterize fractions using descriptions and real-world examples. Finally, children completed a post-conversation version of the mapping task. Discussion content was coded for mentions of fraction properties (e.g. being a number, having a part-whole form, having equal-sized parts, or being related to subdivision) and mentions of symbolic fraction labels. Responses to the question "where do you see fractions during your day" were coded as real-world examples when they contained reference to objects ("pizza"), contexts ("baking"), or ideas ("time") encountered in daily life. Slightly over half of all dyads (58%) explored at least one example, and within this group, many conversations included concrete objects (95%), food items (68%), and/or references to the social context of sharing (32%). Controlling for pre-conversation fraction mapping performance, the number of different real-world fraction examples raised in parent-child discussions positively predicted children's post-conversation fraction mapping performance (beta=0.13, t(54)=3.62, p<.001). These results suggest that conversations that connect fractions to their uses in the real world hold potential for benefitting young children's fraction understanding.

2. **Adults' views on key academic domains: When is literacy more important than math?**

Megan Merrick[1], Giulia Borriello[2], Amanda Grenell[1], & Emily Fyfe[1]
[1]Indiana University-Bloomington; [2]Kent State University

Research has revealed the benefits of early mathematics knowledge for predicting later achievement. Yet, early literacy skills are also of widespread importance. Our goal was to explore how adults viewed these two constructs and their relative importance for predicting key life outcomes. Across two studies, (Study 1: N=294; Study 2: N=292) adults defined math and four related topics, rated the importance of these topics for predicting life outcomes and rated the importance of 12 activities for supporting children's knowledge of these topics. Adults' definitions of math were largely equated with numeracy (using terms like "the study of numbers"). Adults' definitions of literacy were largely equated with reading and writing (using terms like "the ability to read"). While definitions of math and literacy were fairly narrow (including 2 to 3 themes), adults were more confident in their definitions of literacy compared to their definition of math, ps< .001. For predicting life outcomes, adults rated literacy as more important than math for predicting all future life outcomes, except for future math achievement, ps< .001. For rating children's activities as supportive, adults sometimes rated activities as more important for supporting literacy than math (5 out of 12 activities). Surprisingly, activities like "making music" and "using calendars and dates" were rated as supporting literacy skills over math skills, ps< .001. Adults view math knowledge is useful in supporting key life outcomes and see its use across children's activities. However, literacy skills are occasionally viewed more important than math skills in supporting children's knowledge.

3. **Math skills in bilingual and monolingual children with or without specific learning disorders and the role of socio-economic status**

Paola Bonifacci[1], Marina Porrelli[2], Alessia Rapino[3], Lucia Pradelli[4], Carlotta Facini[5], Chiara Gelmini[6], Chiara Nanni7, Anna Gallani8, & Simona Chiodo[2]
[1]University of Bologna; [2]AUSL Bologna; [3]AUSL Modena; [4]AUSL Piacenza; [5]AUSL Parma; [6]AUSL Reggio Emilia; [7]AUSL Imola; [8]AUSL Ferrara

There is evidence that language skills may, at least partly, shape the acquisition of numerical and mathematical skills. More evidence needs to be collected on how children exposed to a heritage language within the domestic context and to the societal language in the school context deal with math scholastic achievements. Further, few studies evaluated math skills in bilingual children with Specific Learning Disorders (SLD), taking into account the role of socio-economic status. The present study included 276 participants between 8 and 11 years divided into four groups: bilinguals with typical development (N=83), bilinguals with SLD (N=58), monolinguals with typical development (N=93), monolinguals with SLD (N=42). Participants were administered a battery of tasks, including reading and writing numbers, mental calculation and symbolic comparison. Results showed a main effect of the diagnostic group in all tasks and an effect of bilingualism in most tasks if SES was not included in the analyses. However, only marginal differences between bilinguals and monolinguals were found when SES was included as a

covariate, particularly in number reading and writing. No main interactions emerged between bilingualism and the diagnostic group. These results highlight how the presence of a SLD leads to similar results in bilinguals and monolinguals. However, socio-economic status needs to be considered in the evaluation of math skills in bilinguals to avoid underestimation. References: Kleemans, T., Segers, E., & Verhoeven, L. (2018). Role of linguistic skills in fifth-grade mathematics. Journal of Experimental Child Psychology, 167, 404–413.

4. **Highlighting contrasts between problems help preschoolers solve pre-algebraic problems**

Chen Cheng[1]
[1]The Hong Kong University of Science and Technology

Early arithmetic is crucial for children's future mathematical learning. Identifying proximal scaffolding area may help uncover children's early computational capacity. Previous research has shown that providing contrast between stimuli can facilitate attention (Childers et al., 2014) and overcome working memory capacity limitations (Zosh & Feigenson, 2015). In three experiments, we examined how highlighting contrasts between problems helps preschoolers solve pre-algebraic problems. In Experiment 1, 24 preschool children (Mage = 6.2 years) were given two non-symbolic solving for unknown addend problems (1+X = 3; 2+Y=3). Each problem was demonstrated three times in a row. At Test, children were asked to identify the problems as well as to use the solutions to solve a new adding problem. Children failed in all trials. In Experiment 2 (N = 49, Mage = 6.37 years), the problem was demonstrated in an alternative pattern so that children could compare the two problem sets. We found above chance performance in all test trials (ps < .02). In Experiment 3, we further examined whether highlighting the contrast between problems help children solve problems that go beyond the small number representation system. Children (N = 49, Mage = 6.33 years) completed the same two non-symbolic unknown-addend problems but with one solution in the small number range (4+X=5) and the other in the large number range (1+Y= 5). Again, children succeeded in all trials. Together we found that providing numerical contrast help children track different problems and help preschool children solve non-symbolic unknown-addend problems.

5. **College students' self-regulated studying of worked examples**

Rebecca Adler[1], Xinran Wang[1], & Bethany Rittle-Johnson[1]
[1]Vanderbilt University

Little is known about how students self-regulate their mathematics studying, including their use of effective study strategies like worked examples. Thus, we conducted a study examining students' self-regulated use and belief for studying correct worked examples, defined as studying correct steps and solutions to a problem; incorrect worked examples, defined as studying common errors to a problem; and problem-solving. Data was collected online; the 63 participants (61% women), who were attending an ultra-selective university in the southeastern United States, received course credit for participation. Participants completed a pretest probability knowledge measure, and then completed a studying session. In this session, participants studied four problem types. They chose what study strategy to use for each of 16 trials, and then completed a posttest identical to the pretest. Lastly, they completed a beliefs measure of the difficulty and effectiveness of the three study strategies. Students' probability knowledge improved—scores on posttest increased an average 20% (SD = 15.6%). In addition, 39% of the trials were studying worked examples—higher than past work (Foster et al., 2018; Zhang et al., 2022). In terms of beliefs, students on average rated the effectiveness of studying correct worked examples and problem-solving similarly high, but lower for incorrect worked examples. Students also on average rated problem-solving as the least difficult of the three study strategies. Unlike past work (Foster et al., 2018), we found an alignment between students' use and belief. More work is needed to more fully understand students' self-regulated use and belief of worked examples and problem-solving.

6. **Relations among parents' own math experiences and their expectancy and value for children's math achievement**

Siqi Zhang[1], Suzanne Varnell[1], Salvador R. Vazquez[1], & Sarah H. Eason[1]
[1]Purdue University

Parents' beliefs play a significant role in how they support young children's learning (Douglas et al., 2021). While existing studies often assess parents' math beliefs based on children's future achievements or school readiness benchmarks, nuances among these measurements remain unexplored, such as distinguishing between parents' expectations and value (Wigfield & Eccles, 2000).This study explored various types of parental math beliefs (i.e., expectations for how well their child will do, importance to them that child does well, and concerns if their child does not do well), and examined distinctive associations between their own math experiences and beliefs for children's math learning. Parents of children aged 3-5 in the United States (n=640) completed a survey through Prolific. Expectation, importance, and concern were found to be moderately positively correlated, r(638)=.34 - .66, p<.001. Controlling for family

demographics and parents' assessment of children's current math abilities, multiple regressions indicated that parents' personal math experiences (i.e., self-concept, enjoyment, and family beliefs) and their general value of math can positively predict their math expectations (personal experience: β=.16, p=.000; general math value: β=.18, p=.000) and importance (personal experience: β=.08, p = .045; general math value: β=.37, p= .000). However, only parents' general value of math was significantly associated with their concerns regarding children's math achievement (β=.36, p = .000). The results highlight the importance of considering the wording of questions when assessing parents' expectations and beliefs about their children's math achievement and understanding variation in parents' beliefs based on their own experiences.

7. **Practicing arithmetic with spatial representations improves fact retrieval**

Elida Laski[1] & Marina Vasilyeva[1]
[1]Boston College

The presented study tested the benefits of spatial representations for arithmetic learning. We hypothesized that incorporating spatial cues to numerical magnitude into arithmetic instruction improves the accuracy of arithmetic retrieval, such that children would be more likely to retrieve answers closer to the actual sum. Participants (first-graders from low-income racially/ethnically diverse backgrounds, N=202) were randomly assigned to arithmetic instruction that included either a spatial cue to numerical magnitude or did not (Spatial vs. Non-spatial). Both approaches involved eight 30-minute small-group sessions focused on solving addition/subtraction problems with totals within 10. In the Spatial condition, children solved problems using materials of varying lengths to represent numbers (i.e., the length of 10 was twice as long as 5). In the Non-spatial condition, children practiced the same problems using equal-sized square tiles to represent all numbers. At pretest and posttest, participants completed a timed measure of arithmetic fluency and their average absolute error was computed. A mixed effects model was conducted to generate estimates of condition effects accounting for the multilevel structure of the data (groups clustered within schools). Condition and pretest reached statistical significance, 95% confidence interval, while sex, age, and school did not. The residual variability was explained by the intercept and the random slope with Intraclass Correlation Coefficients of .22 and 3.78, respectively. Children in the Spatial condition retrieved sums closer to the correct answer (i.e., smaller absolute error). The results point to a causal effect of spatial representations on arithmetic learning.

8. **Linking arithmetic strategy use to spatial skills in children**

Xinhe Zhang[1] & Elizabeth Gunderson[1]
[1]Indiana University

Calculation skills are essential to children's math learning. When solving conventional problems (e.g., 7+5=_), children begin by counting objects and gradually develop advanced strategies, such as decomposition. Prior work has found that mental rotation skills relate to advanced strategies on conventional calculation problems in first-grade girls (Laski et al., 2013), and that training mental rotation leads to improvements on missing-term problems (e.g., 7+_=12) (Cheng & Mix, 2014). Yet, to our knowledge, no study has directly assessed strategies on missing-term problems or other problem types (e.g., two-step calculations like 3+4+5=_). Here, we asked whether spatial skills relate to advanced mental strategy use across genders and problem types. Eighty second- and third-graders completed measures of mental rotation, mental transformation, calculation accuracy, and calculation strategies. We identified a novel transformation strategy, where children manipulate equations (e.g., transforming 7+=12 into 12-7=_), that occurred on 32.6% of missing-term problems. We categorized decomposition and transformation as mental strategies. Compared to boys, girls showed lower mental rotation skills, employed more counting and fewer mental strategies, but did not differ in calculation accuracy or retrieval strategy use. Controlling for gender, mental rotation skill was positively associated with mental strategies in both conventional (r=.27, p=.021) and missing-term calculations (r=.49, p<.001). Mental transformation skill was similarly linked to greater use of mental strategies in missing-term (r=.26, p=.025) and two-step calculations (r=.23, p=.042). These results indicate that the progression from counting strategies to advanced mental strategies not only depends on math learning but also the development of spatial cognition.

L3/S10D: Session 3 (Friday, 10:45-12:00 PM)

1. **Constructing algebra: Conceptual change in algebraic thinking and its relation to arithmetic knowledge and domain-general cognitive skills**
Ulises Xolocotzin[1], Ana Medrano[1], & Teresa Rojano[1]
[1]Cinvestav

Substantial evidence shows that with adequate materials and instruction, elementary students can engage in sophisticated algebraic practices, including noticing, expressing, and justifying generalizations. However, the learning processes involved in these developments still need clarification. This work explores the relationship between arithmetic knowledge, cognitive resources, and algebraic thinking. Our research questions were: (1) How can children construct concepts such as generalization, covariation, and variable, without precedent in the arithmetic domain? (2) How is this construction related to children's cognitive resources and previous mathematical knowledge? We present a mixed-methods study with 105 elementary students (Grades 2, 4, and 6) without early algebra instruction. The students answered an algebraic thinking test and a battery that assessed arithmetic, IQ, and executive function. To answer RQ1, we used qualitative coding derived from a conceptual change framework to characterize the intuitive strategies used to solve the tasks in the algebraic thinking test. As for RQ2, we used a multiple regression model to assess how conceptual change processes related to arithmetic knowledge and domain-general skills such as verbal reasoning, matrix reasoning, and executive functions such as inhibition and switching. The qualitative results suggest substantial individual differences, including students who used entirely arithmetic reasoning forms and students who engaged with sophisticated conceptual change processes. The quantitative results suggest that domain-general skills predict the sophistication of students' conceptual changes over and above arithmetic knowledge. These results will help to refine existing theoretical views of how algebraic thinking develops by accounting for the participation of cognitive mechanisms.

2. **Exploring the utility of home math environment profiles for predicting children's math skills**
Shirley Duong[1], Heather Bachman[1], Elizabeth Votruba-Drzal[1] & Melissa Libertus[1]
[1]University of Pittsburgh

Mixed findings on the home math environment (HME) and links to children's math skills motivate alternative ways to describe the HME, which includes number talk, math activities, beliefs, and attitudes. The present study explored the utility of using profiles of families' HMEs as combinations of these four dimensions to predict children's math skills. Caregivers and their 4-year-old children (n=127) were enrolled in a longitudinal study examining socioeconomic variability in the home learning environment and children's academic skills. A multi-method approach was used to measure the HME: observations of caregiver-child interactions, online questionnaires, and phone interviews. Parents and children completed assessments of their math skills. Correlations were examined between HME features of the same dimension and children's math skills to determine the final clustering features. Cluster analysis using the diversity of home math activities, the diversity of parent number words, parent math anxiety, and parent math benchmark beliefs revealed four HME profiles: Low activity diversity and talk, high anxiety (n=38); Low anxiety and beliefs (n=32); High activity diversity and beliefs, low anxiety (n=33); and Low activity diversity, high talk diversity (n=24). On average, children experiencing high math activity diversity, high parental math benchmark beliefs, and low parent math anxiety had the highest math skills one year later. However, this effect was driven solely by the activity diversity feature. Thus, the HME clusters may not have added value over individual HME variables in predicting math skills. These results motivate further exploration of activity diversity and add to growing knowledge on HME measurement.

3. **Math anxiety hinders the game experience of primary school pupils playing a maths digital game, but only when they play one versus the other**
Pierpaolo Dondio[1], Andre Almo[1], & Mariana Rocha[1]
[1]TU Dublin

While educational maths games are often single player, multi-player games add an interactive social element to the gameplay, often increasing the engagement but potentially introducing social pressure and peer-comparison that might be detrimental for anxious kids. In this pilot study, two 3rd grade classes (N=55) played the same videogame for three weeks in the classroom. The game, called Seven Spells, is a digital strategy card game aligned with the 3th grade maths curriculum. The game is open-ended, allowing players to build strategies of different complexity. One class played the single-player version of the game (player-vs-computer mode), while the other class played the multi-player version (player-vs-player mode). The level of Maths Anxiety (MA) of each player was collected before the study using the mAMAS

scale. We tested the differences between the two versions of the game in terms of complexity and accuracy of the moves executed by the players. Our results showed how players playing the player-vs-player game did more complex moves but, even after controlling for the complexity of each move, these moves were less accurate than the ones in the player-vs-computer group. A significant interaction between MA and game modes was found, by which MA decreased the quality and complexity of the moves in the player-vs-player game, but not in the player-vs-computer game. The findings showed how playing with classmates might push players to try more complex moves, but it could trigger maths anxiety patterns that hinders the quality and complexity of the moves of anxious students.

4. **Mathematical language and its relation to numerical performance in linguistically diverse elementary-school children**

Vera Hilger[1], Sonja Ugen[1], Linda Romanovska[1], Katharina Tremmel[1], & Aurélie Wealer[1]
[1]University of Luxembourg

Recent research has shown that mathematical language is a central predictor of mathematical abilities. Related studies mainly focused on linguistically rather homogenous samples. However, proficiency in the teaching language has been shown to be particularly important in multilingual contexts. In Luxembourg, for example, many student's home languages differ from the language of math instruction, impacting their school performance. We therefore aimed at exploring the link between (mathematical) language and numerical skills in linguistically diverse elementary-school children. Language skills were assessed through a self-developed receptive vocabulary measure with 18 mathematical and 45 general language items. To assess numerical skills, we devised a total of ten tasks (e.g., transcoding, number comparison). Further measures included demographics (language background, socioeconomic status, age, gender) and rapid automatized naming. Data was collected on 598 third-grade children attending Luxembourgish public schools, whereof 56% did not speak the language of math instruction at home. Regression analyses revealed that mathematical and general language both significantly contributed to numerical performance. Moreover, students who spoke the language of math instruction at home had significantly higher outcomes on all measures compared to their peers. Results of a mediation analysis indicated that mathematical language significantly explained the observed performance gaps, even after controlling for children's general language abilities. These findings highlight the important contribution of mathematical language skills to numerical performance in elementary-school children with different language backgrounds. Trainings on mathematical language, in addition to general language, may potentially enhance student's understanding of mathematical instructions and contents, especially in linguistically heterogeneous education contexts.

5. **Math anxiety and math-self concept in children and parents as predictors of mathematical performance in kindergarten children**

Esmeralda Dionicio[1,2], María Inés Susperreguy [1,2], Christian Peake[2,3], Ma. Francisca del Río[2,3], Valentina Giaconi[2,4], & Yovanna Galaz[2,3,5]
[1] Pontificia Universidad Católica de Chile; [2]Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT), Chile; [3]Universidad Diego Portales; [4]Universidad de O'Higgins; [5]Universidad Alberto Hurtado

There is a consensus on the negative association between mathematical anxiety (MA) and performance in mathematics (Barroso et al., 2021; Dowker et al., 2016). Children under the age of eight already report moderate to high levels of MA (Guzmán et al., 2021; Lu et al., 2021). Emergent research informs that parental feelings and beliefs about mathematics are associated with children's beliefs and mathematical performance (del Río et al., 2020; Szczygieł, 2020). However, this area of research is still developing. In the current study, we investigated whether mathematical anxiety and mathematical self-concept of parents, and children's mathematical anxiety predicted their mathematical performance. The sample included 180 children (M age=5y 2m) from seven preschools in Chile and their parents (85% mothers). Preliminary results indicated that children's mathematical performance was not significantly correlated with children's mathematical anxiety ($r = -0.125$, $p = 0.094$), whereas parents' education was significantly correlated with children's mathematical performance ($r = 0.276$, $p < 0.001$). The multiple linear regression model, including children's and parents' MA, children's and parents' mathematical self-concept, and parents' education, explained 12 % of the variance in children's mathematical achievement ($F(5,174) = 4.814$, $p < .001$). These results align with research that has found no significant relation between math anxiety and math achievement in early childhood (Depascale et al., 2023). However, other studies have reported such an association at an early age, suggesting the need for more research in this age group to clarify further the associations between mathematical anxiety and mathematical performance in early childhood.

6. **Mathematics anxiety assessed using AMAS: Measurement invariance in university students across four countries**

Serena Rossi[1], Krzysztof Cipora[1], Alice Masi[2], & Iro Xenidou-Dervou[1]
[1]Loughborough University; [2]Padova, Italy

Many people from childhood to adulthood experience mathematics anxiety (MA), and this can impact their academic success and everyday life activities. Self-report questionnaires are the most common way to measure MA. Among several tools, the Abbreviated Math Anxiety Scale (AMAS; Hopko et al., 2003) is one of the most popular ones. AMAS has been translated and validated in different languages and age groups. However, it remains unclear whether the AMAS items are perceived in the same conceptual way by people in different countries/cultures (measurement invariance), which is a precondition for reliable cross-cultural MA comparisons. This study investigated the cross-cultural measurement invariance of the AMAS in UK, German, Italian, and Polish university students. We included data from a total of 3165 participants taken from an open online database ("Big AMAS database"; Cipora & Caviola, 2022). Although we found partial invariance between two countries at a time, we could not obtain measurement invariance between all four countries. This means that AMAS scores reported by students in these countries cannot be directly compared, which raises a methodological problem to be considered in the cross-cultural investigation of MA. More broadly, this study shows that results on AMAS obtained in individuals from a specific country cannot be generalized a priori to individuals from another country, which has not only methodological but also theoretical implications for the study of MA across countries.

7. **Effects of explicit instruction on non-symbolic estimation of ratios and differences depend on stimulus modality [WITHDRAWN]**

Kate Stuart[1], Nicola J. Morton[1], Simon Kemp[1], & Randolph Grace[1]
[1]University of Canterbury, Christchurch

Grace and colleagues (Grace et al. 2018; Chen et al 2020) found that participants learned to respond accurately to both ratios and differences of intensive (brightness) and extensive (line length) modalities in a non-symbolic task ('artificial algebra'), by feedback and without explicit instruction. However, Masin and colleagues (e.g., Masin et al 2019) found that participants were unable to estimate brightness ratios in a task with explicit instructions (magnitude estimation). These contrasting results suggest that use of numbers and explicit cognition may impede the ability to estimate brightness ratios. To test this hypothesis, we conducted pairs of experiments wherein participants responded to brightness or line length pairs in Grace et al.'s task to estimate ratios or differences. Participants in Explicit groups were told specifically to respond based on differences or ratios, and given numeric feedback after each response, whereas those in Implicit groups were trained on Grace et al.'s original non-symbolic task. Experiments 1a (n = 23) and 1b (n = 40) (Line lengths) found that the Explicit group was more accurate than the Implicit group when estimating ratios of line lengths. In contrast, Experiments 2a and 2b found that the Explicit group was less accurate in estimating brightness ratios than the Implicit group. Explicit instructions had no effect on accuracy for participants trained on differences. These results resolve the inconsistency between Grace et al.'s and Masin's results, suggesting that although the perceptual system can compute brightness ratios, participants have difficulty associating these perceived ratios with numbers.

8. **Approximate ratio processing is numerical and operates independent of language**

Chuyan Qu[1], Sam Clarke[2], & Elizabeth Brannon[1]
[1]University of Pennsylvania; [2]University of Southern California

The approximate number system (ANS) enables organisms to represent the approximate number of items in an observed collection, rapidly and independently of language. Clarke & Beck (2021) proposed that the ANS goes beyond representing natural numbers by representing rational numbers. Prior work has demonstrated that adults and children discriminate ratios in an approximate and ratio-dependent manner, consistent with the hallmarks of the ANS (Szkudlarek & Brannon, 2021). Here, we ask whether non-symbolic ratio discriminations reflect the representation of the number of perceived elements in an array or instead ratios based on continuous properties of the collections compared (e.g., total surface area, density). In Experiment 1, we tested the role of non-numerical confounds in non-symbolic ratio comparison using the connectedness illusion. This illusion allowed us to systematically alter perceived number while keeping non-numerical confounds constant. We found that adult performance was systematically influenced by which items were connected, supporting the hypothesis that ratio comparisons rely on the initial extraction of number produced by the ANS, and not just non-numerical properties. Experiment 2 replicated Experiment 1 while requiring participants to engage in a verbal shadowing task. The addition of this secondary task did not impact

performance, suggesting that ratio discriminations are not dependent on verbal working memory or explicit counting routines. Furthermore, exploratory analyses provide evidence that adults rely on part-whole (like a fraction) rather than part-part (like a genuine ratio) representational formats. These results are consistent with, and serve to refine, the hypothesis that the ANS represents rational numbers.

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9. **Do individual differences in student skills determine effects of spatial training on mathematics performance? [WITHDRAWN]**

Victoria Alexander Terry[1], Kelly Mix[1], & Susan Levine[2]
[1]University of Maryland; [2]University of Chicago

Researchers have used spatial skills training to improve children's mathematical outcomes (Xie, et al., 2020). Although this training has been effective, little is known about the mechanisms by which it works and for whom it works best. The present study evaluated whether spatial training was more effective for students with either low or high levels of mathematics skill or spatial skill, using linear regression in a dataset with 285 first and sixth grade students (Mix et al., 2021). There were three main findings. First, students with stronger initial math skills showed greater growth in mathematical performance after spatial training [$F(1, 79) = 15.67$, $p<.001$]. Second, there was a trend toward students with stronger initial spatial skills also showing greater growth in mathematical performance after spatial training [$F(1, 89)=3.73$, $p=.056$]. Lastly, students' growth in spatial skills was not a predictor of their growth in math [$F(1, 89)= -.05$, $p=.64$]. Thus, spatial training seems to lead to the greatest impact among students who already have strong mathematics and spatial skills, and the effects may be due to priming already strong baseline skills rather than improving weaker skills. Further research is needed to identify whether this trend is consistent across age, gender, and socioeconomic status. References: Mix, Levine, Cheng, Stockton, & Bower. (2021). Effects of spatial training on mathematics in first and sixth grade children. Journal of Educational Psychology. Xie, Zhang, Chen, & Xin. (2020) Is Spatial Ability Related to Mathematical Ability: a Meta-analysis.

L4/S11D: Session 4 (Friday, 2:00-3:15PM)

1. **Children's numerical estimations are biased by males more than females**

Kathleen Cracknell[1], Miaofan Chen[2], Julia Hauss[1], Lin Bian[3], & Jinjing (Jenny) Wang[1]
[1]Rutgers University – New Brunswick; [2]University of Maryland, College Park; [3]The University of Chicago

Despite a majority of elementary school teachers being female across the world (OECD, 2019), math-gender stereotypes are prevalent (Cvencek et al., 2011). Do children learn math differently from males vs. females? One way to test this is to use a classic number estimation task, where children see arrays of dots flash quickly and then guess how many there were. This task has been shown to be easily calibrated by incorrect input from an informant (Sullivan & Barner, 2014). We aimed to explore whether an informant's gender influences children's responses in the number estimation task. Children were presented with arrays of dots and were shown both a male and a female informant providing their answers. Half of the time the male provided the accurate answer (12) and the female provided the wrong answer (24), and half of the time the female provided the accurate answer (12) and the male provided the wrong answer (24). Across two studies with 158 5 to 7-year-old children, we found that children significantly overestimated the subsequent quantities after receiving the wrong answer from the male informant, but not after receiving the wrong answer from the female informant. This gender bias was specific to the numerical domain, as there was no difference in children's performance on a memory task. Exploratory analyses showed that how much children were influenced by the male informant correlated with their gender bias about math. These findings suggest that children's gender-based beliefs could influence how they receive numerical information and impact their performance.

2. **Cognitive predictors of associativity understanding and its contribution to arithmetic and algebraic computation: A latent growth curve analysis**

Eason Sai-Kit Yip[1] & Terry Tin-Yau Wong[1]
[1]University of Hong Kong

Associativity, e.g., (a + b) + c = a + (b + c), is an arithmetic principle that has been proposed to facilitate learners' mathematical performance. However, empirical evidence is awaited about the precursors of associativity understanding and its association with computational skills. The current study aims to examine the cognitive predictors of associativity understanding and whether this principle understanding predicts arithmetic and algebraic computation. Fourth graders in Hong Kong (n = 171) were assessed on their associativity understanding for five times in an interval of six months. Domain-general skills (nonverbal intelligence, verbal working memory, visuospatial working memory, inhibitory control, and spatial cognition) and computation performance (arithmetic and algebraic computation) were measured at the first and last time point respectively. A latent growth curve analysis produced two noteworthy findings. First, while nonverbal intelligence predicted the initial level of associativity understanding, visuospatial working memory and spatial cognition contributed to its growth. Second, while both the intercept and slope of associativity understanding predicted arithmetic computation, only the slope increments significantly predicted algebraic computation. The findings provide empirical evidence of cognition behind the development of the associativity principle, as well as the importance of associativity understanding to advanced mathematics. Practical implications and future research directions will be discussed.

3. **Working memory mediates the relationship between math vocabulary and math performance in Chilean second graders**

Roberto A. Ferreira[1,2], & Cristina Rodríguez[1,3]
[1]Millennium Nucleus for the Science of Learning (MiNSoL); 2Universidad de Talca; [3]Universidad Católica del Maule

Evidence suggests that both general (Peng et al., 2020) and math-specific vocabulary (Peng & Zeng, 2021) are associated with mathematical abilities. Similarly, working memory has been linked to math performance (De Smedt et al., 2009; Meyer et al., 2010). However, there is limited research on the interplay between general vocabulary, math vocabulary, working memory, and math performance. This study investigated the mediating role of working memory between general and math-specific vocabulary and math performance among second-grade students. The participants were 256 students from diverse educational settings in Chile. We employed structural equation modelling (SEM) to explore the complex relationships between working memory (forward, backward, and verbal), math performance (numerical facts, calculation, and concept knowledge), general productive vocabulary, and math-specific vocabulary (recognition and production tasks). The SEM model demonstrated optimal fit across all indices (CFI, TLI, RMSEA, SRMR). Key findings revealed that working memory significantly mediates the relationship between

both general and math-specific vocabulary and math performance. Specifically, working memory's role was underscored by its direct influence on math performance and its mediation in the impact of recognition math vocabulary and general vocabulary on mathematical abilities. These findings highlight the critical role of working memory and vocabulary in enhancing math performance, suggesting that the development of cognitive and linguistic skills could be crucial for improving mathematical learning outcomes. Furthermore, our results indicate that working memory serves as a conduit between vocabulary knowledge and math performance, facilitating the use of linguistic resources in mathematical processing.

4. **Increasing family support professionals' ability to model early math talk: Results from an intervention study**

Sarah Pan[1], Alisha Wackerle-Hollman[1], & Michèle Mazzocco[1]
[1]University of Minnesota

The home is one of the earliest learning environments for young children, and provides daily opportunities to engage in, learn, and practice mathematics. However, math talk in the home is often infrequent (e.g., Levine et al., 2010; Ramani et al., 2015), and thus this pathway for improving children's math skills is underutilized. One way to encourage math talk in the home is through the support families receive from "Family Support Professionals" (FSPs) who are knowledgeable about child development and directly interact with families (e.g., librarians, parent educators, home visitors). To bolster FSPs' knowledge and skills in promoting early mathematics with families, we first developed a set of asynchronous, online professional development modules. We then evaluated the effectiveness of these modules at increasing FSP's early math talk, in part by asking FSPs to write hypothetical mathematical utterances corresponding to each of seven everyday scenes both before and after module completion. We coded each utterance as a math-relevant or non-math statement or question, and identified individual math topic(s) in utterance content. Initial findings indicate that following completion of the module FSPs generated more mathematical statements overall compared to pre-test, and generated more statements in each of the math topics examined. These topics included numbers and counting, measurement, shapes, spatial relations, patterns, and operations, both pre- and post-module. Results suggest that with this training, FSPs can generate more examples of math dialogue for families, enhancing their skill as role models in the support of early mathematical development.

5. **Multidimensionality of home math engagement: Examined through a comparison of preterm and full-term toddlers**

Sivan Lurie[1], Alex Silver[2], & Melissa Libertus[2]
[1]University of Maryland, College Park; [2]University of Pittsburgh

Existing literature investigates how parental practices contribute to developing young children's understanding of numerical concepts in the home setting, commonly termed the home numeracy environment. However, across this research, there is great variation in how the home numeracy environment is measured. In this study, we compare two different aspects of the home numeracy environment–numeracy talk, and home numeracy questionnaire–across two distinct groups: preterm and full-term toddlers. These groups were chosen because prior work has shown children born prematurely disproportionately struggle in math later in life. However, the mechanisms of which remain unclear. In our preliminary results, two-year-old toddlers (N=20) and their parents completed a picture description task which assessed the frequency of parents' number talk with their children. Additionally, parents completed a home numeracy questionnaire and children completed a counting task. Parents of preterm children used more number talk than parents of full-term children. However, parents of preterm children reported participating in significantly fewer home numeracy activities even after controlling for home literacy activities. Limited evidence of a significant difference between birth status (preterm or full-term) and children's counting skills was found. Overall, these findings underscore the importance of distinguishing between various facets of the home numeracy environment, specifically parental number talk and home math activities.

6. **Transdiagnostic factors as moderators of the math anxiety-math performance relation**

Nadine Yildiz[1] & Darcy Hallett[1]
[1]Memorial University of Newfoundland

Introduction: Mathematics anxiety, the experience of negative affect when presented with math stimuli, has been consistently shown to negatively relate to math performance (Barroso et al., 2021; Ashcraft, 2002; Richardson & Suinn, 1972). It has been suggested that intervention strategies that target negative emotions associated with math can positively impact math performance (Ashcraft, 2002; Hembree, 1990; Maloney & Beilock, 2012; Park et al., 2014). This study approaches

math anxiety through a clinical lens by looking at how transdiagnostic factors of anxiety (i.e., common factors that underlie various anxiety disorders and contribute to their development and maintenance) relate to math anxiety and math performance. Method: Three hundred (300) adult participants were recruited through Prolific and completed measures of four transdiagnostic factors (i.e., Emotion Regulation, Distress Tolerance, Intolerance of uncertainty, Anxiety Sensitivity), as well as measures of anxiety (i.e., Math, State, General), and math performance (i.e., fluency, calculation) as well as a measure of mindfulness. Results: Each of the transdiagnostic factors relates to math anxiety and performance in different ways. ER and IU were found to moderate the math performance-anxiety relation for calculation tasks. At the same time, DT and AS significantly predicted an increase in state anxiety during a math task. These findings are consistent with the cognitive interference model of math anxiety and provide theoretical direction to future studies aiming to both better understand and ameliorate math anxiety and improve math performance.

7. **Shared neural processing of grammar and arithmetics: Insights from a meta-analysis**

Nurit Viesel-Nordmeyer[1], Johannes C. Ziegler[1], & Jérôme Prado[1]
[1]Aix-Marseille University

Recent studies suggest a relation between the development of grammatical skills and arithmetic learning (e.g., Chow et al., 2021; Liu et al., 2016; Viesel-Nordmeyer et al., 2021). The ability to understand, extract and apply rules is suggested to be the cause for this association. To date, however, the neural mechanisms underlying the association between grammatical and arithmetic processing are unknown. To identify functional neural overlap between grammatical and arithmetic processing, we conducted an activation likelihood estimation meta-analysis (ALE). Specifically, we focused on fMRI studies including whole brain results for grammatical (n = 38) and arithmetic (n > 40) processing in healthy children and adolescents. On the one hand, we found an overlap between grammatical and arithmetic processing in three brain clusters located in the left Superior Frontal Gyrus (Brodmann Areas 6 and 32), left Inferior Frontal Gyrus (Brodman Area 9), and left Insula (Brodman Area 13). On the other hand, we also found several clusters showing domain-specificity, with three separate clusters for grammatical processing in left Persylvian regions and seven clusters for arithmetic processing in various regions of the left and right hemisphere, including the parietal cortex. The significance of our results with regard to associations between grammatical and arithmetic learning in children and adults with and without learning problems will be discussed.

8. **Seeing beyond the surface: Understanding non-symbolic rational numbers by quantity and its relation to math achievement**

Sangmi Park[1] & Alena Esposito[1]
[1]University of Wisconsin - Madison; [2]Clark University

One of the Common Core Standards for mathematics (2010) is to make sense of quantities and their relationship, yet children often struggle to integrate quantities of fractional magnitude presented with distinct notations (e.g., fractions and decimals; Park & Esposito, 2022). Recently, researchers have highlighted non-symbolic fractions as a potential intervention target to enhance children's symbolic rational number comprehension (e.g., Matthews et al., 2016). However, the link between symbolic and non-symbolic rational number understanding across distinct notations, and how this relates to math achievement, remains obscure. Thus, we examined this in the current research. The Numerical Spatial Arrangement Methods (NSpAM; Park & Esposito 2022) task and a newly developed Shape SpAM (SSpAM), adapted from NSpAM for non-symbolic fractions, were used to assess whether children organize by surface similarity (i.e., notations or shapes) or by the quantitative value when organizing given fractions of distinct notations. We also collected children's levels of math anxiety and math achievement. The findings revealed that children in grades 3 to 5 predominantly conceptualize non-symbolic fractions either by surface features or by quantity, with quantitative conceptualization increasing with higher grade levels. While quantitative conceptualization was associated with higher math achievement, this relation was no longer significant after controlling for math anxiety. These findings support the notion of a foundational cognitive framework that processes quantitative information across non-symbolic and symbolic conceptualizations of fractional magnitudes. Further, with the novel SSpAM task, our research underscores the necessity for employing various measures to investigate the relation between fractional knowledge and math achievement.

WEDNESDAY, JUNE 26

9:00 AM – 10:10 AM

S1A: Can we at least agree on the basics? In search of consensus in mathematical cognition

Chair: Julia Bahnmuller[1] & Krzysztof Cipora[1]
[1]Loughborough University

Integrative Statement:
In the period marked by the replication crisis in psychology, and the quest for a comprehensive understanding of mathematical cognition, a robust initial step to progress would be for us to at least agree on some basics. Despite dynamic growth in mathematical cognition, both in terms of community size and number of publications, our discipline falls short of addressing the agenda set forth by Alcock et al. (2016; JNC). This lack of progress has become apparent during the symposium "Challenges in Mathematical Cognition: Are we making progress?" (Inglis, 2022; MCLS). While this is disappointing, it is not entirely dissimilar from other disciplines. Agreeing on fundamental issues may be a sensible starting point to begin addressing these issues. In this symposium, we bring together approaches which may be used to identify or achieve consensus among the community. The symposium is organised by Julia Bahnmueller and Krzysztof Cipora (both Lecturers, Loughborough University, UK). In the first talk, Mariagrazia Ranzini (Assistant Professor, University of Padova, Italy) will present on the methodology of building theoretical consensus. Subsequently, Attila Krajcsi (Associate Professor, ELTE Eötvös Loránd University, Hungary) will discuss ways of searching methodological consensus in numerical cognition. In the third talk, Melissa Libertus (Professor, University of Pittsburgh, USA) will discuss searching for consensus within the Many Numbers project. The symposium will be concluded by Ella James-Brabham (PostDoc, Loughborough University) presenting efforts on searching for consensus among researchers, practitioners, data, and the literature with regards to predictors of mathematics achievement.

Presentation 1: How to build theoretical consensus in numerical cognition

Mariagrazia Ranzini[1] & Alex Miklashevsky[2,3]
[1]Department of General Psychology, University of Padova, Italy; [2]Potsdam Embodied Cognition Group, University of Potsdam, Germany; [3]Brain Language Laboratory, Free University of Berlin, Germany

In the time of replication crisis and consequent lack of trust in scientific theories, it seems crucial to delineate fundamental points to which all the researchers in a specific domain could agree. This is particularly true for numerical cognition, a relatively young yet diverse field of research that sometimes seems lacking in acknowledged assumptions. Numerical cognition should benefit from the consensus practice. However, how can researchers build theoretical consensus in numerical cognition? In this talk, we first define some critical theoretical issues in numerical cognition for which different theoretical models have been advanced. Then, we capitalize on published consensus articles from domains connected to numerical cognition to define possible ingredients for building theoretical consensus. Through description and analysis of consensus papers in psychological research, we define some contexts in which it is essential and possible to think about building consensus. Finally, we discuss the possible existence of different forms of consensus in research, namely: (1) whether a consensus means the acceptance of one view and rejecting the others or if it could be the co-existence of different views and (2) what the intermediate steps between these opposite forms of consensus could be.

Presentation 2: Finding consensus about applied methods in numerical cognition

Attila Krajcsi[1] & Bert Reynvoet[2]
[1]ELTE Eötvös Loránd University, Department of Cognitive Psychology, Hungary; [2]KU Leuven, Brain and Cognition, Belgium

Choosing the right method for research on numerical cognition could be difficult. For example, different approaches are often not contrasted, some advanced methods are difficult to find or apply, or there is no consensus in the literature about the optimal solution. All classic dissemination methods have their shortcomings: Peer review papers are evaluated only by a few experts, papers in journals or in handbooks are not updated, and conference talks and discussions may not be appropriate to cite, just to name a few problems. Here, we propose two alternative solutions. (1) We provide a procedure for writing a multi-author consensus paper which can be regularly updated. (2) We present an online, open peer-review numerical cognition methods database that can be edited by any expert. Compared to the classic methods, these tools provide more consensual methods;

potentially, they are more frequently updated, and they work more transparently.

Presentation 3: The ManyNumbers Project: Creating a global network of early numeracy labs

Melissa Libertus[1], Roberto Abreu-Mendoza[2], David Barner[3], Isabelle Boni[4], Pierina Cheung[5], Sara Cordes[4], Lisa Feigenson[7], Elizabeth Gunderson[8], Daniel Hyde[9], & Veronique Izard[10]
[1]University of Pittsburgh, USA; [2]Indiana University, USA; [3]University of California San Diego, USA; [4]Boston College, USA; [5]Nanyang Technological University, Singapore; [7]Johns Hopkins University, USA; [8]Indiana University, USA; [9]University of Illinois Urbana-Champaign, USA; [10]CNRS Universite Paris Descartes, France

The NSF-funded ManyNumbers project consists of two "Foundational" studies that unite an international network of 150+ labs to investigate new ideas regarding the conceptual foundations of early numeracy by simultaneously creating methodological consensus. Foundation 1 specifically examines 2- to 5-year-old children's number word knowledge across many different countries (n=29) and languages (n=18) involving many labs that previously did not contribute to this literature. All participating labs will administer the same versions of the Give-N, Highest-count, non-symbolic number comparison, and visual picture memory tasks. To create these tasks, the core principal investigators of the ManyNumbers project reviewed the literature, pilot-tested different versions of the tasks in different countries and labs, and wrote a registered report. Participating labs were invited to provide feedback during virtual meetings and by commenting on drafts of the registered report. ManyNumbers also provides opportunities for further collaboration and consensus building among participating labs through exploratory extension projects. By creating openly available materials, standardizing training and administration, and involving a large number of labs around the world, one goal of ManyNumbers is to achieve greater consistency in measurement of early numeracy to replicate and extend previous findings and rigorously test theories of children's number word acquisition. In addition, we hope that the same versions of the tasks will be used in future research studies ensuring more robust and comparable research findings across the literature.

Presentation 4: Triangulating consensus on domain-specific predictors of mathematics achievement

Ella James-Brabham[1], Krzysztof Cipora[1], & Julia Bahnmueller[1]
[1]Loughborough University, UK

Several basic domain-specific numerical skills (e.g., number system knowledge, magnitude understanding, order processing) have been found to be significant predictors of current and future mathematics achievement as children enter and progress through school. However, to date, much of our understanding of numerical predictors on later development has been based on correlational evidence, leaving our understanding of causal mechanisms lacking. Before we can test causality, it is essential we establish consensus on which numerical skills to target. This raises the question: which domain-specific predictors are most likely and strongly causally related to improvements in mathematics achievement, thus warranting targeted investigation through randomised controlled trials?To find evidence-based and practice-informed consensus on this question, within the ESRC Centre for Early Mathematics Learning (CEML) at Loughborough University (UK), we triangulate evidence from (i) an online Delphi process with experts in mathematical cognition and mathematics education, (ii) focus groups with educational practitioners, (iii) comprehensive analyses of existing large-scale assessment data, and (iv) a large-scale, preregistered systematic review and meta-analysis. This presentation will offer insights into our ongoing endeavours drawing from multiple sources of evidence and will provide detailed results of the Delphi process involving experts in mathematical cognition and mathematics education.

S1B: Mathematics vocabulary: Complexities to consider in intervention and assessment

Chair: Danielle Lariviere[1]
[1]University of Texas at Austin

Integrative Statement:

Mathematics vocabulary is associated with mathematics proficiency across a range of domains including early number knowledge, word-problem solving, and fractions (Lin et al., 2021). Yet, more research is needed on the most efficacious approaches for instruction and assessment of mathematics vocabulary. The studies addressed in this symposium center on instruction and assessment of mathematics vocabulary for students with mathematics difficulty in Grades 1–5 (i.e., 6–11 years old). In the first study, Lariviere and colleagues share critical mathematics vocabulary words to teach to students with mathematics difficulty in Grades 3–5. These terms were identified through an analysis of commonly-used curricula in the United States, the United States Common Core standards, and state-level test items. The second and third studies include interventions for students with mathematics difficulty. Lesner and colleagues describe Whole Number Foundations – Level 2, a Grade 2 intervention developed in the United States

that emphasizes mathematics vocabulary. In the third study, Lin shares results from a fraction vocabulary intervention study with Grade 4 students in China. Last, De Keersmaeker and colleagues share a mathematics-vocabulary assessment developed in Belgium for students in Grades 1–3. These four presentations provide insight into mathematics-vocabulary instruction and assessment across diverse geographic locations, languages, student performance levels, and grade levels.

Presentation 1: Some or sum? Identifying critical mathematics words to teach in grades 3–5

Danielle Lariviere[1], Mackenna Vander Tuin[1], Elizabeth Stevens[2], & Sarah Powell[1]
[1]The University of Texas at Austin; [2]University of Kansas

Mathematics-vocabulary knowledge supports overall mathematics proficiency (Riccomini et al., 2015), because teachers and students regularly use mathematics vocabulary to express mathematical reasoning. Because of the role of mathematics vocabulary in mathematics learning, we analyzed mathematics-vocabulary terms within frequently referenced instructional resources in the United States. Our analysis centered on the elementary grades, with an emphasis on Grades 3–5 (i.e., students typically aged 8–11 years old). In this presentation, we share data on mathematics-vocabulary terms included in several sources: (a) three published mathematics curricula, (b) the United States Common Core mathematics standards, and (c) high-stakes test items from 14 states regionally distributed across the United States. We present data on the breadth and frequency of terms across sources, consistency of terms throughout grade levels, and distribution of terms across mathematics domains. Based on these analyses, we present critical mathematics terms that should be prioritized in Grades 3–5 within intervention development, assessment creation, and classroom instruction. Acknowledgement of funding source: Institute of Education Sciences R324A230238ReferencesRiccomini, P. J., Smith, G. W., Hughes, E. M. & Fries, K. M. (2015). The language of mathematics: The importance of teaching and learning mathematical vocabulary. Reading & Writing Quarterly, 31(3), 235–252. https://doi.org/10.1080/10573569.2015.1030995

Presentation 2: Developing a second grade mathematics intervention with attention to mathematics vocabulary

Taylor Lesner[1], Gena Nelson[1], Marah Sutherland[1], & Ben Clarke[1]
[1]Center on Teaching and Learning, University of Oregon

In the talk entitled, "Developing a Second Grade Mathematics Intervention with Attention to Mathematics Vocabulary," Taylor Lesner and Gena Nelson will discuss the development of Whole Number Foundations – Level 2 (WNF-2). WNF-2 is a 60-lesson, Tier 2 mathematics intervention program designed for second grade students at risk for mathematics learning disabilities and difficulties. We will present an overview of the design and development of WNF-2, with a focus on program features that enhance students' opportunities to learn and apply mathematics vocabulary. Key features to be discussed include clear and accurate mathematics language in program scripting, explicit vocabulary instruction with frequent review, pairing key vocabulary with hand gestures to reinforce learning, differentiation of words that have different meanings in mathematics versus other contexts, and “math talk” opportunities that prompt students to discuss key concepts. We also review supplemental home-based materials for WNF-2 that emphasize how families can engage in “math talk.” The intervention includes weekly handouts that provide families with practical suggestions for how to practice and reinforce mathematics concepts from WNF-2 in everyday routines such as at home, in the car, or at the grocery store. Finally, we review how mathematics vocabulary development was prioritized in the development of the proximal assessment designed to accompany the WNF-2 program. Discussion will focus on strategies utilized to integrate mathematics vocabulary instruction with other critical areas of early mathematics learning throughout the WNF-2 program.

Presentation 3: Unique and combined effects of fraction vocabulary and arithmetic instruction

Xin Lin[1]
[1]University of Macau

Recent research indicates that understanding mathematics vocabulary is crucial for developing mathematics skills (Powell & Nelson, 2017; Purpura et al., 2021). However, many students, particularly those with mathematics difficulty (MD), need help with mathematics vocabulary (Forsyth & Powell, 2017; Lin et al., 2021). Therefore, it is essential to investigate the effects of a mathematics vocabulary intervention on the mathematical knowledge of students with MD. We discuss a fraction vocabulary intervention for Grade 4 Chinese students with MD. Students participated in three activities for each lesson: (1) Read and Match, (2) Vocabulary Grid Instruction, and (3) Keyword Fill In. For

vocabulary terms related to fraction arithmetic procedures, we combined arithmetic instruction with fraction vocabulary instruction. We compared the effectiveness of this combined approach to instruction focused solely on vocabulary. To account for the time difference between the two conditions, students in the fraction-vocabulary-only group participated in an activity called Word Clouds. We randomly assigned 72 students to three conditions: fraction vocabulary only, fraction vocabulary with an arithmetic component, and a business-as-usual (BaU) condition. The students in the fraction vocabulary intervention groups participated in 10 sessions, occurring three times per week. Both intervention groups showed significantly better performance in fraction vocabulary knowledge than the BaU group. However, no notable distinctions were observed between the two intervention conditions in terms of fraction procedural skills. Only students who received the fraction vocabulary intervention with an arithmetic component exhibited enhanced performance in subtraction and multiplication compared to the BaU group.

Presentation 4: Towards a valid and reliable instrument to measure advanced mathematical language in the early grades

Karen De Keersmaeker[1], Patrick Onghena[2], & Wim Van Dooren[1]
[1]Centre for Instructional Psychology & Technology, KU Leuven; [2]Methodology of Educational Sciences, KU Leuven

Children in the early grades of primary education start to develop advanced mathematical competencies such as patterning, proportionality, and probability (Verschaffel et al., 2023). These competencies heavily rely on mathematical language (e.g., in turn, double, certain). Some studies have already investigated the impact of children's mathematical language in these domains, but instruments were limited in scope and of questionable quality. We aimed to develop a high-quality instrument to measure first, second, and third graders' mathematical language in advanced topics, such as patterning, proportionality, and probability. To assure content validity, we selected appropriate language terms based on previous research and mathematical textbooks. Next, the item set was optimized based on expert feedback and individual piloting. The final instrument, which addressed 32 mathematical terms, was administered to 236 first, second, and third graders. The internal consistency was excellent ($\alpha = .933$), and the test-retest reliability ($r = .704$) suggests stable results over time. The developed mathematical language task is suitable for first, second, and third graders, and can be used by teachers and researchers to evaluate development of mathematical language over time. References. Verschaffel, L., De Smedt, B., Luwel, K., Onghena, P., Torbeyns, J., & Van Dooren, W. (2023). Development and stimulation of early core mathematical competencies in young children: Results from the Leuven Wis & Co project. In R. Leikin (Ed.), Mathematical challenges for all (pp. 25–50). Springer. https://doi.org/10.1007/978-3-031-18868-8_3

S1C: What's the difference? Contextual factors, caregiver beliefs, and children's home math experiences

Chairs: Nicole Scalise[1] & Jenny Yun-Chen Chan[2]
[1]Washington State University; [2]The Education University of Hong Kong

Integrative Statement:

A wealth of research has documented the importance of home mathematics experiences during childhood on developing mathematics attitudes, beliefs, and achievement (Daucourt et al., 2021; Eason et al., 2022). However, there remain significant gaps in our understanding of the home math environment, with calls to include more diverse samples and methods to deeply examine the role of caregivers' beliefs in association with their provision of math experiences (Hornburg et al., 2021). Our symposium directly addresses these gaps by examining how contextual factors and individual differences relate to caregivers' provision of math experiences. The first paper describes Hong Kong preschoolers' math experiences, examining differences associated with context (home vs. school) and caregiver beliefs about the malleability of children's abilities (Chan). The second paper examines distinct home mathematics engagement patterns within a sample of Latine families in the U.S. and its associations with families' demographic characteristics (Cosso). The third paper investigates variability in U.S. parents' home math engagement with their children during the COVID-19 pandemic, finding patterns of individual differences related to parental beliefs and child characteristics (Brown). Finally, the fourth paper describes characteristics of U.S. adults' memories of their earliest math experiences and associations with their current math beliefs and abilities (Scalise). Taken together, the findings from our symposium highlight the variability in and predictors of differences in children's home math environments, with implications for their longer-term mathematics success.

Presentation 1: Early math learning landscape in Hong Kong: Parent and teacher beliefs and practices in numeracy, spatial, and pattern activities

Jenny Yun-Chen Chan[1], Nicole Scalise[2], Hailey Hoi Lam Cheng[1], & Shirley Yuen Man Tsang[1]
[1]The Education University of Hong Kong; [2]Washington State University

Children's early math experiences at home and school lay the foundation for their later math achievement (Eason et al., 2022). Prior research has shown that US parents engage children in numeracy activities more frequently compared to spatial or pattern activities (Zippert & Rittle-Johnson, 2020). Here, we test the effects of topic (numeracy vs. spatial vs. pattern), context (home vs. classroom), and Hong Kong caregivers' beliefs about the malleability of math ability on their frequency of engaging children in early math activities. A total of 163 parents and 56 teachers of preschoolers completed a 20-minute online questionnaire that asked about their beliefs and practices in early childhood math learning. We conducted a multilevel model with frequency of math activities as the outcome variable, math topic (numeracy vs. spatial vs. pattern), caregiver (parent vs. teacher), and caregivers' math belief as fixed effects, and participant and item ID as the random effects. We found that both parents and teachers engaged children in pattern learning activities less frequently compared to numeracy activities (B=-1.20). Furthermore, compared to parents, teachers engage children in spatial (B=0.43) and pattern learning activities (B=0.18) more frequently, but parents' vs. teachers' frequency of numeracy activities was not significantly different. Caregivers' math belief was not a significant predictor of their frequency of engaging children in math activities. The findings extend prior research on US parents' home math activities and reveal areas in which parents and teachers can further support children's math learning.

Presentation 2: Numeracy engagement patterns of U.S. Latine families

Jimena Cosso[1] & Gigliana Melzi[2]
[1]The Pennsylvania State University; [2]New York University

Recently, there have been calls to build a more inclusive knowledge base of the home mathematics environment (HME) by diversifying the populations of our descriptive research. Given that Latine children are the fastest-growing population in the United States, it is of the utmost importance to include Latine families and children in these efforts. The present study examined the unique ways in which U.S. Latine families support the early math learning of their children by: (1) identifying distinct math engagement patterns, and (2) examining if these patterns were related to families' demographic characteristics. Participants were 488 caregiver-child dyads (child Mage = 4.29 years, SD = 1.23). Results of a latent profile analysis identified two main profiles of Latine family numeracy engagement. The Balanced Numeracy Engagement profile (79.82%) exhibited the lowest levels of formal and household home math activities indicators and a moderate mean value of the play-based numeracy activities. The Non-Play Numeracy Engagement (20.18%) profile exhibited the highest mean values on formal and household home numeracy activities indicators and the lowest mean value on the play-based numeracy indicator. Using a manual three-step approach, which added key covariates into the model, we found that caregivers' formal educational level and relationship with the child were significantly associated with the profiles. These findings emphasize the need to diversify the contexts and the populations included in future exploration of the HME, as well as the importance of examining both across and within ethnocultural and linguistic groups.

Presentation 3: Sources of variability in parents' support for mathematics learning at home

Kaitlyn Brown[1], Pooja Sidney[1], Charles Fitzsimmons[2], Jennifer Taber[3], Karin Coifman[3], & Clarissa Thompson[3]
[1]University of Kentucky; [2]University of North Florida; [3]Kent State University

How did parents make decisions about when and how to support children's mathematics learning at home during the COVID-19 pandemic? The nature of children's home mathematics environment (HME), which is largely constructed by their parents and caregivers, shapes their informal mathematics knowledge and provides support for formal, in-school learning. A growing body of research demonstrates that the home environment is an important factor in children's learning, however, less scholarship has been aimed at understanding the sources of variation in children's HMEs. Our talk focuses on sources of variability in how parents supported mathematics learning at home during the COVID-19 pandemic. We examined several sources of variability in parents' mathematics homework helping behaviors within two online, national samples of US parents (n = 93, n = 163). Parents self-reported the frequency and nature of mathematics activities at home, as well as their evaluation of their own ability to help, their self-perceived mathematics knowledge, their own mathematics anxiety, their anxiety around helping, and perceived importance of tasks. During the COVID-19 pandemic, most parents did help children with mathematics learning, however, variability in parents' mathematics helping behaviors was

predicted by their child's level of school (elementary vs. middle vs. high school), parent individual differences (e.g., gender, anxiety), and type of mathematical task (e.g., counting vs. measurement). This research provides insight on why, and when, parents and caregivers engage in mathematics with their children and reveals key gaps and levers for enhancing children's home math environments.

Presentation 4: Memories of early math experiences predict adult math anxiety, values, and achievement

Nicole Scalise[1], Isabella Santiago[1], & Elizabeth Canning[1]
[1]Washington State University

Many adults dislike or experience anxiety about math. Early experiences with math at home during childhood may contribute to levels of math anxiety, engagement with math, and math achievement in adolescence and adulthood. However, less is known about what people remember about their early math learning experiences over time. The present study examined 161 emerging adults' earliest memories of mathematics and reading experiences (Mage= 19.6 years, SDage= 2.1). Results suggest that participants were younger on average during their earliest memories of reading compared to their earliest memories of math, and they rated their memories of reading more positively than their memories of math. However, participants with more positive early memories of math tended to have lower math anxiety ($r(127)= -.23$, $p < .001$), value math more ($r(126)= .29$, $p < .001$), and have higher math achievement ($r(127)= .22$, $p < .05$) as adults. These associations were domain-specific, such that more positive early memories of reading did not relate to adult math outcomes. In addition, participants were more likely to describe someone else as actively participating in their earliest reading memory compared to their earliest math memory. However, participants who described other people in their earliest math memories who were actively participating in the activity with them rated their experience more positively. These findings shed light on potential long-term associations between early math experiences and later math anxiety, values, and achievement, and suggest that socially interactive early math experiences at home may lead to more positive outcomes over time.

S1D: Unraveling complex relations between math anxiety and math performance in childhood. Insights from various predictors across different countries

Chair: Flavia Santos[1]
[1]University College Dublin

Integrative Statement:
This symposium showcases cross-sectional and longitudinal studies involving 3930 children, ranging from kindergarten to 6th grade, living in Chile (Susperreguy and colleagues), Finland (Halme, Veermans, and McMullen), Ireland (Gomides and colleagues), and the US (Maghami-Sharif, Ganley, and Cook). Math Anxiety has been observed worldwide, regardless of wealth and educational systems, suggesting that other factors play a role in its impact on math performance. These studies focused on the intricate relations between children's math anxiety and their math performance, considering various predictors, such as demographics, confidence levels, motivations, math attitudes, and parents' math anxiety, through advanced statistical methods and conceptual frameworks. Overall, the four studies consistently found some negative associations between math anxiety and math performance in pupils including children from disadvantaged areas. However, some predictors included in their models did not explain the association. Notably, engagement in home math activities was directly associated with math performance among kindergarteners. The effect of parental math anxiety on children's math performance yielded conflicting results across studies; possible sources of discrepancy are children's age and trait anxiety. Interestingly, math confidence and math interest did not appear to mitigate the negative effects of math anxiety on math performance. While math anxiety may hinder the development of adaptive rational number skills, the use of strategies such as relational reasoning might be an alternative learning strategy in 5th and 6th graders. These studies offer valuable insights for advancing theoretical perspectives and developing interventions to address math anxiety and enhance students' mathematical learning.

Presentation 1: Evaluating indirect pathways in the association between parental math anxiety and chilean kindergartener's math performance

María Inés Susperreguy[1], M. Francisca Morales[2], M. Francisca del Río[3], Ana María Espinoza[4], & David J. Purpura[5]
[1]Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT), Pontificia Universidad Católica de Chile; [2]Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT); [3]Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT), Universidad Diego Portales; [4]Millennium Nucleus for the Study of the Development of Early Math Skills (MEMAT), Universidad de O'Higgins; [5]Purdue University

Caregivers' math anxiety relates to their children's math performance (Becker et al., 2022). However, there is a need for a better understanding of mechanisms that explain this association, as proposed by the Parent and

Child Math Anxiety Network model (Carkoglu et al., 2023). This study investigated whether the association between parents' math anxiety and children's math performance is simultaneously explained by children's math anxiety and by parent's home math activities. The participants were 292 Chilean kindergartens (M age = 5.5 years; 53.8% males) and their parents (88.0% mothers) from low-SES schools from two geographical regions. Parents completed a questionnaire including sociodemographic information, home math environment questions, and a math anxiety scale. Children completed a math anxiety scale and the applied problems subtest of the Batería Woodcock Muñoz. Preliminary results with structural equation modeling indicated an adequate fit of the model $\chi2(265) = 366.971$, $p = .000$; RMSEA = 0.036; SRMR = 0.054; CFI = 0.95; TLI = 0.94. However, no significant direct effects of parent's math anxiety on children's math performance or indirect effects through children's math anxiety and home math activities were observed. Regarding regression paths, only home math activities were directly associated with children's math performance ($\beta = 0.19$, SE = 0.34, $p = .010$). We will discuss these findings and future directions for studying the mechanisms explaining associations between parental math anxiety and children's mathematical performance.

Presentation 2: The potential undoing effects of positive math attitudes on the math anxiety-math performance relation

Zahra Maghami-Sharif[1], Colleen M. Ganley[1], & Olivia K. Cook[1]
[1]Department of Psychology, Florida State University

It is widely accepted that math anxiety leads to poor math performance. Therefore it is important to understand what factors might reduce this relation in order to inform the development of effective interventions. Drawing on Fredrickson's broaden-and-build theory (1998)—which posits that positive emotions broaden cognitive processes and build enduring personal resources—we hypothesized that positive math attitudes, specifically interest and confidence, may buffer the negative relation between math anxiety and performance. Using Structural Equation Modeling, we analyzed data from a sample of elementary school children (n=2,872 49.6% girls) in the United States, spanning kindergarten through third grade. The results showed an overall negative relation between math anxiety and math performance. Contrary to expectations, neither math interest, nor math confidence alleviated the negative effect of math anxiety on performance. Instead, we found that although math confidence generally relates to better performance, high confidence did not buffer the negative relation between anxiety and performance. In fact, the opposite was true, students at all confidence levels performed worse as their math anxiety levels rose, but this relation was most pronounced for students with higher math confidence. Conversely, math interest did not alter the anxiety-performance relationship and was negatively associated with performance in one model, suggesting that increased interest, after accounting for math anxiety and confidence, is associated with poorer math achievement. These findings provide a nuanced understanding of the complex interplay between math attitudes, anxiety, and performance in this specific age group, underscoring the need for targeted interventions to specifically address math anxiety.

Presentation 3: Cognitive and affective factors in the development of adaptive rational number knowledge

Hilma Halme[1], Koen Veermans[1], & Jake McMullen[1]
[1]University of Turku, Finland

While routine mathematical knowledge builds a foundation, the competence to apply one's mathematical knowledge beyond routine textbook tasks should be a sought-after outcome of education. This is referred to as adaptive expertise (Verschaffel et al., 2009). Mathematics anxiety is a known limiting factor in mathematical development (Namkung et al., 2019) and recently shown to be negatively related to students' performance on routine and adaptive rational number tasks already in primary school (e.g., Halme et al., 2022; Starling-Alves et al., 2022). Mathematics anxiety is suggested to compete with cognitive resources, making it more difficult to process complex mathematical tasks (Ramirez et al., 2018; Vukovic et al., 2013). Previously, relational reasoning abilities were shown to support performance on similar tasks (McMullen et al., 2016; 2022). However, it is unclear how mathematics anxiety and relational reasoning influence the development of adaptive expertise with rational numbers. Understanding these relations is crucial for developing interventions. The aim is to investigate how motivational, cognitive, and mathematical factors relate to the development of adaptive rational number skills in 5th and 6th grade students (N = 522). Adaptive knowledge was measured with students' performance on a non-routine rational number task, while routine knowledge was measured with textbook-like fraction tasks. The test battery also included measures of mathematics anxiety, self-efficacy, and relational reasoning. Preliminary SEM modeling shows that mathematics anxiety hinders and relational reasoning ability supports the development of adaptive

rational number skills, even after controlling for routine fraction skills.

Presentation 4: Is parental math anxiety impact on children's math performance independent of the children's own math anxiety?

Mariuche Gomides[1], Sophie Leonard[1], Aoife Durkan[1], Mariana Rocha[2], Pierpaolo Dondio[2], & Flavia H. Santos[3]
[1]UCD Music and Math Cognition Lab, University College Dublin; [2]School of Computer Science, Technological University Dublin, Dublin, Ireland; [3]School of Psychology, University College Dublin, Dublin, Ireland

Higher frequency of home math activities has been associated with lower math performance and higher math anxiety (Cosso et al., 2023; Maloney et al., 2015). In this study, we explored the impact of parents' math anxiety on home math-related interactions and whether the effect of these activities on children's math learning outcomes is influenced by parents' math anxiety. We took into account potential confounding variables, including children's age, gender, and trait anxiety, as well as parents' education and attitudes towards math. A total of 244 parents participated in the study (Mean age = 41.96 years, SD = 5.36; 81.6% mothers) and their third and fourth grader children (Mean age = 9.06 years, SD = 0.96; 54.5% girls). We analyzed the variables using multiple and hierarchical regression models. Our findings indicate that children whose parents exhibit higher levels of math anxiety tend to have lower math performance. However, we did not find a significant association between parents' math anxiety and their children's math anxiety. Interestingly, children's math anxiety was solely explained by their trait anxiety, indicating that children with higher general anxiety also exhibited heightened levels of math anxiety. Furthermore, we did not replicate previous findings suggesting that the influence of home math-related interactions on children's learning outcomes is moderated by parents' math anxiety. We discuss these findings in light of potential factors that may contribute to this divergent outcome and propose future directions to address issues that could enhance research in this field.

S2A: Panel discussion 1: US Government funding agencies (NIH, NSF, & IES)

S2B: Link between language, concepts and mathematics: Influence of the semantic content in word-problem solving

Chair: Anne LaFay[1]
[1]Université Savoie Mont Blanc

Integrative Statement:

Word-problem (WP) solving is a core component of the primary and secondary mathematics curriculum (Common Core Standards for Mathematics, 2010). WP solving is critical to high-school success, but is also the best predictor of employment and income in adulthood (Murnane et al., 2001). However, WP are known to be particularly challenging for children and adults, as they involve understanding a mathematical situation through words. WP solving indeed is a complex and difficult task (Daroczy et al., 2015) and many children struggle to solve them (Fuchs et al., 2015; Lewis & Mayer, 1987; Riley et al., 1983). WP solving involves both numerical and linguistic skills (Daroczy et al., 2015). According to the Language function hypothesis (Peng et al., 2020), language serves as a thinking function that contributes to math reasoning. Moreover, the Semantic Congruence model (Gros et al., 2020) describes the central role of world semantics in the problem encoding, recoding, and solving. A main difficulty thus concerns the misalignment between the semantic content and the solution of the WP. The researches presented in this symposium will discuss the role of language and concepts in WP solving, in examining the influence of the lexical ambiguity and the semantic content on WP solving of adults and children. The symposium will provide theoretical insights on WP solving and generate empirically-validated recommendations for practice. Understanding WP mechanisms will inform educators to better adapt their teaching.

Presentation 1: "Does it mean anything else?" The role of ambiguous words in math problem reading

Ana Taboada Barber[1]
[1]University of Maryland, College Park, MD

In the first paper, Ana Taboada Barber (University of Maryland) found in a recent work based on the Language function hypothesis (Peng et al., 2020) that language skill measured as math lexical ambiguity (i.e., knowledge of ambiguous math word [e.g., operation; expression; order; difference, round]) directly and indirectly mediated the influence of executive functions (EF) skills in 8–10-year-old students' math WP performance. Knowledge of common and math definitions of lexically ambiguous words was assessed with an orally administered 5-item measure adapted from Zipke et al.'s homonym task (2009). Lexical ambiguity mediated the influence of EF skills on math WP in English-Spanish bilingual students' (Cartwright et al., 2022). This follow up study aimed to determine how bilingualism and math performance moderate the mediation of ambiguous math word knowledge between EF skills and math problems. Two

moderated mediations were used and results showed that, in 8–10-year-olds, bilingual status and math performance, both moderated the mediation of ambiguous word knowledge between EF skills (working memory, inhibition, and cognitive flexibility) in children's performance on math WP solving. Findings show that students who have further developed bilingualism tend to leverage the use of ambiguous words in the service of math reasoning to a higher degree than students who are less bilingual. Implications are that bilinguals' EFs serve their language knowledge of ambiguous words to foster their reading of math WP.

Presentation 2: Influence of the unknown and the semantic relation in children's mathematical word-problem solving

Anne Lafay[1], Mélodie Bulinski[2], & Carole Berger[2]
[1]Université Savoie Mont Blanc, Chambéry, France; [2]Université Savoie Mont Blanc

In the second paper, Anne Lafay, Mélodie Bulinski, and Carole Berger (Université Savoie Mont Blanc) based their work on the Semantic Congruence model (Gros et al., 2020) and assessed the development of children's math WP solving in relation to the unknown of the WP and the semantic content. A total of 16 second, 22 third, and 42 fourth graders were asked to solve 12 Compare and 3 Change WP (distractors). We manipulated three unknowns (difference, compared, and referent) and four semantic relations (taxonomic such as tiger and rabbit, slot-filler which include contextually-related objects such as cat and dog, one-to-one functional such as pen and cap, and one-to-many functional such as vase and tulip). Analysis showed an effect of the WP unknown, in second and third graders, that greatly depended on the semantic relation. In fact, second and third graders were more likely to correctly solve compared unknown WP than difference unknown WP when they solved slot-fillers WP. This effect was not observed with the three other semantic relations. The results thus suggested an effect of the semantic relation and an effect of contextual cues on children's WP-solving development. Manipulating words that represent objects in the same category and in the same context helped children to consider them in the same category and to add them. On the contrary, manipulating words that represent same category objects non-contextually-related (taxonomic relation) or that represent different-category objects (functional relation) did not enhance children's solving of compared unknown WP.

Presentation 3: Using drawing productions to investigate the development of cardinality and ordinality

Hippolyte Gros[1], Jean-Pierre Thibaut[2], & Emmanuel Sander[3]
[1]CY Cergy Paris University, Paris, France; [2]Université de Bourgogne, Dijon, France; [3]University of Geneva, Geneva, Switzerland

In the third paper, Hippolyte Gros (CY Cergy Paris University), Jean-Pierre Thibaut (Université de Bourgogne), and Emmanuel Sander (University of Geneva) assessed the nuanced role of non-mathematical content in solving WP in exploring the intersection of mental representations, drawing production, and strategy selection. They used dual-strategy isomorphic WP that shared the same mathematical structure but varied in the entities mentioned in their statements. This variation in the problems' semantic content was hypothesized to prompt some problems to induce a specific (cardinal) encoding aligned with a 3-step solving strategy, while others were thought to encourage an alternative (ordinal) encoding congruent with a 1-step strategy instead. Fifth graders and adults were asked to solve the same 12 arithmetic WP and instructed them to draw a diagram for each. The joint analysis of the drawing and solving tasks revealed that the cardinal and ordinal diagram features correlated with the hypothesized semantic properties of the problems and significantly influenced the choice of solving strategy. This correlation persisted across participants of varied experience levels, indicating that strategy use is governed by problem representation, as shaped by the non-mathematical content in the problem statement. Interestingly, the characteristics of participants' drawings—whether highlighting cardinal or ordinal features—were predictive of their chosen solving strategies, underscoring the drawings' relevance in revealing the underlying semantic influences on problem representation. The findings underscore the value of drawing tasks in exploring mental representations and enhancing mathematical development in educational settings.

Presentation 4: Influence of semantic relation in word-problem solving: An eye-tracking study

Mélanie Barilaro[1], Jessica Bourgin[2], & Anne Lafay[2]
[1]Concordia University, Montreal, QC, Canada; [2]Université Savoie Mont Blanc

In the fourth and final paper, Mélanie Barilaro (Concordia University), Jessica Bourgin, and Anne Lafay (both at Université Savoie Mont Blanc) investigated the impact of the semantic relation between the referent and the compared quantity in solving mathematical compare WP using an eye-tracking method. Undergraduate students (N = 25) solved inconsistent compare WP. Those

problems involved either functional (net and fishes), collateral (apple and pear), or control (pie and pie) relation between the referent and the compared quantity. The results showed no difference of performance across the three types of relations, while response time was higher for WP involving functional relation. Furthermore, when solving WP containing functional and collateral relations, participants spent more time fixating the referent and the compared quantity and demonstrated a higher number of revisits on those components, compared to WP containing control relation. Finally, they made more saccades when solving WP containing functional relation compared to collateral and control relations. Taken together, these data show that, despite similar performance in solving inconsistent compare WP containing different types of semantic relations, higher cognitive effort is required to process collateral relations, and, to an even greater extent, functional relations. This study provides important evidence of the impact of semantic knowledge on solving WP.

S2C: Home math environment and early math development in various sociocultural contexts

Chair: Fraulein Retanal[1] & Dominic Gibson[2]
[1]University of Ottowa; [2]Foundry10

Integrative Statement:

The home math environment includes activities and interactions that support children's math development. Evidence from empirical work indicates that the home math environment serves as an important context for children's math learning. The symposium considers caregivers' beliefs in shaping the home math environment of children in preschool to fourth grade using data from Canada, the USA, and China. The first two presentations examine the important role of caregivers' math beliefs on the math input they provide their children, and the latter two investigate the influence of such beliefs on family engagement in math activities. Specifically, the first study focuses on parental estimations of their children's math knowledge and the types of number input they believe is most helpful for their children's math learning (Gibson). The second presentation examines the relationship between parents' beliefs about math and their number prompts during parent-child shared book reading (Yang). The third presentation investigates parental math engagement across diverse socioeconomic backgrounds, exploring both commonalities and differences in parental engagement and beliefs regarding different math activities (Lu). Lastly, the fourth presentation uses qualitative analysis of parent interviews to explore the factors that shape parents' selection of home numeracy tools (Retanal). These studies, composed of diverse samples, shed light on the preferences, perceptions, and practices of parents in fostering math skills in their children within diverse cultural and socio-economic contexts. The symposium aims to provide a comprehensive understanding of the complexities surrounding parental contributions to children's home math environment and, in turn, their children's mathematical learning.

Presentation 1: Caregivers' perceptions of their children's number knowledge and corresponding number input needs

Dominic J. Gibson[1], Allie Tung[1], & Mikka Hoffman[1]
[1]foundry10

Recent studies have raised questions about the effectiveness of child-directed number input when it does not align with children's current level of number knowledge (Gibson, Gunderson, & Levine, 2020; Silver et al., 2023). One reason that caregivers may overestimate their children's number knowledge and perhaps misalign their input to what their children already know is that children are capable of learning to recite the count list (e.g. "one" through "ten") without having a deeper understanding of what these numbers mean or how the process of counting relates to their meaning (i.e., cardinal number knowledge). Therefore, we examined caregivers' perceptions of their own children's early numeracy skills and number input needs. The current study surveyed 177 caregivers of preschool aged children and found that caregivers overwhelmingly appear to recognize that their children can count to greater numbers than they can respond appropriately to when asked for a certain number of things. Still, caregivers provided higher estimates of their children's cardinal number knowledge than are typically observed when researchers measure this knowledge using the Give-a-Number task (Wynn, 1990). Moreover, we examine caregivers' beliefs about the input that their child would find most helpful (e.g., talk about cardinal values of small numbers vs. talk about the cardinal values larger numbers) and the extent to which it aligns with their estimates of their children's cardinal number knowledge. These findings suggest that caregivers' own perceptions of their children's number knowledge could play an important role in the type of number input they provide their children.

Presentation 2: "How many ladybugs left?": Relations of parent prompts during book reading to math beliefs and child numeracy

Qianru Tiffany Yang[1], Iris Jeffries[1], Ziqin Xie[1], Paul L. Harris[1], & Meredith L. Rowe[1]
[1]Graduate School of Education, Harvard University, USA

Parent number input is important for children's numerical development (Levine et al., 2019). However, little is known about whether parent prompts that may not explicitly include number words (Eason et al., 2021) make a unique contribution to learning. This study addresses this gap by examining parent prompts during shared book reading, as well as their associations with parental math beliefs and children's numerical development. Participants were 44 families of 4-year-olds (girls = 23; Mage = 53.02 months) from an urban region in China. Each parent-child dyad was invited to read Ten Little Ladybugs by Melanie Gerth, after which parental math beliefs and children's numeracy skills were measured. Video-recorded interactions were analyzed for types of number talk (e.g., cardinality, numeral identification) in prompt (e.g., "How many ladybugs left?"; "This number is?") and statement forms (e.g., "I see two ladybugs."; "This is two."). Poisson regression analysis indicated that parents who valued daily exposure to math were more likely to ask their children to identify numbers (estimate = .72, $p < .001$), which in turn was uniquely associated with children's production of numeral identification talk (estimate = .14, $p < .001$). Furthermore, parent cardinality prompts were distinctly linked to children's cardinality talk (Poisson regression estimate = .05, $p < .001$), which in turn was positively related to their knowledge of cardinality and symbolic magnitude understanding (βs = 0.31, $ps < .05$). These findings have implications for understanding the sources and aspects of parental input during book reading that can support children's numerical development.

Presentation 3: Linking socioeconomic status to home math environments: Exploring commonalities, differences, and impacts on early childhood math development

Linxi Lu[1], Marina Vasilyeva[1], & Haoyu Novak Chen[2]
[1]Applied Developmental and Educational Psychology, Lynch School of Education and Human Development, Boston College, USA; [2]Graduate School of Art and Science, Columbia University, USA

SES-related differences have been identified in children's early math development, highlighting the importance of investigating the nuances within early home math environments across different socioeconomic statuses. The current study employed a mixed-method research design to address this need. Parents (N = 120) and their preschool children from diverse socioeconomic backgrounds in China were observed in formal and informal math interactional contexts. Parental math interests, beliefs and values were obtained via questionnaires and interviews. Children's early math performances were measured using a standardized test. The study demonstrated that parents without a high school diploma place substantial emphasis on math and offer a level of formal math activity comparable to that of higher SES parents. However, these parents are less involved in informal math activities and provide fewer math-related talk during play interactions. This disparity is partially attributed to the higher levels of state anxiety and the lower levels of interests experienced by lower SES parents when engaging in math-related tasks. The difference in the quantity and quality of informal - rather than formal- home math activities serve as a predictor of children's early math performance. Aligned with the quantitative results, qualitative analyses revealed that lower SES parents are notably more dedicated to securing an early educational advantage for their children, treating math education as a distinct and serious endeavor separate from routine daily activities. Practical implications are discussed.

Presentation 4: What parents want: A qualitative analysis of parents' knowledge and preferences about math resources

Fraulein Retanal[1], Aira Tanagras[1], Elora Wales[1], Diya Kamineni[1], Emily Larkin[1], Jo-Anne LeFevre[2], Helena P. Osana[3], Sheri-Lynn Skwarchuk[4], John Sylvestre[1], & Erin Maloney[1]
[1]School of Psychology, University of Ottawa, Canada; [2]Department of Psychology, Carleton University, Canada; [3]Department of Education, Concordia University, Canada; [4]Faculty of Education, University of Winnipeg, Canada;

Research on improving children's math outcomes using home numeracy experiences has primarily focused on the frequency with which parents use resources such as videos, worksheets, or math games to support children's learning. Few researchers have considered the factors that might encourage parents to use these resources. Using a grounded theory approach, we investigated the math homework tools and resources preferred by Canadian parents of children ages 7 – 10 (N = 62; 49 women). Our goal was to understand the reasons behind their preferences. The goal of grounded theory is to generate explanations for phenomena based on the data collected, allowing theories to emerge directly from the data rather than being imposed upon it beforehand. Through iterative coding of interviews, several themes emerged, such as the ease of use for parents and children, the perceived positive impact on children's math learning, and the potential to increase parents' own math knowledge. Videos and other online resources were

most often mentioned by parents. Interestingly, when investigating the areas where parents wanted to enhance their math knowledge, a prevalent subtheme was a desire to understand the "new math" their children are learning. Uncovering these themes and preferences is instrumental in creating resources that are likely to be selected and used by parents to help them help their children learn math.

S2D: A socio-cognitive perspective to mathematical development across the school years: The role of learners' motivations and attitudes towards mathematics

Chair: Megan Botello[1] & Christina Barbieri[1]
[1]University of Delaware

Integrative Statement:

We have rich evidence of how children think about mathematics as well as optimal instructional supports for fostering this growth (e.g., Braithwaite & Siegler, 2021; Jordan et al., 2020). These recommendations are supported by various agencies (e.g., US IES Practice Guides, Eurydice) and used to inform classroom practices globally. Yet learners continue to struggle with math. The field of motivation has published rich empirical work that examines relations between math attitudes and motivation as well as their role in predicting math achievement more broadly (Howard et al., 2021). Math cognition scholars have strengths in math learning that could benefit from consideration of children's socio-emotional development as well. The current symposium focuses on the role that children's views of themselves in relation to mathematics have in explaining learning and development. The investigators in this collection of papers ask critical questions that will determine potential leverage points for fostering growth in mathematical cognition and math attitudes across all grade levels. They examine 1) the role of language we use when referring to students engaging in math tasks (e.g., mathematician versus do math) on persistence, 2) the role of stronger fraction sense in learners' math interest, value, and self-efficacy, 3) the role of neural mechanisms recruited when solving arithmetic in explaining changes in math attitudes over time, and 4) the role of sense of belonging and math identity in geometry learning. We consider math attitudes as antecedents or mediators of learning as well as outcomes across a range of mathematical development.

Presentation 1: Do words matter? Investigating how language shapes children's engagement in math

Gillian Grose[1], Hanna-Sophia Shine[2], & Geetha Ramani[1]
[1]University of Maryland; [2]Harvard University

Children's engagement and persistence in math are important in acquiring math knowledge (Gunderson et al., 2018). Using identity rather than action language has been shown to decrease child engagement in academic domains such as science (Rhodes et al. 2019); however, it is unknown whether identity language harms children's math engagement. Our studies examined whether the language children hear before performing a math task affects their persistence. First graders (N = 120; Mage = 6.28 years) were randomly assigned to one of three conditions: identity language ("be a mathematician"), action language ("do math"), or the control ("do an activity"). Condition language was embedded throughout the introduction, in which children were introduced to math concepts such as calculating, addition, and subtraction. Then, children answer arithmetic problems. Persistence was measured by how many math problems children chose to answer. A survival curve analysis examined persistence levels across conditions, controlling for accuracy. There was no main effect of condition on persistence $\chi2(2) = 2.82$, $p = .24$. Additionally, when participants' gender was added to the model as an interaction, we found no effects. We found similar results in a parallel study where math was presented as spatial problems (Children's Mental Transformation Task) (N = 112; Mage = 5.52 years). These results suggest that action-focused descriptions of math did not benefit children's math persistence more than identity or non-math language. Additional exploratory analysis is planned to examine how language may have affected children's goal orientation.

Presentation 2: Assessing the impact of a fraction sense intervention on middle school students' achievement and motivation

Megan Botello[1], Taylor-Paige Guba[1], Nancy Dyson[1], Heather Suchanec-Cooper[1], Teomara Rutherford[1], & Nancy Jordan[1]
[1]University of Delaware

Not seeing value in mathematics—like how useful it can be for their lives—has implications for students' continued engagement and learning in class (Hulleman & Barron, 2013). In particular, fractions are difficult for many students, especially for those with mathematical learning difficulties (Fuchs et al., 2013). In this study, 19 middle school classrooms participated in a randomized controlled trial where they were assigned to either a fraction sense intervention or in a business-as-usual classroom. The intervention aimed to build fraction sense in students with mathematics difficulties. Teachers implemented an evidence-informed fraction sense

intervention (FSI) within their 6th-grade intervention classrooms. All of the students (N = 129) took a fractions assessment and motivation survey (measuring student value, interest, self-efficacy, and cost for fraction learning) at pre and post-test. Using mixed-ANOVA, results showed that the intervention had no effect on students' motivation for fraction learning, even though students in the intervention group's fraction achievement statistically significantly increased. Furthermore, none of the motivation variables at pretest predicted student performance at posttest. However, students' pretest reported cost for fractions and interest in fractions did correlate with students' pretest scores, indicating students' motivation may have already been a factor in their performance. Given this association and prior research linking motivation and achievement (e.g., Chen et al., 2013; Wu et al., 2021), a prolonged intervention may be necessary to impact motivation and post-test achievement. Future research will examine elements of the intervention hypothesized to relate to motivation using qualitative and/or in-the-moment methods to determine motivation-enhancing opportunities within.

Presentation 3: Temporal cortex activation during multiplication explains children's longitudinal gains in math attitudes

Macarena Suarez Pellicioni[1] & James Booth[2]
[1]University of Alabama; [2]Vanderbilt University

Math attitudes are related to achievement, yet we do not know how the brain supports changes in math attitudes. To fill this gap in the literature, 51 children solved a single-digit multiplication task inside the fMRI scanner when they were approximately 11 (time 1; T1) and 13 (time 2; T2) years old. Participants' task was to indicate whether the proposed solution to the problem was correct or incorrect. We used a standardized test to collect measures of children's math attitudes at T1 and T2 and we calculated gains in math attitudes over time (T2-T1). More specifically, this study aimed to answer three questions: (1) What are the brain correlates associated with math attitudes at T1?; (2) What are the brain correlates that, at T1, explain math attitudes improvement over time?; (3) What brain regions change over time with changes in math attitudes? Results revealed clusters in the left middle to superior temporal gyri (MTG/STG) at T1 associated with math attitudes at T1 and with their longitudinal improvement (T2-T1). This cluster overlapped with an independent verbal localizer. However, changes in attitudes were not associated with brain changes over time. Improvement in math attitudes also correlated with multiplication performance gains. These findings suggest that relying on the storage of arithmetic facts, involved in memory retrieval, explains the development of positive math attitudes.

Presentation 4: The role of adolescents' sense of belonging to mathematics and math identity in geometry learning

Christina Barbieri[1], Dana Miller-Cotto[2], Julie Booth[3], Casey Griffin[1], & Elena Silla[1]
[1]University of Delaware; [2]Kent State University; [3]Temple University

Sense of belonging to mathematics predicts algebra learning (Barbieri & Booth, 2016). Belonging is particularly important in predicting learning for underrepresented racial and ethnic minority (URM) students (Barbieri & Miller-Cotto, 2021). URM students reported a markedly lower sense of belonging than non-URM students which partially explained their lower posttest scores, even when accounting for socioeconomic status. Prior work did not assess mathematics identity which has been established as important for student learning and success in mathematics and intent to pursue STEM degrees and/or careers (e.g., Cribbs et al., 2021; Jackson et al., 2021). In the current study we consider the predictive utility of math identity and belonging for geometry learning in a diverse sample of high school students (N=406; 46% URM; 43% Low-SES; 52% female, 48% male). We also assess whether URM (Black, Latine, Multiracial students) students and those from low-income homes experience different levels of belonging and math identity in geometry classrooms compared to non-URM (White, Asian) students and middle-income students, respectively. Both math identity and belonging were positively related to geometry performance across the school year but math identity holds more weight. URM and non-URM students did not differ in their reported feelings of math belonging and identity. Both groups reported equally moderate levels of belonging and identity with few students reporting strong feelings of either construct. Students from low-income homes reported significantly lower levels of math identity than their middle-income peers. There is considerable room for improvement in fostering high schoolers' sense of belonging and mathematics identity.

S3A: Panel discussion 2: Foundations and other gencies (AERA, NaED, foundry10)

S3B: Essential components of word-problem instruction for supporting students with mathematics difficulty

Chair: Katherine Berry[1]
[1]University of Texas at Austin

Integrative Statement:
To show mathematics competency, students need to understand how to set up and solve word problems. Because many mathematics items in textbooks and on assessments are embedded within word-problem scenarios, word-problem proficiency is necessary to demonstrate successful mathematics performance. Of concern, students with mathematics difficulty (MD) demonstrate lower word-problem performance and make significantly more errors when solving word problems than peers without MD (Kingsdorf & Krawec, 2014). Word problems may pose a challenge for students with MD because of the numerous steps involving in setting up and solving (Fuchs et al., 2010). Without formal instruction, most students rely on the immature strategy of adding or subtracting all the numbers presented in the word problems without reflecting upon the word-problem question (Brissiaud & Sander, 2010). Given the expectation for students to solve word problems in classrooms and on standardized tests, there is a need to understand the most effective components of word-problem instruction. In this symposium, we introduce researchers and educators to efficacious interventions that support math word-problem solving, and we emphasize three essential components of word-problem instruction for students with MD: vocabulary practice, the use of a metacognitive strategy, and fact-fluency practice. Our objectives are to: (1) highlight the current research on effective word-problem interventions; and (2) demonstrate the necessary components of word-problem instruction, particularly for students with MD.

Presentation 1: Interventions that support mathematics word-problem solving: A systematic review and meta-analysis
Terhi Vessonen[1]
[1]University of Helsinki

Mathematical word-problem solving skills are crucial for students, yet such tasks pose challenges for individuals with and without difficulties in mathematics (Jaffe & Bolger, 2023). Therefore, identifying evidence-based approaches to support such skills is important. The objective of this systematic review and meta-analysis was to identify and evaluate the effects of mathematical word-problem solving interventions among elementary school-aged children. As the effects may be altered by various factors, the role of several moderators such as student's age, difficulty status, intervention type, and study quality were investigated. For reporting the current study, Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) framework was utilized (Page et al., 2021). Records for the systematic review were obtained through five electronic databases and citation searching. All records were evaluated against the eligibility criteria in two phases (i.e., abstract and full-text phase) by two independent reviewers. According to the preliminary analysis, 68 reports met the eligibility criteria of the current meta-analysis. Preliminary meta-analyses (40 studies and 135 effect sizes) from random-effects models with robust variance estimation (RVE) indicated word-problem solving interventions to have strong weighted overall effects (Hedges' $g = 0.77$, $p < .01$). However, heterogeneity between the effects exist ($Q = 3678.03$, $p < .0001$), highlighting the importance of examining factors that may alter the effects (i.e., moderators). We present findings from the current study, and emphasize the extent to which different types of word-problem solving interventions are effective and for whom they are effective, which can be employed in designing instruction.

Presentation 2: Essential components of word-problem instruction: Vocabulary practice
Elizabeth Stevens[1] & Sarah Powell[2]
[1]The University of Kansas; [2]The University of Texas at Austin

Research shows a positive relationship between students' mathematics vocabulary knowledge and their mathematics outcomes (e.g., computation, algebra; Peng et al., 2020), and this relationship is strongest for word-problem (WP) solving (Lin et al., 2021). It is well documented that students' language comprehension, which largely includes vocabulary knowledge, plays a critical role in reading comprehension (e.g., Gough & Tunmer, 1986), and students' mathematics-specific language comprehension is especially important for WP solving (Fuchs et al., 2018). Students' mathematics word knowledge is integral to understanding the WP, developing a representation of the problem, and solving the problem successfully (Fuchs et al., 2018; Fuchs et al., 2021). We present an instructional routine for teaching mathematics vocabulary during WP solving. We tested this routine experimentally using a randomized control trial comparing WP intervention with explicit vocabulary instruction (WP+V), WP intervention without vocabulary instruction (WP-only), and business-as-usual intervention (BAU). On a WP vocabulary measure, students in WP+V significantly outperformed students in WP-only (ES = 0.43) and BAU (ES = 0.83). On a WP measure, students in the WP+V outperformed students in WP-only (ES = 0.08)

and BAU (ES = 0.43) with small to moderate effect sizes, although these were not significant. We explain the components of the vocabulary routine and how we selected which words to teach, including terms needed to understand the word-problem process (e.g., label), terms with multiple meanings (e.g., equal), homophones (e.g., some vs. sum), and terms that occurred within word-problem text (e.g., some as an unknown amount in a change problem).

Presentation 3: Essential Components of Word-Problem Instruction: The Use of a Metacognitive Strategy

Katherine Berry[1]
[1]The University of Texas at Austin

Several meta-analyses (e.g., Montague et al., 2011) on effective word-problem interventions have highlighted the use of a metacognitive strategy as an evidence-based practice for supporting the problem-solving skills of students with math difficulty (MD). A metacognitive strategy requires students to reflect and think about "what they are doing" and "what they have done" (Berardi-Coletta et al., 1995), and often involves using a mnemonic device to promote questioning and cognitive understanding. In our word-problem research with elementary students with MD (ES >2.00), we have utilized UPS Check to prepare students to set up and solve word problems. The first step in UPS Check is to understand by reading. During the U, students read the problem, underline the label or what the problem is mostly about (e.g., crayons), and cross out irrelevant information, or any numbers not related to the label. Next, students complete the P by planning. To plan, students determine how they will solve the problem by identifying the word-problem schema, or problem type. They write the appropriate schema equation (e.g., P1 + P2 = T for the total schema) or draw a graphic organizer to represent the problem. Teachers also can integrate concrete manipulatives like counters or clips to aid in planning. Next, students complete the S by solving the problem and labeling the answer. Lastly, students check their answer by completing the inverse operations or reviewing for reasonableness. In this session, we explain how researchers and educators can use a metacognitive strategy to enhance students' word-problem solving.

Presentation 4: Essential components of word-problem instruction: Fact-fluency practice

Gracie Douglas[1] & Tessa Arsenault[1]
[1]The University of Texas at Austin

Mathematics fact fluency, defined here as students' ability to recall mathematics facts (i.e., single-digit addition, subtraction, multiplication, and division; Hinton et al., 2014), is a critical skill for demonstrating competency with more complex mathematical tasks like word-problem solving (Shapiro & Clemens, 2023). Improved fluency alleviates stress on working memory, increases confidence, and makes other math tasks easier. However, students with mathematics difficulty (MD) tend to experience higher levels of difficulty with fact fluency than peers without MD (Jordan, 2003). Many interventions have been developed to improve students' fact fluency, and those with brief (i.e., < 5 min), daily practice components with modeling yielded the best outcomes (Codding et al., 2011). In our word-problem research with elementary students with MD (ES > 2.00), we have included 2, one-min timed trials of fact-fluency practice with flashcards. During the first trial, students answer as many addition and subtraction flashcards correctly in 1 min. Interventionists provide immediate feedback by reviewing incorrect cards. The process is repeated for a second trial. Students graph their highest score from the two trials to encourage self-monitoring and goal setting. In later lessons, students practice multiplication and division facts. Students use visual aids of a counting up strategy poster and multiplication table for additional support. An unintended benefit of fluency practice within the word-problem intervention was overall improved fluency skills for intervention students over the control group (ES = 0.77). In this session, we explain how researchers and educators can use our fact-fluency activity to improve students' problem-solving skills.

S3C: Bringing families into the equation: Collaborative approaches to family math engagement research

Chair: Sarah Eason[1]
[1]Purdue University

Integrative Statement:

As research aimed at promoting families' support of early math learning progresses, there is an exciting movement towards incorporating multiple perspectives into the work. Specifically, researchers are recognizing that to develop family math interventions that draw on families' strengths and intentionally target their greatest needs, we need to consult the expertise of families themselves along with those working with families. The four papers presented in this symposium demonstrate different approaches to bringing family and community voices into family math research. In Paper 1, the author interviewed Black parents in the United States to gain insights into the

strengths that Black families bring to young children's math learning and what types of resources they most value. In Paper 2, authors integrated large-scale secondary data to inform workshops with parents and educators in the United Kingdom, aimed at developing materials to support home math activities. In Paper 3, authors drew on the knowledge of preschool educators to co-design family math kits aimed at promoting home-school partnerships in U.S. Head Start centers and evaluate the impact of the kits on families' attitudes. In Paper 4, the authors evaluated the effectiveness of a family math resource that was co-designed with U.S. parents to enhance parent-child math talk during everyday activities. All four papers emphasize asset-based approaches to resource development and the particular importance of including the voices of families who are often under-represented in research. Together, the symposium will showcase the potential for more collaborative and co-design approaches in family math research.

Presentation 1: "You're making me think about it more for sure": Engaging Black families in discussions about family math engagement

Ashli-Ann Douglas[1]
[1]WestEd, United States

Family math engagement is significantly related to preschool-aged children's math skills (Daucourt et al., 2021). However, little is known about Black families' efforts to, beliefs about, and desired resources for supporting their preschool-aged children's math learning (see Eason et al., 2022 for a review). Thus, the current study aimed to center the voices of Black families about their efforts to support their preschool-aged children's math development and engage them in discussions about enhancing their efforts. Thirteen Black parents were interviewed. The current analysis focuses on a random subset of the parents (three mothers who spoke English, had at least some college education, and ranged substantially in household income) whose discussions were coded using Interpretative Phenomenological Analysis (Smith et al., 2009). Two of the parents shared several examples of when and how they support their children's development of math skills such as counting and cardinality, arithmetic, repeating patterns, and shapes. Notably, the third parent shared that the interview discussion helped her recognize the importance of family math engagement and develop practical ideas for this: "I'm glad we're having this conversation because I feel like we have put more emphasis on the reading and the words than the math and I'm cognizant of it now having had this talk with you. So, it's important... you're making me think about it more for sure". Implications for understanding the assets and needs of Black families as they support their preschool-aged children's development of strong math skills and positive feelings about math will be discussed.

Presentation 2: Nothing for us without us: Working with families to support home learning

Victoria Simms[1], Abbie Cahoon[1], Ben Hunt[1], Ella James-Brabham[2], Emma Blakely[3], & Danielle Matthews[3]
[1]Ulster University, United Kingdom; [2]Loughborough University, United Kingdom; [3]Sheffield University, United Kingdom

"Engagement with home mathematics activities (HMAs) has been proposed to support mathematical development and to narrow attainment gaps (Elliott & Bachman, 2018). The type and frequency of HMAs that young children are exposed to have been shown to relate to children's early mathematics skills (for a review see Daucort et al., 2021). In addition, children from lower socio-economic status (SES) families tend to demonstrate lower mathematical skills than their higher SES peers (Blakey et al., 2020). SES has been found to play a role in the adoption of HMAs among parents of young children (e.g. Galindo & Sonnenschein, 2015; Muñez et al., 2021). In the current study we have worked with parents of children between the age of 3-5 years-old from lower SES backgrounds as well as early years educators to co-produce accessible and affordable mathematics resources to be used in the home environment. First, we conducted a large-scale secondary analysis project to increase our understanding of the influence of the HMAs in the UK. We used this information to inform the development of prompt material for parent and educator workshop materials. Workshops followed co-production principles. Within the workshops we identified the types of activities that parents already used at home and then collaborated with parents to extend these activities to support development and develop concrete materials. We worked with early years educators to ensure the developmental appropriateness of the materials. In this presentation we will discuss the development process and how our findings from workshops has informed intervention development."

Presentation 3: Home-school collaboration to support children's early math learning

Julie J. Kim[1], Sara Schnitzer[1], Graciela Borsato[2], & Eric Dearing[1]
[1]Boston College, United States; [2]Stanford University, United States

The value of home-school collaboration has been repeatedly touted in psychology and education (e.g., Pomerantz et al., 2007). However, impacts on learning may depend on whether home-school relationships are, in fact, truly collaborative. Indeed, the importance of educators having asset-based partnership attitudes – viewing families as partners who bring assets to the collaboration, including knowledge, skills, and cultural capital – and the pedagogical skills to make use of these assets has become clear in the literature (McWayne et al., 2022). Yet, many questions remain around how asset-based partnership practices can be supported for teachers working with marginalized and disadvantaged families. In the present study, we examined preschool teacher uses of family math kits that were co-designed to build asset-based home-school partnerships in 24 Head Start classrooms. The co-design team included researchers, preschool center leaders, and teachers (different centers than our study classrooms) of diverse backgrounds. Our research questions address whether variability in teachers' uses of kits predicts: (a) families' attitudes toward home-school collaboration and early math learning; (b) teachers' knowledge of family strengths, and how these strengths can be used in the classroom for math learning; and (c) families' confidence for engaging in early math learning at home. Preliminary results indicate considerable variability in teachers' consistency of use of the kits and attitudes toward using the kits to build home-school collaboration. We are presently analyzing whether this variability was consequential for (a) teacher knowledge of families and/or (b) family attitudes and confidence in engaging in early math learning at home.

Presentation 4: Parents as partners: A co-designed family math resource to enhance parent-child math talk

Sarah H. Eason[1], Can Carkoglu[1], Siqi Zhang[1], & Salvador R. Vazquez[1]
[1]Purdue University, United States

Family math interventions show promise for promoting math skills (Nelson et al., 2023). To ensure that intervention materials are relevant and useful, we must consider families' contexts, such as recognizing their funds of knowledge (Gonzalez et al., 2001). Incorporating families' experiences into intervention design can effectively promote engagement (e.g., Harris et al., 2020; Leyva et al., 2022). In this study we used a co-design process with parents of preschoolers to develop and evaluate the effectiveness of a family math resource. Based on input from parents of preschoolers, collected over a four-part co-design process and follow-up feedback sessions, we designed a two-part resource: an informational sheet about early math, and a guided activity offering support to implement the recommendations. We then conducted an experimental study with parents and 3- and 4-year-old children across the U.S. (n = 71). Parents were randomly assigned to view the informational math content (Math Condition) or to read about early nutrition (Control Condition). Parents and children participated in two playful activities during a Zoom session with a researcher (the guided activity and an unguided, near-transfer activity). Math Condition parents received tip cards to enhance math engagement during the guided activity. Preliminary results indicated that Math Condition parents reported higher levels of confidence in supporting children's math learning during the activities compared to Control Condition parents ($t=3.21$, $p=.002$). Interactions were recorded, transcribed, and coded for quantity and quality of math talk. We will present findings on how the math resource influenced parent-child math interactions.

S3D: Mathematics anxiety in elementary and middle school: Concurrent correlates and longitudinal predictors

Chair: Rachel Conlon[1]
[1]Leeds Trinity Unviersity

Integrative Statement:

Mathematics anxiety emerges early in development (e.g., Lu et al., 2021) and shows negative relations with mathematics achievement (Barroso et al., 2021). Though important for effective intervention design, research on factors associated with children's mathematics anxiety and its development is limited (Sorvo et al., 2019). This symposium brings together four studies utilising both correlational and longitudinal approaches to examine cognitive, attitudinal, and environmental correlates and predictors of mathematics anxiety in elementary and middle-school students.The first talk highlights a negative relation between mathematics anxiety and achievement in U.S. elementary school students, and how self-regulated learning may play an additional role in mathematics achievement. The second talk discusses associations between Scottish students' mathematics anxiety, their achievement, and their teachers' mathematics anxiety in early primary school. The third talk describes the relation between negative math interpretation biases and anxiety in U.S. middle school students. Finally, the fourth talk discusses results from latent change score models suggesting that higher mathematics anxiety levels lead to greater declines in

mathematics self-concept for U.S. elementary schoolers, but that increasing math interest can speed the decline in mathematics anxiety. Taken together, these findings underscore that mathematics anxiety is important to address early in education, given its clear relation with achievement, and potential to negatively affect other key mathematics attitudes. Despite this, associated factors, such as student math interest, interpretation bias, and teacher math anxiety, represent promising candidates to explore in our efforts to develop interventions that decrease math anxiety in children and young people.

Presentation 1: Applying a self-regulated learning framework to math anxiety: Implications for parent–child interactions and later math achievement

Olivia K. Cooke[1], Zahra Maghami Sharif[1], Sara A. Hart[2], & Colleen Ganley[3]
[1]Department of Psychology, Florida State University; [2]Department of Psychology & Florida Center for Reading Research, Florida State University; [3]Department of Psychology & Florida Center for Research in STEM, Florida State University

Children's self-regulation – or the ability to adapt to environmental stimuli in the service of a specific goal (McClelland et al., 2015) – has been linked to long-term academic achievement. Similarly, negative relations between math anxiety and math achievement have been established (Barroso et al., 2021). Despite regulatory processes (i.e., math anxiety and self-regulation) existing alongside components of motivation (i.e., math interest) in models of self-regulated learning later on in development (Efklides et al., 2018), the interplay between these skills with regard to parent–child interactions and math achievement during early childhood remains an area for further exploration. As part of a longitudinal study, 105 elementary-school students (K-3; 48% female, 79% Caucasian, 20% students of color) completed questionnaires about their math interest and anxiety (Ganley & McGraw, 2016) and completed grade- and season-specific versions of the Elementary Mathematics Student Assessment (Schoen et al., 2021). Caregivers completed a survey in which they reported on their children's self-regulation, how often they helped their child with math homework, and their emotional experiences while helping their child with math homework (DiStefano et al., 2020). Preliminary findings demonstrate a positive relation for self-regulation (β = .30, $p < .01$) and a negative relation for math anxiety (β = -.68, $p < .01$), but not math interest, on children's math achievement. However, only children's self-regulation had a significant relation with parents' positive emotionality during homework help interactions (β = .36, $p < .01$). Additional findings focused on self-regulated learning within the context of math will be presented.

Presentation 2: Is teachers' maths anxiety related to the maths attainment and maths anxiety of young school children?

Dawn Short[1] & Janet McLean[1]
[1]School of Applied Science, Abertay University

Previous work suggests that teachers' maths anxiety is related to their students' maths attainment. However, this has typically only been explored in children aged over 7 years (e.g., Beilock et al., 2010; Schaeffer et al., 2020). Few studies have explored the relationship between teachers' and students' maths anxiety in the early school years (e.g., Szczygiel, 2020). In the current longitudinal study with 421 younger children (Mean age at first testing = 5.02 years, SD = 0.32), we investigated these teacher-student relationships in the first three years of formal education in Scottish state primary schools. Each year, children completed the numeracy and problem-solving subscales from the standardized Wechsler Individual Achievement Test-3rd UK Edition (WIAT-iii UK) (Wechsler, 2017), along with an adapted Child Maths Anxiety Questionnaire (CMAQ) (Ramirez et al., 2013). Teachers completed the abbreviated Mathematics Anxiety Rating Scale (MARS) (Suinn & Winston, 2003). Cross-lagged panel analysis revealed children's maths anxiety and maths attainment each predicted the other; high maths anxiety and lower maths attainment occurred together. Teachers' maths anxiety was associated with both children's maths anxiety and children's maths attainment. These results highlight a relationship not reported previously, that of a relationship between the maths anxiety of children from age 4 years, and the maths anxiety of their teachers, linked to maths attainment. It demonstrates the importance of addressing maths anxiety in the early school years, both to reduce the maths anxiety of teachers and children and to improve maths attainment.

Presentation 3: Investigating the unique relation between children's math interpretation biases and math anxiety

Connie Barroso[1], Raashi Sangwan[1], & Anjali Chaudhary[1]
[1]Department of Educational Psychology, Texas A&M University

Negative interpretation biases, or cognitive inclinations to process ambiguous stimuli as threatening, have been linked to the development of generalized anxiety disorders (MacLeod & Mathews, 2012). This relation may also exist in a math context but has yet to be investigated.

In this study, we examined the unique role of math interpretation bias in explaining the variance in children's math anxiety. Eighty-five U.S. children aged 8-14 (mean=11.56 years) completed a math anxiety scale, general interpretation bias measure, and two interpretation bias measures adapted to math-related situations. Students rated their level of enjoyment to ambiguous scenarios using the Ambiguous Math Scenarios Test (AMST) and also indicated how related ambiguous sentences were to certain positive and negative words in the Word Sentence Association Paradigm (Math). Both measures use a 1-5 scale (not at all to very). WSAP-M negative bias scores were calculated by subtracting positive word-sentence associations ratings from negative ones.In separate linear regression models, WSAP-M (b=.67; p<.001) and AMST (b=-.39; p<.001) each had significant, moderate-to-strong unique relations with math anxiety after accounting for age, gender, and general interpretation bias. Results indicate that students with greater inclinations to interpret ambiguous math scenarios as threatening and less enjoyable tend to have greater levels of math anxiety. These findings highlight the need for future longitudinal and intervention studies to better understand the possible causal relation between math interpretation bias and math anxiety during childhood.

Presentation 4: Developmental relations between math self-concept, interest, and anxiety in elementary school: A latent change score modeling study

Rachel A. Conlon[1] & Colleen M. Ganley[2]
[1]School of Psychology, Leeds Trinity University; [2]Department of Psychology & Florida Center for Research in STEM, Florida State University

Math attitudes represent a promising target for intervention to increase the number of students pursuing further education and careers in Science, Technology, Engineering, and Math (STEM), as they are found to predict students' likelihood of progression to STEM pursuits above and beyond their math achievement. Understanding how math attitudes develop and co-develop, especially earlier in education when these attitudes form, is crucial for designing effective interventions. Research on the co-development of math attitudes in elementary education was traditionally limited to examining either the growth of each attitude individually over time or how earlier mean levels of one attitude might influence later levels of another. In this study, we employed the unique approach of latent change score modelling with an accelerated cohort design to simultaneously model growth in the attitudes of math self-concept, interest, and anxiety and how they may influence each other over time, in a sample of 2,954 US students from a three-wave study covering fall of kindergarten to spring of third grade. Results indicated higher levels of self-concept earlier on led to a slower decline in interest, higher levels of interest led to more decline in anxiety and higher levels of anxiety led to more decline in self-concept. A greater decline in interest over time was also associated with less subsequent decline in anxiety. Findings suggest that interventions focusing on maintaining high levels of math interest and self-concept, and reducing math anxiety, may be particularly fruitful due to subsequent positive effects on other attitudes.

S4A: Measuring mathematical skills in early childhood: Current evidence and future directions

Chair: Laura Outhwaite[1]
[1]University College London

Integrative Statement:

This symposium will bring together three presentations focused on the evaluation and use of assessment and screening tools designed to measure mathematical skills in early childhood. Paper 1 will present a systematic review of 38 assessment tools and 22 screeners, which have been evaluated for their psychometric properties with children aged 0-8 years. This review highlights several important evidence gaps. For example, many of these measures rely on trained assessors to administer them, which can pose challenges for large-scale, school-based intervention research. Furthermore, many of these measures have been developed and evaluated in Western, Educated, Industrialised, Rich, and Democratic societies, and thus limit the possibility of cross-culturally valid research in mathematical learning and cognition. In addressing these evidence gaps, Paper 2 presents the development and implementation of the Early Math Assessment (EMA)@School. This measure is a teacher-implemented formative assessment package, which has been validated with over 150,000 children aged 4-10 years in Canada. This paper will also reflect on the importance of co-production with teachers to maximise buy-in and improve access to effective measures of mathematical skills. Paper 3 presents a cross-national evaluation of the Numeracy Screener with over 8,000 children from five continents. A meta-analysis of performance on the paper-and-pencil based non-symbolic and symbolic numerical magnitude comparison tasks highlights cross-cultural insights into mathematical cognition, which are important for future research. The symposium discussant will draw out themes across the three presentations and add their reflections on their

experiences in developing and using measurement tools for early mathematical skills.

Presentation 1: A Systematic review of assessment tools and screeners for early mathematical development

Laura Outhwaite[1], Pirjo Aunio[2], Jaimie Ka Yu Leung[1], & Jo Van Herwegen[1]
[1]UCL's Faculty of Education and Society; [2]University of Helsinki

Successful early mathematical development is vital to children's later education, employment, and well-being outcomes. However, recent synthesises in mathematical learning and development highlight the infrequent use of established assessment tools to i) measure children's mathematical skills and ii) identify children with or at-risk of mathematical learning difficulties. In response, this pre-registered systematic review identified 38 assessment tools and 22 screeners, which have been evaluated for their psychometric properties for measuring the mathematical skills of children aged 0-8 years. The reliability and validity of these measurement tools were then synthesised, including in relation to common acceptability thresholds. Results showed around half of the assessment tools had acceptable internal consistency (n = 19) and test-retest or inter-rater reliability (n = 14). Nine assessment tools met common acceptability thresholds for measures of construct validity. Eight assessment tools had acceptable concurrent validity, mostly in comparison to the Woodcock-Johnson Math subtests. Just under half of the screeners also had acceptable internal consistency (n = 10). Few screeners were found to have acceptable test-retest reliability (n = 4), diagnostic accuracy (n = 2), construct validity (n = 2), or concurrent validity (n = 1). Although predictive validity was considered in six screeners, none met the common acceptability threshold. Overall, although a relatively large number of assessment tools and screeners were identified in the current review, there remains significant gaps in the appraisal of these tools. Building on this evidence and improving measurement quality is vital to raising methodological standards in mathematical learning and development research.

Presentation 2: The development and implementation of the early math Assessment@School in Canadian classrooms

Rebecca Merkley[1], Heather Douglas[1], Shuyuan Yu[1], & Jo-Anne Lefevre[1]
[1]Department of Cognitive Science, Carleton University, Ottawa, Canada

The EMA@School is a formative assessment package that is based in research on early mathematical learning and developed in response to the need for a valid and reliable assessment of number skills in students from kindergarten to grade 4. Importantly, the EMA@School was designed to be administered by classroom teachers and is being used as a pre- and post-test measure to evaluate interventions developed through research-practice partnerships with Canadian school districts. To date, over 150,000 students have been tested with the EMA@School across four Canadian provinces. Through our partnerships, we have learned about educators' perspectives on early math assessment. For example, many educators are concerned that timed assessments can cause anxiety in students. Educators also want to ensure assessments are aligned with the curriculum and consider the diverse needs of Canadian students. Through the Assessment and Instruction for Mathematics (AIM) Collective, a dynamic community of researchers and educators committed to sharing evidence-informed math education tools and resources, we are working to ensure more Canadian educators have access to effective math assessment tools. In this presentation, we will share what we have learned about the importance of working in collaboration with educators to ensure buy-in and uptake of early numeracy assessment practices based in research.

Presentation 3: Cross-national evaluation of quantity comparison skills and math performance: Beyond the Global North

Daniel Ansari[1] & Nadir Díaz-Simón[1]
[1]Western University

Proficiency in quantity comparison skills is essential in navigating daily tasks, enabling individuals to make informed decisions ranging from financial planning and shopping to time management. The Numeracy Screener (NS) is a paper-and-pencil assessment tool for non-symbolic and symbolic numerical magnitude comparison skills. In the last decade, NS has been administered to more than 8 thousand school-aged children on 5 continents, allowing us to analyze numerical processing information from populations with a wide variety of socio-economic and educational realities. This study presents a meta-analysis of the association between symbolic and non-symbolic comparison performance with math abilities. In addition, the mediating effect of country-level information on such relationships was evaluated. The results of the multi-level random-effect models show a stronger association between math abilities and symbolic ($r = .537$, 95% CI [.380, .694], $p < .001$) than for the non-

symbolic (r = .462, 95% CI [.363, .562], p < .001) magnitude comparison skills. Moreover, the countries' Human Development Index (HDI) negatively moderates the association between non-symbolic comparison skills and math abilities (0 = 1.035, HDI = -.722, p = .014), with developing countries showing a stronger relationship between non-symbolic comparison skills and math abilities. These findings show the systematic relationship between magnitude comparison skills and mathematical performance, with a greater impact for symbolic numerical comparison abilities. However, these results also suggest that country-specific socio-economic and educational characteristics impact this relationship, which should be considered for future research.

Discussion led by

Jo-Anne Lefevre[1]
[1]Department of Cognitive Science, Carleton University, Ottawa, Canada

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S4B: "Ask me anything" with funding panelists and agencies

S4C: Children's and parents' spontaneous mathematical focusing tendencies

Chair: Lauren Westerberg[1]
[1]Purdue University

Integrative Statement:

Children's spontaneous tendencies to focus on mathematical features in non-mathematical contexts predicts their future mathematics performance (McMullen et al., 2020). Foundational to this area of research is investigating children's spontaneous focus on numerosity (SFON: Hannula & Lehtinen, 2005), which is an individual's unprompted attention toward, and numbering of, a given set of items (Hannula & Lehtinen, 2005). Recent work has demonstrated that children's spontaneous focusing tendencies go beyond numerosity (e.g., number symbols: Rathé et al., 2019; spatial aspects: Perez & McCrink, 2019; patterning: Wijns et al., 2020). The objectives of this symposium include examining additional forms of mathematics that children spontaneously attend to including, numerical order and mathematical language, in addition to traditional aspects of numerosity, and how these tendencies relate to a broad range of mathematical abilities (e.g., numerical ordering, geometry, and spatial skills). Additionally, this symposium considers how parents' own SFON relates to the types of mathematics stimulation they provide at home. Specifically, the first study examines longitudinal relations between four-year-olds' tendencies to spontaneously focus on numerical order and their numerical ordering skills. The second study examines relations between three-, four-, and five-year-old's tendencies to spontaneously focus in three areas: numerosity, quantitative mathematical language, and spatial mathematical language, and their performance in a broad range of mathematics tasks. The third study examines relations between parents' SFON and the mathematical input they provide to their children at home, including their mathematical talk and their frequency of mathematics activities. Melissa Libertus will facilitate a discussion following the presentations.

Presentation 1: The longitudinal relations between children's spontaneous focusing on numerical order and their numerical ordering skills

Heidi Harju[1], Jo Van Hoof[1], Jake McMullen[1], Cristina Nanu[1], & Minna Hannula-Sormunen[1]
[1]Department of Teacher Education, University of Turku, Finland

While grasping the ordinal properties of numbers is a crucial part in children's early numerical development (Fuson, 1988; Lyons et al., 2016), longitudinal studies investigating the development of numerical ordering skills are scarce. Apart from individual differences in numerical skills, research has showed variability in children's tendency to spontaneously focus on mathematical aspects in everyday situations (McMullen et al., 2019), which have repeatedly been associated with higher concurrent and later mathematical skills (e.g., Hannula & Lehtinen, 2005; Poltz et al., 2022).In the present study, we investigate the longitudinal development between children's tendency to spontaneously focus on numerical order (SFONO) and their numerical ordering skills. Longitudinal data from a large group of four-year-olds (n = 150) was collected three times over a one-year time period. Every six months, a battery of activities was administered to measure children's SFONO tendency and numerical skills. The measures included three SFONO tasks (Harju et al., submitted) and a numerical ordering task (Spaepen et al., 2018). The following research questions are addressed: (1) Do children's numerical ordering skills and SFONO increase over a one-year time period and (2) what are the longitudinal relations between children's numerical ordering skills and their SFONO. Preliminary results suggest improvements in SFONO and ordinal skills and a positive longitudinal relation between these two. Further depth to these findings will be presented at the conference.

Presentation 2: More than numerosity: Spontaneous focusing on mathematical language and its relations to children's mathematics performance

Lauren Westerberg[1], Patrick Ehrman[1], Fabiola Herrera[1], Suzanne Varnell[1], Yemimah King[2], Avery Closser[1], Elizabeth Clark[1], Can Carkoglu[1], Tamika McElveen[3], & David Purpura[1],
[1]Human Development & Family Science, Purdue University, West Lafayette, IN; [2]Early Childhood and Elementary Education, Georgia State University, Atlanta, GA; [3]Psychology, Miami University, Oxford, OH

Children's spontaneous focus on numerosity (SFON) has been hypothesized to be an important early predictor of mathematics ability. Previous studies have also found that additional forms of spontaneous focus beyond numerosity (e.g., space) are related to future mathematics performance. One area that has not yet been examined is children's spontaneous focus on mathematical language (e.g., quantitative and spatial language), despite growing evidence on the importance of children's knowledge of mathematical language in their early mathematics development (Purpura et al., 2017; 2019). This study evaluated the relation of children's spontaneous focus on numerosity, quantitative language, and spatial language with various early mathematics skills (e.g., numeracy, quantitative and spatial language, cardinality, numeral identification, geometry, and spatial skills). Participants included 344 preschool-aged children (Mage= 4.30 years, SD = 0.62 years). Children completed a 12-image spontaneous focus on mathematics task and were scored based on their usage of number, quantitative language, and spatial language. Children also completed a broad range of other mathematics assessments (e.g., cardinality). Findings revealed that children's spontaneous focus on spatial language was related to their performance on numeracy, cardinality, and quantitative and spatial language knowledge assessments, even when children's focus on numerosity and quantitative language were included in the models. Children's spontaneous focus on numerosity and quantitative language were not significantly related to any outcomes. Examining other forms of children's spontaneous focusing ultimately provides greater insight into how children employ mathematical concepts in naturalistic settings and how this attention relates to broader mathematical development.

Presentation 3: Spontaneous focus on numerosity in parents of preschoolers: Is it related to the math input they provide?

Linxi Lu[1], Marina Vasilyeva[1], Elida Laski[1], & Novak (Haoyu) Chen[2]
[1]Applied Developmental and Educational Psychology, Boston College; [2]Graduate School of Arts and Science, Columbia University

There is substantial variability among parents in the amount of math input they provide at home, which is related to differences in children's early math knowledge (Casey et al., 2018; Gibson et al., 2020; Vasilyeva et al., 2018). The current study examined whether parents' Spontaneous Focus on Numerosity (SFON) predicts the math input they provide at home – both in terms of their math talk and frequency of math activities. Parents (N = 124) from diverse socioeconomic backgrounds in China were presented with a SFON picture task. Unique to the present investigation, two conditions were used to determine SFON. The conditions differed only in the hypothetical conversational partner: an adult-oriented and a child-oriented condition. No effect of SFON was found for math activities, but there was an effect on math talk: child-oriented SFON (but not adult-oriented SFON) predicted the amount and diversity of math talk parents produced during play interactions. Further, parents' education was associated with their SFON and its relation to math talk. Parents with more advanced education had greater SFON scores than those with lower education. Importantly, the positive relation between parents' SFON and their math talk was moderated by SES, such that the effect was primarily driven by low-SES parents. Together, the findings suggest that SFON may be a promising construct in the study of parent math input, but parent's SES and the nature of the SFON task must be taken into consideration.

Discussion led by

Melissa Libertus[1]
[1]Department of Psychology, University of Pittsburgh, PA

S5A: Embodied learning in mathematics: Nurturing cognitive development through motor skills, finger-based strategies, and bodily actions"

Chair: Venera Gashaj[1]
[1]Loughborough University, UK

Integrative Statement:

This symposium brings together a range of perspectives, both in terms of target populations and scientific approaches, at the intersection of embodied learning and mathematics education in order to investigate the role played by motor skills, finger-based strategies, and bodily actions in shaping mathematical development. Speakers from Hong Kong, UK, and Switzerland, each bring distinct methodological approaches, yet all explore cognitive development through the lens of embodied cognition. The first presentation, by Bo Lyu and colleagues, investigates

the mediating roles of number line estimation and patterning skills in the relationship between motor skills and math achievement in kindergarten children. The findings reveal a nuanced influence of fine and gross motor skills on mathematical performance. The second presentation discusses the effects of a year-long finger-based intervention on arithmetic learning. Venera Gashaj and colleagues showed that the intervention had immediate and sustained benefits on written addition and subtraction. This result provides causal evidence for the efficacy of embodied learning strategies in primary school mathematics curriculum. The final presentation examines students' movements while they make sense of derivatives. A more advanced mathematical topic. Julia Chatain and colleagues investigate both spontaneous and directed hand movements during this learning process, identifying key action characteristics through a mixed methods approach. Collectively, these presentations weave a narrative around embodied learning in mathematics, focusing on the role of finger and hand movements at different stages of learners' development. Together, the symposium highlights the impact of embodiment on cognitive processes and offer practical insights for educators and researchers alike.

Presentation 1: Association between motor skills and math achievement: The role of number line representation and patterning

Bo Lyu[1], Kerry Lee1, Xiaozi Gao[1], Catherine M. Capio[2], & Sum Kwing Cheunga[1]

[1]The Education University of Hong Kong, Hong Kong SAR; [2]Metropolitan University, Hong Kong SAR

Motor skills are positively related to math performance, but the mechanism that produces this relation remains unclear. This study examined whether number line estimation and patterning skills play a mediating role in the relation between motor skills and math performance. A sample of 1182 kindergarteners (M age= 56.12 months) from 63 kindergartens were tested on fine motor skills (FMS), gross motor skills, number line estimation, patterning, and a standardised math achievement task. Structural equation modelling showed that number line estimation and patterning mediated the relations between motor skills and math achievement after controlling for age, sex, and SES. Comparison with a multiple regression model with the same explanatory variables showed that the mediation model provided a better fit to the data. In addition to the indirect relations, the mediation model showed that the direct relations between the two motor skills and math achievement remained significant despite the mediation. The magnitude of the overall relations (i.e., direct + indirect) involving FMS (.25) is larger than that of gross motor (.16). This is consistent with previous studies showing that FMS are more closely associated with cognitive development. The findings also showed that the relations between FMS, patterning, and math achievement were the strongest amongst all indirect relations. Although these findings are consistent with an embodied cognition role for FMS, the available data do not allow us to determine whether the associations between FMS and patterning are due to the direct influence of one on the other or some other shared mechanisms.

Presentation 2: Facilitating early mathematics learning through finger-based strategies – An intervention study

Venera Gashaj1, Mirjam I. Frey2, Hans-Christoph Nuerk[3,4], & Korbinian Moeller[1,4,5]

[1]Loughborough University, School of Science, Loughborough, United Kingdom; [2]Department of Clinical Psychology and Experimental Psychopathology, University of Groningen, the Netherlands; [3]Department of Psychology, University of Tübingen, Tübingen, Germany; [4]LEAD Graduate School and Research Network, University of Tübingen, Tübingen, Germany; [5]Leibniz-Institut für Wissensmedien, Tübingen, Germany

There is an ongoing debate on the role of finger use in early mathematics instruction. Correlational evidence indicates finger use's positive impact on early math learning, but causal evidence is limited. We ran a pre-post-follow-up intervention study to investigate the impact of finger-based strategies on arithmetic learning. In a year-long program integrated into standard mathematics instruction in first grade (mean age 6.48 years, SD = 0.35), we compared a finger-based training group (n=119) with a control group (n=123) following the conventional curriculum. Propensity score matching was used to ensure comparability of groups at the pre-test on relevant covariates (e.g., precursor skills, general cognitive ability, etc.). A mixed measures ANOVA demonstrated significant differential learning trajectories across measurement time-points between groups. In particular, children completing the finger-based training outperformed the control group in written addition and subtraction at the end of first grade and maintained their advantage in a follow-up test nine months later in second grade. For addition, the finger-training group exhibited a significantly stronger performance gain from pre- to post-test compared to the control group, with advantages persisting through the follow-up test. Similarly, for subtraction, the intervention group outperformed the control group. Intriguingly, there was no training effect for number line estimation tasks supported by Bayesian analysis. Taken together, our findings provide causal evidence suggesting beneficial effects of finger-based

strategies in primary school mathematics education, offering empirical support for an embodied representation of numbers.

Presentation 3: How do students move when making sense of derivatives?

Julia Chatain[1,2], Bibin Muttappillil[1], Robert W. Sumner[1], & Manu Kapur[2]
[1]Dept. of Computer Science, ETH Zurich, Zurich, Switzerland; [2]Dept. of Humanities, Social and Political Sciences, ETH Zurich, Zurich, Switzerland

While mathematics is conventionally viewed as an abstract discipline, contemporary perspectives on embodied cognition underscore the significance of integrating students' bodily experiences into the learning process. Specifically, students perform various bodily actions when making sense of mathematical concepts. First, they may perform spontaneous bodily actions, meaning they spontaneously use their bodies to express mathematical meaning and understanding. Second, they may perform directed bodily actions, moving their bodies as requested per a certain learning activity or tool. In this work, we are interested in designing digital interactive embodied learning activities for mathematics, specifically the topic of derivatives. To gain an understanding of the underlying design space, we conducted two exploratory studies to answer the following research question: How do students move when making sense of derivatives? Specifically, we are interested in identifying the key characteristics of students' bodily actions during the embodied learning process, focusing on hand movements specifically. We performed a qualitative study of learners with different mathematical abilities and interest levels and observed their spontaneous bodily actions while solving tasks exploring derivatives in different contexts. We then performed a quantitative study with learners (n=130) interacting with an embodied learning activity on the topic of derivatives in Virtual Reality as well as on a tablet and observed their directed bodily actions. Derived from both studies, we propose design recommendations, advocating for expanded embodied interaction design, consideration of embodied metaphors, coarse gesturing for deep features identification, supporting for sense-making anchors, and in-VR learning assessments.

Discussion led by

Firat Soylu[1]
[1]Department of Educational Studies, College of Education, The University of Alabama

S5B: How neuroscience may inform cognitive arithmetic: From individual mechanisms to intergenerational transmission

Chair: Nicolas Masson[1] & Jérôme Prado[2]
[1]Psychological Sciences Research Institute, Université catholique de Louvain, Belgium; [2]Centre de Recherche en Neurosciences de Lyon (CRNL), INSERM U1028 - CNRS UMR5292, Université de Lyon, France

Integrative Statement:

Arithmetic knowledge is crucial for daily life and serves as the foundation for advanced mathematical skills essential to success in STEM fields. Therefore, understanding the cognitive mechanisms supporting arithmetic problem-solving in individuals, as well as how this cultural skill is passed down from one generation to the next, is critical. In this symposium, we will argue that neuroscience can inform these questions through various complementary methodologies, including innovative uses of EEG, fNIRS, and fMRI. The presentations will feature a unique combination of studies investigating the neural mechanisms of arithmetic processing in individuals and across generations. Collectively, this research aims to understand the neuro-cognitive mechanisms supporting single-digit and multi-digit arithmetic processing, as well as the ways interactions and similarities between parents and children may underlie skill transmission. N. Masson will describe how intermodulation components in frequency-tagged EEG may reveal that different types of arithmetic operations (addition versus multiplication) rely on different types of cognitive mechanisms (counting versus retrieval) in adults. X. Yao will show how fNIRS may be used in adults to investigate the mechanisms supporting multi-digit addition and subtraction problems. C. Constant will present neuroimaging work exploring the similarity in neural representations of arithmetic problems between parents and children. Finally, A. Marzoratti will demonstrate how EEG multiscale entropy may capture social processing differences between parent-child dyads in an arithmetic task. Together, the presentations will highlight how combining various neuroscience methods may contribute to a better understanding of cognitive arithmetic and its cultural transmission.

Presentation 1: Distinct procedures underlying additions and multiplications revealed by intermodulation components in frequency-tagged electroencephalogram

Nicolas Masson[1], Christine Schiltz[2], & Talia L. Retter[2]
[1]Psychological Sciences Research Institute, Université catholique de Louvain, Belgium; [2]Institute of Cognitive Science and Assessment (COSA), Department of Behavioural and Cognitive Sciences (DBCS), Faculty of Humanities, Education and Social Sciences (FHSE), University of Luxembourg, Luxembourg

Until recently, there was a consensus that children start to solve single-digit additions and multiplications by costly procedural strategies and progressively switch to a memory-based resolution when encountering these problems recurrently. However, the idea that adults use retrieval for single-digit additions was challenged by behavioral studies. Instead, it was suggested that additions are solved by fast counting procedures akin to shifts of attention along a mental number line (MNL). Because additions are also associated to an over-estimation bias termed operational momentum (OM), it was proposed that the attentional shifts are going too far when navigating on the MNL. The trace of the OM at the neuronal level remained to be explored. Here, we used frequency tagging with electroencephalogram (EEG) to identify the neural signature of OM while adult participants viewed single-digit additions and multiplications with proposed solutions that were either correct, incorrect-smaller (correct-1) or incorrect-larger (correct+1). The problem and the proposed solution were presented visually and flickered at distinct frequencies (F1 & F2, respectively). We searched for EEG responses at intermodulation frequency terms (e.g., f1+f2) that occur only if the two flickering stimuli are integrated into a single representation by responding neurons. Accordingly, correct trials elicited temporoparietal and frontocentral responses at intermodulation frequency terms, indicating an integration of the problem and its' solution. Incorrect conditions did not reveal intermodulation, with the exception of incorrect-larger addition, compatible with the OM. This supports the theory that single-digit additions and multiplications are solved by mechanisms of a distinct nature.

Presentation 2: Neurocognitive correlates of multi-digit arithmetic: An fNIRS study

Xinru Yao[1], Beatrix Barth[2], & Christina Artemenko[1]
[1]Department of Psychology, University of Tuebingen, Germany; [2]Department of Psychiatry and Psychotherapy, University of Tuebingen, Germany

Arithmetic is represented in a fronto-parietal network in the brain, including frontal brain areas (e.g., inferior frontal gyrus and middle frontal gyrus) associated with domain-general cognitive processes and parietal brain areas (e.g., intraparietal sulcus) associated with domain-specific numerical processes. In multi-digit addition and subtraction, difficulty increases due to carry and borrow operations. When arithmetic gets more difficult, frontal activation might increase due to manipulating larger numbers (e.g., number magnitude processing increased by problem size). In this preregistered fNIRS study (https://osf.io/sf65n), we aimed to investigate whether the difficulty of multi-digit arithmetic is mainly processed in domain-general frontal areas or in domain-specific parietal areas. By using functional near-infrared spectroscopy (fNIRS), we could implement an ecologically valid production paradigm to study multi-digit addition with 0, 1 or 2 carry operations and subtraction with 0, 1 or 2 borrow operations (N = 50). The results showed that subtraction was more difficult than addition, and difficulty further increased with each carry and borrow operation. According to preliminary fNIRS results, arithmetic difficulty is not only associated with frontal brain activation but also parietal brain activation. This suggests that multi-digit arithmetic might be driven by both domain-specific and domain-general processes.

Presentation 3: Family-specific transmission of brain circuits for arithmetic

Charlotte Constant-Varlet[1], Tomoya Nakai[1], Léa Longo[1], Honorine Bouchet[1], & Jérôme Prado[1]
[1]Centre de Recherche en Neurosciences de Lyon (CRNL), INSERM U1028 - CNRS UMR5292, Université de Lyon, France

A major source of individual differences in children's academic learning stems from their families. Environmental factors explain some of these differences, with associations between family socio-economic status and children's academic knowledge. Genetic factors also contribute, as evidenced by the heritability of learning disabilities. However, academic skills are multifaceted, typically involving domain-specific and domain-general components. For instance, arithmetic knowledge depends on both specific representations of numerical magnitudes within the intraparietal sulcus (IPS) and on executive functions linked to the prefrontal cortex. What are the components of arithmetic knowledge that are passed down from parents to children? To explore that question, we used fMRI to study the similarity in the neural underpinnings of arithmetic processing in a sample of 37 mother-child dyads who were presented with single-digit addition and subtraction problems. Similarity in neural representations of arithmetic problems between mothers and 8-year-old children was assessed using whole-brain searchlight representational similarity. Non-family-specific neural similarity between all mothers and children was tested by running all possible permutations across the entire sample. This analysis revealed between-generation similarities within a broad fronto-parieto-occipital network encompassing the

bilateral IPS. Family-specific neural similarity was then assessed by comparing related dyads against all possible unrelated dyads. Family-specific neural similarity was observed in a prefrontal network that excluded the IPS and showed no overlap with the regions demonstrating non-family-specific similarities. These findings suggest that the parent-child transmission of arithmetic skills is more likely related to domain-general functions supported by prefrontal mechanisms than domain-specific representations of numerical information in the parietal cortex.

Presentation 4: Influences of autism symptom severity on the relationships between math skill and biological and observational measures of social functioning

Analia Marzoratti[1], Megan E. Liu[1], & Tanya M. Evans[1]
[1]School of Education and Human Development, University of Virginia, Charlottesville, VA, USA

Learning, an inherently social process, is influenced by one's social processing skills. Social aptitudes are challenging to differentiate observationally, particularly among individuals with autism spectrum disorder (ASD), characterized by atypical social behaviors. Electroencephalographic multiscale entropy (MSE), a neurobiological measure associated with social perception, has the potential to better capture social processing variability among neurodiverse individuals. We assessed relationships between 21 typically-developing and 17 autistic children's math competency, parent-reported child and parent ASD symptom severity (autism quotient [AQ]), and child-parent interaction quality during a joint math-task. Measures of interaction quality included dual-coded observation-based behavioral attunement scores and windowed cross-lagged correlations across MSE time-series. Woodcock-Johnson-IV math fluency scores assessed math skills. Analyses utilized linear mixed effect models in R-3.4.2, controlling for child IQ, age, sex, and EEG signal quality. Preliminary analyses revealed that math skills were positively associated with child-parent behavioral attunement ($r(39)=0.39$, $p=0.01$), suggesting parent-child relationship quality may scaffold math skill acquisition. As predicted, children's AQ was negatively associated with typically-normed behavioral attunement scores ($r(39)=-0.41$, $p<.001$). Importantly, math fluency was not associated with AQ, suggesting that children with higher AQ may not necessarily show lower math proficiency irrespective of its relationship to behavioral attunement. By analyzing the extent to which MSE moderates these relationships, we will evaluate a potential mechanism for the relationship between behavioral attunement and math competency beyond AQ. We will also assess concurrent validity among observational and biological metrics of child-parent social interaction quality, comparing their utility for capturing social processing differences across the autism spectrum.

S5C: Understanding strategy use in math problem solving and learning

Chair: Qiushan Liu[1]
[1]Department of Psychology, Florida State University

Integrative Statement:

Using effective strategies plays a pivotal role in math learning and problem solving. However, relatively little is known about learners' strategy selection in mathematical domains such as proportional reasoning, how different cognitive factors contribute differentially to strategy usage, and how learners employ different strategies for learning mathematical concepts. The present symposium investigates students' strategy use in the contexts of proportional reasoning, linear algebraic equations, and employing study strategies across three age groups, from elementary school to college. The first presentation scrutinizes people's strategy use during proportional reasoning, revealing that people's strategies change based on visual stimulus features that may impact their attention to proportion, with an observed age-related variance, suggesting that people's strategy selection changes with age. The second presentation concentrates on unraveling the relationship between diverse cognitive factors and the selection of strategies among 8th-12th grade students in algebra equation solving. Findings indicate that when an innovative strategy is available that is more efficient than the standard strategy, students rarely use it spontaneously. Conceptual knowledge predicts likelihood of selecting and correctly executing such innovative strategies. The third presentation delves into the self-regulated study strategies of college students taking a mathematics course. The study finds that students predominantly rely on studying worked examples and problem solving practice, emphasizing their dependence on retrieval practice for mathematical learning. By examining learner' strategy use from these three distinct perspectives, the current symposium offers unique insights into the dynamics of strategy use during mathematical learning and problem solving.

Presentation 1: Children's use of a numerator strategy for comparing proportions of different kinds

Michelle A. Hurst[1]
[1]Department of Psychology, Rutgers University

Despite successfully comparing probabilities using undivided game-spinners, children fail when spinners are divided so that the numerator contradicts the proportion (e.g., 2/3 vs. 4/9 where 4>2, but 2/3>4/9), presumably because they are primarily relying on absolute number (e.g., Hurst & Cordes, 2018). Here, we mathematically formalize strategies to estimate the probability that children rely on a proportion strategy vs. numerator strategy, as well as how strategy use changes across development and as a function of the proportion's visual features. In Study 1, 4- to 11-year-olds (N=93, Park et al., 2020), compared two ratios, presented as ratios of sets of dots or line lengths. In Study 2, 4- to 6-year-olds (N=30) compared two proportions, presented as integrated dots, separated dots, a partially colored blob, or separate blobs, based on which had a higher probability of an orange (vs. blue) outcome using a cover story about a magic ball. We find that children are most likely to use a numerator strategy for blobs, M=.57, and dots, M=.52 (Study 2), M=.53 (Study 1), followed by lines, M=.34. However, children were also more likely to use a numerator strategy with spatially separated dots, M=.55, vs. integrated, M=.48, p=.02. Finally, children's reliance on a numerator strategy for dots decreased with age, Study 1: r=-.30, Study 2: r=-.40, ps<.05. Together, these findings suggest that children's strategies vary not just across discrete and continuous stimuli, but also across development and within discrete and continuous stimuli based on features that may impact children's attention to proportion.

Presentation 2: Investigating strategy flexibility in algebra: The role of executive function, procedural fluency, and conceptual knowledge

Qiushan Liu[1] & David W. Braithwaite[1]
[1]Department of Psychology, Florida State University

Strategy flexibility is an important aspect emphasized in math education (Verschaffel et al., 2009). Being able to flexibly select and efficiently apply strategies allows students to solve problems in fewer steps, leaving less room for error. The current study examines the differential role of conceptual knowledge, procedural fluency, and executive function on students' strategy flexibility. We separate strategy flexibility into two aspects: the ability to select strategies adaptively (strategy selection) and the ability to execute the more efficient strategy (strategy execution). We tested our research question in the domain of algebra. 8th to 12th grade students (N = 88, 41% female) completed assessments of executive function, procedural fluency, and conceptual knowledge and strategy flexibility. We found that on average, participants used the innovative strategy spontaneously in 10% of the trials. Both procedural fluency (b = .11, t(81) = 4.46, p < .001) and conceptual knowledge uniquely contributed to students' strategy execution (b= .11, t(81) = 4.44, p < .001). However, only conceptual knowledge uniquely contributed to students' strategy selection (b = .71, t(81) = 3.03, p = .003). Executive Function did not uniquely contribute to either aspect of strategy flexibility. The study further clarifies the unique relationship between three common predictors of math achievement with strategy flexibility. Furthermore, the finding on the importance of conceptual knowledge and students' low use of innovative strategy shows the importance of emphasizing conceptual understanding and teaching multiple strategies during math education.

Presentation 3: College students' use and belief of math study strategies

Rebecca Adler[1], Xinran Wang[1], & Bethany Rittle-Johnson[1]
[1]Department of Psychology and Human Development, Vanderbilt University

Much of our knowledge of students' self-regulated study strategy use is about general study strategy use and is not specific to particular subjects. Yet, optimal study strategies almost certainly vary by subject matter as the nature of content and assessment varies. We explored U.S. college students' use and beliefs of study strategies for their college mathematics courses, for which problem solving is central. Data was collected online, with 50 participants from across the United States (50% women). Average age of the sample was 21.5. Race was self-identified, with 62% White, 14% Asian, 12% biracial, 8% Black, and 4% other. Twenty-two percent of the sample self-identified as of Hispanic, Latino, or Spanish origin. Common college math courses included statistics and calculus. Students rated their use from 1 to 7 (not at all, to a lot). The highest average rating was for studying worked examples (M = 5.72, SD = 1.40) and doing practice problems (M = 5.80, SD = 1.47). When asked their preference between problem-solving and studying examples, a plurality preferred problem-solving (40%) to studying examples (26%). Students indicated they use problem-solving practice as a way to learn (57% of students) and as a way to monitor their learning (67% of students). Problem solving can be considered a form of retrieval practice, so these findings contrast with findings from general college study strategy surveys that retrieval practice is underutilized and students do not recognize its dual purposes as a way to learn and to monitor learning.

Discussion led by

Caroline Byrd Hornburg[1]

[1]Department of Human Development and Family Science, Virginia Tech

S5D: What about mathematics writing? Effects of instruction and training in mathematics-writing strategies

Chair: Tessa Arsenault[1]
[1]University of Texas at Austin

Integrative Statement:

Mathematical reasoning and communication frequently are demonstrated through mathematics writing (Powell et al., 2021). Mathematics writing is defined as a written composition in mathematics with embedded visuals and equations, and can be used to explore, explain, create arguments, or think about mathematics creatively (Casa et al., 2016). Increasingly, students are expected to demonstrate their mathematics-writing knowledge in the classroom and on high-stakes assessments (Powell & Hebert, 2022). However, little research has examined effective instruction and intervention, assessments, and teacher training in mathematics writing (Powell et al., 2017). As the prevalence of mathematics writing increases in the classroom and on assessments to support mathematical reasoning and communication (Powell & Hebert, 2022; Powell et al., 2021), a significant need exists for research on mathematics writing to determine best practices in mathematics-writing instruction. In this symposium, we present four studies that examine the effectiveness of mathematics-writing strategies for supporting students and teachers in improving their mathematics-writing performance. Three presentations focus on how mathematics-writing instruction can improve mathematics-writing outcomes for students in Grades 4 to 10. The fourth presentation addresses pre-service teacher self-efficacy and mathematics-writing outcomes after participation in a mathematics-writing training module. Our objectives are to highlight the current research on (1) students' mathematics-writing instruction and (2) teacher training in mathematics writing to confirm the importance of mathematics-writing for overall mathematics success.

Presentation 1: Mathematics writing within a word-problem intervention for grade 4 students with mathematics difficulty

Tessa Arsenault[1]
[1]The University of Texas at Austin

Although students are required to write explanations about word-problems in classroom instruction and on high-stakes assessments, little research has examined supporting such explanations by combining writing instruction with word-problem instruction (Powell et al., 2017). Creating mathematics-writing explanations can be especially complex for students with mathematics difficulty (MD) who perform below the average range in mathematics (Hughes et al., 2020). I examined the effects of a word-problem intervention with embedded mathematics-writing instruction on the mathematics writing outcomes of students with MD. Students were randomly assigned students to one of three conditions: word-problem intervention and mathematics writing (WP+MW; n = 21), word-problem intervention alone (WP-alone; n = 21), or business-as-usual (BaU; n = 22). Participants were fourth-grade students with MD. Researchers implemented individual lessons with the student three times per week for a total of 18, 35-minute lessons. For both the WP+MW and WP-alone conditions, students participated in four aligned activities per session that targeted mathematics fact fluency, word-problem solving, and computations. Students in the WP+MW condition also completed an explicit writing mathematics-writing prompt while students in the WP-alone condition completed a mathematics-review activity that did not involve writing. Pretesting results indicated no significant differences among conditions on mathematics writing. Initial results from pretest to posttest demonstrated that students in the WP+MW condition showed growth in number of words written, inclusion of word-problem specific vocabulary and equations, and accurate solutions. This study can inform instruction and future research on how to support reasoning and communication within mathematics, especially for students with MD.

Presentation 2: Effects of a mathematics-writing strategy on grade 4, 5, and 6 student performance

Elizabeth Hughes[1]
[1]The Pennsylvania State University

Fostering mathematical reasoning is fundamental to developing critical mathematical thinkers. Mathematical reasoning develops over time, with experience, practice, and scaffolded instructional supports. One effective way educators support students' mathematical reasoning is through written discourse (Graham et al., 2020; Xin et al., 2019). Written discourse, or mathematical writing, is a promising way to promote students' mathematical reasoning (Nachowitz, 2019) and express understanding of mathematics content (Hughes et al., 2019; 2020; Powell et al., 2017). This study extends work of Author (2019, 2020, in press) to evaluate a mathematics-writing (MW) intervention for students in Grades 4-6. We posed the following research question: What are the effects of a

mathematics-writing strategy on students' written expression of mathematical reasoning? Data collection took place in three middle schools in a northeastern state from Fall 2022-Spring 2023. Students were randomly assigned to treatment or comparison groups. The treatment group received a 12-day intervention during which they learned a strategy (PRISM-Check) to solve word problems and explain their mathematical reasoning. In PRISM-Check, students read the "Problem", "Represent" the problem, and "I do" by solving. Next, they "State, Say, Share" by responding in writing to the problem and conclude the written response with My Answer. Finally, they Check their work. The comparison group practiced solving word problems and explaining mathematical reasoning without the writing strategy instruction. Preliminary analyses of pre- and post-assessments suggest students in the treatment group scored significantly higher on post-assessments and interaction effects. Results from full analyses will be shared in the presentation.

Presentation 3: Effects of rate of change mathematics interventions on middle and high school students' mathematics writing

Kaitlin Bundock[1]
[1]Utah State University

Analyzing students' mathematics writing may help capture aspects of students' understanding of concepts not typically revealed by quantitative mathematics items. Additionally, students increasingly are asked to communicate their understanding of mathematics through writing. This presentation will examine the effects of two mathematics interventions consisting of an integrated concrete-representational-abstract (CRA-I) approach, explicit instruction, and a structured problem-solving strategy (POD Check) on students' mathematics writing. Study 1 included four participants in 7th-9th grades with high-incidence disabilities, and Study 2 included seven participants in 6th-10th grades with high-incidence disabilities. The research question for each multiple-baseline-across-participants design study was: Is there a functional relation between an intervention incorporating CRA-I and POD Check and students' mathematics-writing proficiency, as measured by scores on researcher-created writing prompts? During each study, interventionists met individually with participants via Zoom three times per week. Participants completed mathematics assessments that included writing items; writing prompts varied between Study 1 and Study 2. Researchers used rubrics to score participants' responses. In Study 1, responses were scored for accuracy, vocabulary, specific labels and quantities, and support. In Study 2, responses were scored for accuracy, precision, and support. Also, in Study 2, researchers counted the frequency of general problem-solving strategies, intervention-related strategies, specific mathematics vocabulary, and total words. There were mixed results within and across Study 1 and Study 2. This presentation will focus on participants' overall mathematics writing, in addition to specific components of participants' mathematics writing. Potential strengths and limitations of different ways to measure mathematics writing outcomes will be discussed.

Presentation 4: Examining relationships between preservice teachers' self-efficacy across teaching domains and mathematical writing performance

R. Alex Smith[1] & Erin Smith[1]
[1]University of Nevada, Las Vegas

Teachers' self-efficacy is subject-matter specific and can impact teaching performance and student achievement (Tschannen-Moran & Hoy, 2001; Klassen & Tze, 2014). Prior research examining preservice teachers' (PSTs) self-efficacy primarily has focused on teaching mathematics (e.g., Charalambous et al, 2008; Utley et al., 2005). To date, few studies have examined PSTs' self-efficacy in teaching mathematics writing. The purpose of this study was to examine (1) relationships between PSTs' self-efficacy in teaching mathematics, writing, and mathematics writing with mathematics-writing performance and (2) the impact of an asynchronous mathematics-writing focused module on PSTs' self-efficacy across the three domains. 111 elementary, special, or dual-education PSTs across two universities completed a 12-question survey with questions assessing self-efficacy in teaching mathematics, writing, and mathematics writing prior to completing the module. Results indicated that PSTs' self-efficacy differed across the three domains with the lowest rates in mathematics writing and the highest in writing. Results examining the relationship between PSTs' mathematics-writing performance and self-efficacy are still in the analysis phase, but mean scores indicate a partial understanding of the third-grade content embedded within the task (i.e., operations, number) and difficulties constructing written responses that demonstrated mastery in mathematics and writing. Furthermore, the mathematics-writing module had a significant ($p < .001$) positive effect (ES = 0.65) on PSTs' self-efficacy in teaching mathematics-writing. The results from this study demonstrate that mathematics-writing should be explicitly targeted in

teacher preparation with a specific focus upon building PSTs' own mathematics-writing competencies.

S6A: Number and mathematics across perceptual modalities and language experiences

Chair: Deanna Gagne[1]
[1]Gallaudet University, Washington, DC, USA

While representations of quantity and number are ubiquitous in the human experience, the way we understand and use quantity, and by extension, mathematics, depends on our individual experiences. This includes the modalities in which we interact with the world, both perceptually and linguistically. Here we explore such interactions in individuals whose primary modes of communication are either visual or tactile. Paper 1 explores the visual exigencies of deaf students in mixed deaf and hearing classrooms to better understand the contribution of visuality to the understanding and learning of mathematical problems. Paper 2 introduces the concept of tactile quantity and number representations in a fully tactile language emerging among DeafBlind adults, in order to later ask how learning such tactile representations influences DeafBlind children's mathematical learning. Paper 3 takes a step back to understand the interaction among spatial representations available in visual languages, general spatial habits, and academic anxieties, exploring how these factors may impact mental rotation abilities. Paper 4 examines how early vs. later language experiences contribute to later language and numerical abilities, as well as patterning skills, contributing to our understanding of which skills may be language dependent (regardless of modality) and which may depend on experience or other factors. This symposium introduces the audience to critical ways of thinking about how individuals with varied language and perceptual modalities may acquire, use, and experience numerical and mathematical concepts, leading to a better understanding of human learning in general.

Presentation 1: Rethinking math problem instructions in initial teacher education for working with deaf students

Fabio Alexandre Borges[1]
[1]Universidade Estadual de Maringá, Maringá, Paraná, Brasil

One of the advocated approaches for a more inclusive education in Brazil involves designing activities that are simultaneously suitable for everyone and tailored to each individual, considering the individual characteristics. In classrooms where deaf and hearing students study together, one of the assumptions of our research is the importance of visuality as something fundamental for deaf students, which can also benefit hearing students. In this sense, we discuss in this symposium a research where our choice was to focus on the statements of mathematical problems and value the visual aspects. The main objective of the research was to investigate the performance of future teachers of the Early Years of Elementary Education in the elaboration of problem situations of additive structures, whose inclusive scope for deaf and hearing students is established in the way the statements are presented. The data was produced through the application of an activity to 468 Pedagogy undergraduates from a Brazilian university. For data analysis, 30 of the developed activities were selected. In the activities, the academics were invited to formulate a problem represented in written language as well as to transpose it into two other forms of representations: in diagram and in illustration. The results pointed out the following aspects: the algorithmization of visual resources; emphasis on problem responses to the detriment of visual adaptation; and inconsistencies among different representations. It highlights the need for the formulation of diversified problems in their representations to be part of teacher education strategies towards an inclusive perspective.

Presentation 2: Emergence of counting systems in DeafBlind adults using protactile language with DeafBlind children

Deanna Gagne[1] & Hayley Broadway[1]
[1]Gallaudet University, Washington, DC, United States

Protactile is a novel, touch-based language that has emerged among DeafBlind adults since 2007. Protactile is unique in that all adult protactile users have prior experience with (visual or tactile-modified) American Sign Language (ASL). However, ASL does not easily afford tactile perception. As such, protactile has crossed modality boundaries, emerging as a tactile language among former visual language users. Part of this emergence is the natural elimination of ASL-based number productions, which are difficult to decipher by touch, and replacing them with efficacious touch-based productions. As part of a larger study investigating the use of quantity reference with DeafBlind children acquiring protactile as their first language, we are documenting the emergence and use of quantity representations in DeafBlind adults. DeafBlind adults are representing number related concepts in some expected and novel ways. Small quantities are often represented using tactile spatial representations, touching 1, 2, or 3 locations on the body or using the listener's fingers to represent

ordinal or list items (up to five). Larger numbers are now represented by modifying DeafBlind adults' most ready access to print: Braille. This is replacing "print on palm" approaches which represent visual print forms. Time has unexpectedly been adapted from a commonly used clock, altering what the device represents as long and short vibrations to long and short presses representing exact time (e.g. 1:30) or duration (e.g., "five hours"). Discussion will involve implications for cognition and acquisition, including early child number representations and the dynamics involved with emerging languages.

Presentation 3: Examining the interplay between anxiety, spatial cognition, and experience with a spatial language in STEM outcomes

Rachel Pizzie[1], Rachel Sortino[1], Christina Kim[1], Rachel Inghram[1], & Isabelle Diaz[1]
[1]Gallaudet University, Washington, DC, USA

Spatial cognition skills, such as mental manipulation, are an important predictor of STEM outcomes. However, many individuals struggle with anxiety related to quantitative and visuospatial skills, such as spatial anxiety, math anxiety, and science anxiety. These anxious emotions detract from the performance of quantitative and spatial skills and negatively impact interest in STEM. Deaf and hard-of-hearing (DHH) people are vastly underrepresented in these fields and may also experience increased levels of anxiety associated with STEM content. However, many DHH people also have extensive experience with American Sign Language (ASL), a highly visuospatial language. This study explored the relations between academic anxieties, spatial habits, and spatial language to predict performance on a mental rotation task. Moreover, we explored how different types of academic anxiety, spatial habits, and ASL experience relate to interest in STEM. Participants completed several online tasks, including academic background and anxiety questionnaires, spatial cognition questionnaires, a language background questionnaire, and a mental rotation task. We find that math anxiety and science anxiety were the most robust predictors of mental rotation ability, above and beyond the variance accounted for by spatial anxiety, spatial habits, and ASL experience. Spatial anxiety was not a robust predictor of mental rotation accuracy. Exploring STEM outcomes, we again found that math and science anxiety were negatively associated with interest in STEM for DHH and hearing individuals. These results suggest that math and science anxiety are essential predictors of STEM outcomes across both DHH and hearing communities.

Presentation 4: Mathematical development of deaf and hard-of-hearing (DHH) children – are there associations between repeating patterning, numerical ability, and language skills?

Viktor Werner[1] & Barbara Hänel-Faulhaber[1]
[1]Universität Hamburg, Hamburg, Germany

Repeating patterning in early mathematics development predicts mathematical knowledge and growth (e.g. Zippert et al., 2020). Children with developmental language disorder struggle with their mathematical knowledge, but not with pattern tasks (Fyfe et al., 2019). In our study, we investigate whether these findings can also be seen in DHH children who have heterogeneous access to language. 20 DHH children (ages 5;6 – 7;9, mean: 6;7) participated in the study. 10 children had at least a deaf parent and were exposed to German Sign Language (DGS) from birth (Early DGS), 10 children had hearing parents and acquired DGS at some point after birth (Later DGS). They completed the following tasks: (1) a set of activities on repeating patterns, (2) a German test battery on numerical abilities (MBK 0; Krajewski, 2018) translated into DGS (Werner & Hänel-Faulhaber, submitted) and (3) a DGS Sentence Repetition Task for children (DGS-SRT kids) (Wienholz et al., 2023). Early DGS children obtained moderately better results in repeating patterning than the Later group. They also performed significantly better in numerical and DGS abilities. Correlation analyses showed a strong association between (a) repeating patterning and numerical abilities and (b) numerical and DGS abilities, but not between repeating patterning vs. DGS abilities in DHH children. Thus, the results suggest that early language access may influence numerical abilities but not repeating patterning in DHH children. We conclude that language (in any modality) is essential for the development of age-related numerical abilities whereas patterning skills depend less on language experience.

S6B: Neural insights into conceptual and procedural fraction understanding

Chair: Miriam Rosenberg Leeq[1]
[1]Department of Psychology, Rutgers University – Newark, NJ, USA

Integrative Statement:

Rational numbers, especially fractions, are a challenging numerical format for learners to master. Initial neuroimaging results in adults established that, like whole/natural numbers, fractions engage the intraparietal sulcus and display numerical distance effects (greater activity for near than far comparisons). Building on these foundational studies, this symposium examines open

questions in conceptual and procedural fraction understanding that neuroimaging is uniquely positioned to answer. Park and colleagues will present developmental work testing the neuronal recycling hypothesis that brain areas for nonsymbolic proportional reasoning form a conceptual foundation for symbolic fraction understanding. Rosenberg-Lee and colleagues further probe the relationship between symbolic and nonsymbolic representations by considering whether brain responses for symbolic fractions are most similar to those for continuous or discretized nonsymbolic proportional representations. Then, Wortha and colleagues will aim to identify the neural basis of procedural fraction skills (i.e., fraction arithmetic), as distinct from fraction magnitude processing and whole/natural number arithmetic. Finally, discussant Edward Hubbard will integrate these results and discuss fruitful areas for future work and potential pedagogical implications, especially for instructional materials to introduce fractions.

Presentation 1: Developmental changes in non-symbolic and symbolic fraction processing in primary school children

Yunji Park[1,2], Priya B. Kalra[1,3], Yun-Shiuan Chuang[1], John V. Binzak[1], Percival G. Matthews[1], & Edward M. Hubbard[1]

[1]Department of Educational Psychology, University of Wisconsin – Madison, WI, USA; [2]Department of Psychiatry & Behavioral Sciences, Stanford University, CA, USA; [3]Western Institute for Neuroscience, Western University, London, Canada

A substantial body of research demonstrates that human and nonhuman animals can process the magnitudes of nonsymbolic ratios. Lewis et al. (2015) outlined a cogent account of how Dehaene and Cohen's (2007) neuronal recycling hypothesis might apply to cognitive architectures used for nonsymbolic ratio processing to support acquisition of symbolic fractions knowledge. We tested this account by comparing neural signatures of ratio and fraction processing among 2nd-graders, who have not yet received formal symbolic fraction instruction, and 5th-graders, who have. During fMRI scanning, children were presented with nonsymbolic ratios, symbolic fractions and mixed nonsymbolic/symbolic pairs and determined which of two ratios/symbolic fractions was larger. Consistent with the recycling hypothesis, both cohorts exhibited behavioral and neural evidence of processing nonsymbolic and symbolic fractions magnitudes, with performance modulated by holistic numerical distance between stimuli. Univariate analysis revealed neural distance effects in a bilateral parietal-frontal network for both 2nd- and 5th-graders. However, 2nd-graders' neural distance effects were mainly observed for nonsymbolic ratio comparisons, whereas 5th-graders' neural distance effects were observed for both nonsymbolic and symbolic fractions in regions that overlapped with, but extended beyond, those found for 2nd-graders. Neural representational similarity analysis confirmed that the bilateral IPS, a key region for numerical processing, encoded ratio distance information. These results present the first neuroimaging evidence that neural substrates for ratio magnitude exist prior to formal learning, which may then be recycled to process symbolic fractions. Future studies may elucidate ways to leverage this recycling to optimize pedagogy.

Presentation 2: Continuous or discretized? Examining the nonsymbolic underpinnings of fraction magnitude understanding

Miriam Rosenberg-Lee[1], Roberto A. Abreu-Mendoza[1,2], & Chinedu Nkwo[1]

[1]Department of Psychology, Rutgers University – Newark, NJ, USA; [2]Department of Psychological & Brain Sciences, Indiana University – Bloomington, IN, USA

Nonsymbolic representations of fractions are thought to be a powerful tool for improving learners' understanding of this challenging numerical notation. Young children can reliably identify the larger proportion when presented with continuous representations, like partially shaded bars. However, performance plummets when those bars are segmented into sections, and the number of shaded sections contradicts the proportional information. Even adults struggle with these misleading discretized comparisons (e.g. 3/5 segments vs. 4/7 segments). Behavioral studies have noted correlations between nonsymbolic and symbolic performance. Yet, the nature of this relation remains unknown. Does it depend on proportional understanding, indexed by continuous stimuli or on whole number interference, which affects fractions and discretized? We used neuroimaging to determine whether proficient adults' (n=19) brain responses for symbolic fractions are most similar to responses for nonsymbolic continuous or discretized stimuli. We found that the intraparietal sulcus, a crucial region for numerical magnitude processing, is sensitive to distance for all three formats: more activity for near (4/5 vs. 7/9, distance=.02) than far (3/4 vs. 4/9, distance=.31) comparisons. Notably, the strongest neural distance effects were found for misleading discretized and symbolic stimuli. Representational similarity analysis revealed that symbolic responses were most similar to discretized responses, especially for misleading stimuli. These results suggest that proficient performance on fractions involves ramping up the distance processing for

misleading cases. Further, behavioral relations between symbolic and nonsymbolic understanding may be supported by the engagement of distance processing for cases where whole number knowledge contradicts the correct response, rather than pure proportional reasoning.

Presentation 3: Identifying the neural correlates of fraction arithmetic: An fMRI study in young adults

Silke M. Wortha[1], Elise Klein[2], Thomas Dresler[3], & Korbinian Moeller[1]
[1]Centre for Mathematical Cognition, School of Science, Loughborough University, Loughborough, United Kingdom; [2]University of Paris, LaPsyDÉ, CNRS UMR8240, La Sorbonne, Paris, France; [3]Department of Psychiatry &

In recent years, there has been an increasing emphasis on investigating the neural correlates of conceptual fraction understanding, in particular fraction magnitude processing (Wortha et al. 2020). However, while conceptual understanding is crucial for a fundamental processing of fractions, evidence suggests that procedural knowledge plays a more significant role when it comes to fraction arithmetic (Braithwaite & Siegler 2023). Nevertheless, our understanding of the mechanisms underlying procedural knowledge of fraction arithmetic is still limited. Therefore, the current study aimed at investigating the neural correlates of fraction arithmetic in more detail. Brain activation was measured in 24 young adult participants (age rage: 18 – 30 years) while solving fraction arithmetic problems encompassing all basic arithmetic operations - addition, subtraction, multiplication, and division. Furthermore, control tasks involving natural number arithmetic, fraction magnitude processing and working memory capacity were included for assessment. Results indicated specific activation associated with fraction arithmetic after partialling out influences of control variables. Additionally, similarities and differences were observed in brain activation patterns associated with the four arithmetic operations. Thereby, the present study indicated contributions of processes specific to fraction arithmetic in addition to more general number related activation. To the best of our knowledge this is the first study which aims to identify the neural mechanisms underlying procedural fraction knowledge in more detail. The results suggest that procedural aspects of fraction arithmetic are associated with additional activation in brain areas not typically associated with processing fraction magnitude.

Discussion led by

Edward Hubbard[1]
[1]University of Wisconsin

S6C: Flexible and adaptive strategy use in mathematics: Enabling and hindering factors

Chair: Marian Hickendorff[1]
[1]Institute of Education and Child Studies, Leiden University, the Netherlands

Integrative Statement:

Strategy flexibility and adaptivity, being able to solve a problem in multiple ways and select the best strategy, are important goals in mathematical development. However, not everyone is equally prepared to use a variety of strategies for solving mathematics problems. Furthermore, even if someone has a variety of strategies at hand, choosing the most suitable strategy (i.e., choosing adaptively) can prove difficult. This symposium brings together three studies addressing the factors enabling and hindering strategy flexibility and adaptivity in arithmetic, in both children and adults. The first contribution relates adaptive number knowledge with adaptivity in secondary school students, finding that students with high adaptive number knowledge are also more adaptive mathematical problem solvers. The second contribution focuses on how grade level is related to second, third, and fourth graders' flexibility and adaptivity in multi-digit subtraction, finding that third graders show most flexibility, but fourth graders more often choose the strategy that works best for them. The third contribution addresses how misconceptions concerning the order of operations may inhibit adaptive strategy use, specifically strategies using the associativity principle, in adults solving three-term arithmetic problems. Together, these studies provide insight as to what does and doesn't help children and adults to flexibly and adaptively solve math problems, which can help teachers address these factors more accurately. The results will be integrated and discussed by prof. Bethany Rittle-Johnson, a renowned expert in the field of mathematical flexibility.

Presentation 1: Adaptive number knowledge is related to adaptivity in high school students

Jake McMullen[1], Irene Pampallis[1], Koen Veermans[1], & Jon Star[2]
[1]University of Turku, Finland; [2]Harvard Graduate School of Education, USA

Adaptive expertise has long been regarded as an important element of students' mathematical development (Baroody, 2003). One component of adaptive expertise with arithmetic is adaptive number knowledge (ANK), the well-connected understanding of numerical characteristics and relations which can be used to solve novel problems. ANK is related to, but distinct from procedural and conceptual knowledge of arithmetic and uniquely predicts later algebra proficiency.

ANK is expected to support adaptivity, as it should allow for using numerical relations in identifying efficient solution strategies. However, the relationship between ANK and adaptivity remains unclear. In this study, a sample of 405 US high school students aged 13-18 completed a pen-and-paper test of ANK and adaptivity with arithmetic and algebra. ANK was measured with the arithmetic sentence production task with whole and rational numbers (McMullen et al., 2016). Adaptivity was measured in a two-part assessment in which students were asked to solve a set of arithmetic (whole and rational number) and algebra (multi-step univariate) problems two times, using a different solution strategy (Coppersmith & Star, 2022). Adaptive solvers (n = 85) were those who chose to use a "better-than-standard" algorithm on a least one item in the first instance of the adaptivity assessment. A paired-samples t-test revealed a significant difference in ANK between adaptive and non-adaptive problem solvers: adaptive problem solvers had on average 3 more correct solutions on the ANK task than non-adaptive problem solvers. These results suggests a relationship between ANK and adaptivity in high school students.

Presentation 2: What strategy works for whom? Flexible and adaptive strategy use in multi-digit subtraction

Marian Hickendorff[1] & Erika Schlatter[1]
[1]Institute of Education and Child Studies, Leiden University, the Netherlands

The ability to use multiple strategies and select the optimal strategy to solve an arithmetic problem are important goals in mathematics education. Previous research shows students do not use all the strategies they know and often stick to a single strategy, even if that strategy is not mathematically optimal (i.e., requires the easiest and/or smallest number of steps). The current study used an innovative, personalized choice/no-choice paradigm to determine the flexibility and adaptivity of Dutch second, third, and fourth graders' (N = 204) strategy use in multi-digit subtraction. They first solved eight subtraction problems in an unrestricted choice condition. Next, they solved subtraction problems in a personalized no-choice condition, which allowed for investigating which strategy worked best for them in terms of accuracy and speed: the strategy of their choice or the mathematically optimal strategy. Students overwhelmingly chose one single strategy on all eight free-choice problems, showing limited flexibility (flexibility was highest in third graders). When prompted, students were able to produce additional strategies, which increased with grade. Students rarely used or recognized the mathematically optimal strategy suited to a particular problem: task-specific adaptivity was low. Furthermore, results from the no-choice condition showed that this mathematically optimal strategy was the strategy that worked best for students only 31% of the time, compared to the strategy of their choice being the best-working strategy 59% of the time. Fourth graders were more able to choose the strategy that worked best for them (individual-based adaptivity) than second and third graders.

Presentation 3: Misconceptions of the order of operations and the use of adaptive arithmetic strategies

Joanne Eaves[1], Camila Gilmore[2], & Nina Attridge[3]
[1]University of Nottingham, UK; [2]Loughborough University, UK; [3]University of Portsmouth, UK

Adaptivity with arithmetic strategies (the ability to select accurate, efficient strategies) strongly predicts mathematical expertise and success in a range of subjects. However, many children lack adaptivity and instead use routinised, entrenched procedures. For example, the problem "6+38–35" is predominantly solved in one of two ways 1) "left-to-right", where the individual performs the addition (6+38=44) before the subtraction (6+38=44, 44–35=9), and 2) a "shortcut" strategy, where the individual performs the subtraction before the addition (38–35=3, 3+6=9). The shortcut is adaptive in that it is more efficient and less prone to error, for most people. However, our research suggests that as many as 50% of adults do not use it. Our work explored whether misunderstanding of the order of operations explained adults' limited shortcut use. First, we developed an instrument that quantitatively measures how people interpret the order of operations. We then used this instrument in a pre-registered study (N=130) to investigate whether those interpretations relate to use of the shortcut. We found that only 16% of adults fully understood the order of operations, and that a particular misconception of the order of operations (a 'literal' misconception of BODMAS) hinders shortcut use. We conclude that procedural rules can compromise strategy adaptivity and flexibility, if those rules are faulty and/or rigidly adhered to. Teachers should be made aware of the dangers of misconceptions, and could use our instrument.

Discussion Led by

Bethany Rittle-Johnson[1]
[1]Vanderbilt University, USA

S6D: Individualized approaches to education: Student profiles and teacher practices

Chair: Patrick Ehrman[1]
[1]Human Development and Family Science, Purdue University

Integrative Statement:

When attempting to support students learning mathematics, person-centered approaches allow for the opportunity to understand specific strengths and needs for support, which ultimately provides important opportunities for refining instruction and intervention efforts. The four studies in this symposium detail the potential impact and usefulness of individualized approaches to learning, specifically for children who may struggle to learn mathematics. The first study (Ehrman) presents preliminary results of a latent transition analysis investigating early academic and cognitive antecedents to mathematics performance. The second study (Ouyang) identifies kindergarten children at high risk for dyscalculia and investigates their early domain-general and numerical precursors. The third study (Yip) examines the cognitive and mathematics skills associated with different levels of mathematics achievement in fourth graders. The fourth study (Bullen) reports how different teacher instructional practices impact students learning in an inclusive classroom. The four studies in this symposium detail the early classification and development of separate profiles of learning from a research and methodological perspective as well as detailing the role teachers play in supporting mathematical thinking in inclusive education settings. These studies explore these topics in diverse samples from multiple countries, across grade levels, and in different contexts. These studies present a mix of person-centered approaches to understanding the trajectories and support available to children who struggle with mathematics.

Presentation 1: Longitudinal profiles of early mathematics learners

Patrick Ehrman[1], Brianna Devlin[2], Robert Duncan[1], Sarah Schmitt[2], & David Purpura[1]
[1]Human Development and Family Science, Purdue University; [2]University of Oregon

There is a large amount of heterogeneity in the mathematics abilities of children in preschool (Starkey et al., 2004). There are also many skills that contribute to later mathematics success, such as language and executive function (Schmitt et al., 2021). Taking a person-centered approach to understand the various ways children's academic profiles develop over time can provide important insights for students struggling to learn mathematics, specifically those that do not demonstrate improvement. Data from 684 preschool aged children from low-income backgrounds who were followed over the course of their preschool and kindergarten years were used to conduct a latent transition analysis. Children were assessed on multiple measures of early mathematics, executive function, literacy, vocabulary, and mathematical language. Latent profiles for each time point were run to identify the best fitting model for each time point. Then, a latent transition analysis was run using the best fitting profile solutions from the LPAs for the fall of preschool and the fall and spring of kindergarten. Preliminary results provide evidence for a six-profile solution from the start of preschool through the end of kindergarten. Children who started in the top performing profile were highly likely to remain in the top performing profile. There was a large amount of movement between profiles over time. The number of children who remained in the low-performing profiles was lower at each time point. Findings suggest that the use of person-centered approaches can reveal patterns of heterogeneity in academic profiles and improvement over time.

Presentation 2: Domain-general and numerical precursors of mathematical difficulty in kindergarten children at high risk for dyscalculia

Xiangzi Ouyang[1] & Xiao Zhang[2]
[1]Department of Psychology, Lingnan University; [2]Department of Education, The University of Hong Kong

This study aims to identify kindergarten children at high risk for dyscalculia and investigate their early domain-general and numerical precursors. This study followed 299 Hong Kong kindergarten children (151 boys; mean age = 57.29 months, SD = 5.05) from the second kindergarten year to the end of the third kindergarten year. Using latent class growth modeling, we identified five groups of children with differing trajectories of mathematical achievement. We compared 32 children with poorest mathematical achievement and thus at high risk for dyscalculia to 120 children with low achievement and at lower risk for dyscalculia. Logistic regression showed that poor working memory, receptive vocabulary, number recognition, and subitizing skills predicted the odds of being identified as children at high risk fo mathematical difficulty compared to low achievers. Early identification of children at high risk for dyscalculia and their risk factors can help address their learning needs at a young age.

Presentation 3: Associations of cognitive and mathematics skills with different levels of mathematics achievement in fourth graders

Charles Yip[1], Xiangzi Ouyang[2], Christine Tong[1], & Terry Wong[1]
[1]Department of Psychology, The University of Hong Kong; [2]Department of Psychology, Lingnan University; Eason Yip, Department of Psychology, The University of Hong Kong

Mathematics development relies on a variety of cognitive and mathematical skills, which can have varying effects on students depending on their achievement levels. This study aimed to investigate how students' skill profiles contribute to their levels of achievement in mathematics. A sample of 272 fourth graders participated in assessments that measured different cognitive and mathematical abilities. Through latent profile analysis, four distinct classes of math achievement were identified: mathematics learning disability (MLD), average achievers, high achievers, and mathematically gifted students. Logistic regression analysis revealed that, compared to average achievers, students struggling with fraction magnitude understanding and number sentence construction in word problems are more likely to suffer MLD, students with better spatial skills and fraction magnitude understanding are more likely to be high achievers, and students with better arithmetic principle understanding are more likely to be mathematically gifted. The present results highlight the cognitive attributes exhibited by students at different levels of mathematics achievement. These findings enable educators to tailor their teaching approaches based on the specific needs of students in each level.

Presentation 4: What is "good teaching?": Insights from instructional practices in inclusive education classrooms

Jennifer Bullen[1], Nancy Tseng[2], & Nicole Sparapani[3]
[1]Department of Psychiatry and Behavioral Science, MIND Institute, University of California Davis; [2]School of Education, University of California Davis; [3]MIND Institute, School of Education, University of California Davis

Introduction. Teacher-level factors such as instructional practices are known to impact neurotypical student' mathematical achievement (e.g., Crosnoe et al., 2010; Grammer et al., 2016). However, little is known about how teacher instruction impacts neurodivergent student learning, or if instructional practices change in the context of inclusive education classrooms. The current study seeks to understand the relationship between teacher-level factors and mathematical achievement in a sample of neurodiverse elementary school-aged students in inclusive general education classrooms. The objectives of the study are as follows: 1) Identify instructional practices teachers are using in inclusive education classrooms; 2) Understand the impact of instructional talk on math achievement across the school year, and if this talk impacts neurodivergent children differently. Method. Videos from Fall mathematics lessons of 18 teachers in K-3rd grade classrooms were coded using an adapted version of Balzar and Pollard's (2022) mathematics instructional practice codes. The Numeration and Applied Problem Solving subtests from the KeyMath-3 provided a measure of mathematical achievement 108 children (M = 7.02 years, SD = 1.51) and were collected in the Fall and Spring. Planned Analyses. Confirmatory Factor Analysis will be used to evaluate the factor structure of the instructional practice codes and identify which instructional practices were used most often. Correlational and regression analyses will be used to investigate the impact of instructional practices on changes in student's mathematical achievement Fall and Spring time points and to determine if instructional practices impact neurodivergent youth differently than neurotypical peers.

S7A: Acquisition of early numerical concepts and numerical reasoning in Deaf and Hard of Hearing children and adults

Chair: Stacee Santos[1]
[1]Department of Psychology and Neuroscience, Boston College

Integrative Statement:
Understanding the role language plays in mathematics achievement has been a of topic of interest in numerical cognition for decades. Here, we present four talks focusing on the mathematical abilities of a unique population with varying language experience with language from birth: Deaf and Hard of Hearing (DHH) children and adults. In this symposium we will present new research highlighting the impact of language experience on emerging numerical concepts and the underlying neural correlates of numerical processing. This symposium aims to 1) highlight the importance of early language access for the emergence of early numerical concepts; 2) provide longitudinal evidence to support the benefits of American Sign Language in the development of symbolic and non-symbolic number concepts; and 3) shed light on the neural mechanisms recruited in numerical processing in DHH adults. These presentations will offer new insights into the role language plays in mathematics.

Presentation 1: Geometry in the adult signing brain – fMRI evidence

Josefine Andin[1] & Åsa Elwér[1]

[1]Linköping University, Department of Behavioural Sciences and Learning

Deaf individuals have been shown to excel in some visuospatial tasks, suggesting that geometry is a mathematical domain of strength for this group. Geometry taps into processes such as mental rotation which is necessary to represent objects in space and to change perspectives in sign language, argued to be important for sign language skills. While the posterior superior and inferior parietal regions (pSPL and IPL) support geometry processing in hearing individuals, little is known about which neural correlates underlie geometry processing in deaf individuals. The aim of the present study was to better understand similarities and differences in the neural networks underlying geometry processing in deaf compared to hearing individuals. Twenty-two adult deaf signers and 25 hearing non-signers were enrolled in an fMRI study. A geometry decision task was used and different geometric properties such as euclidean construction, sense and transformation and metrics were included. The expected advantage in visuo-spatial skills of the deaf signers was not manifested in the geometry task as the hearing non-signers showed more accurate performance across task types. Given its role in spatial processing, both groups showed robust activation of the pSPL. However, we also found additional recruitment of anterior parietal regions for the deaf individuals, possibly reflecting an extended dorsal stream in deaf signers. In sum, the present study provides initial evidence on how geometry processing is differently affected by spoken and sign language background.

Presentation 2: Neural processing of finger-number configurations: Differential responses in Deaf signers and hearing controls

Virginie Crollen[1], Margot Buyle[1], & Aliette Lochy[1,2]
[1]Psychological Sciences Research Institute (IPSY) and Institute of NeuroScience (IoNS), Université Catholique de Louvain, Louvain-la-Neuve, Belgium; [2]Department of Behavioural and Cognitive Sciences, Faculty of Humanities, Social and Educational Sciences

The linguistic counting system of deaf signers comprises a manual format employing specific structures for number words. Intriguingly, number signs from 1 to 4 in Belgian sign languages align with the finger-counting habits of hearing individuals. Consequently, these hand configurations can be regarded as signs within the language system of deaf signers, whereas they are merely numerical gestures devoid of linguistic significance for hearing controls. In this presentation, I will outline the findings of two EEG Fast Periodic Visual Stimulation studies (FPVS) investigating whether deaf signers process these finger-number configurations differently from their hearing counterparts. While the initial experiment revealed that deaf signers exhibit heightened discrimination responses to finger-monitoring configurations, a subsequent control experiment illustrated that this discrepancy isn't solely attributable to the familiarity deaf signers possess with hand configurations. Notably, brain responses did not differ between groups when finger-counting configurations (i.e., numerical gestures in both populations) were presented. Finger-number configurations are thus processed differentially by deaf signers, particularly when they are part of their language system.

Presentation 3: The role of language modality and experience on early number concept acquisition

Casey Spelman[1], Sarah Kimbley[2], & Ilaria Berteletti[1]
[1]Educational Neuroscience Program, Numeracy and Educational Neuroscience Lab, Gallaudet University; [2]San Diego State University

Developmental models in numerical cognition are primarily based on hearing children who use spoken language. How Deaf children acquire foundational numerical knowledge is still largely unknown. Most studies have investigated language deprivation in deaf children, ignoring the role American Sign Language (ASL) may play in supporting numerical concept acquisition. In ASL, numerical information is conveyed more prominently through the morphological process of numerical incorporation1, making the numerical information salient and explicit. In our study, we specifically want to investigate the early numerical skills in 3-5-year-old deaf children exposed early to ASL and if exposure to ASL morphological properties can support a faster developmental acquisition of the cardinality principle. Our hypotheses are that Deaf children exposed early to ASL will show comparable acquisition of early numerical skills to hearing children. Further, based on studies on numerical grammatical markers, we also hypothesize that ASL exposed children will show a faster acquisition of the first cardinality number levels compared to what is observed with hearing children. In our longitudinal study, children were tested on several tasks measuring symbolic and non-symbolic skills. Initial analyses show that Deaf children exposed early to ASL acquire numerical concepts according to what would be considered kindergarten readiness. Further analyses will allow us to explore if the progression of the cardinality principle is impacted by exposure to ASL. This is the first study attempting to understand how sign languages may support numerical concept acquisition. Results will be discussed with their potential translation to educational policies for Deaf children.

Presentation 4: Spontaneous focusing on number in oral deaf and hard of hearing children and its role in early numerical concepts

Stacee Santos[1], Hiram Brownell[1], Marie Coppola[2], Anna Shusterman[3], & Cordes Sara[1]
[1]Department of Psychology and Neuroscience, Boston College; [2]Departments of Psychology and Linguistics, University of Connecticut, [3]Department of Psychology, Wesleyan University

Deaf and hard of hearing (DHH) children have been reported to underperform on measures of math ability for decades. Recent research suggests that the language experience (defined here as the cumulative amount of time that a child has had auditory access to language) of DHH children using primarily listening and spoken language accounts for differences in early numerical concepts between DHH children and their hearing peers (HP). However, some DHH children still struggle, even when accounting for language experience. This study explores spontaneous focusing on number (SFON) in oral DHH children and its relation to counting knowledge and numerical discrimination abilities. Three – to six-year-old DHH preschoolers and their HP completed four numerical tasks measuring number knowledge (Give-N), numerical discrimination (Panamath), and SFON (Match-to-Sample and Imitation stamp task). Our results confirm previous research showing lower performance in number knowledge and numerical discrimination for DHH children, and these group differences disappeared when considering the child's language experience. Interestingly, DHH children performed similarly to their HP on both SFON tasks, suggesting that language experience itself may not be a primary factor influencing attention to numerical information in the environment. Further, numerical discrimination and number knowledge were not linked to either SFON measure. We discuss implications of this work along with important considerations for future directions.

S7B: Exploring the relations between executive function and mathematics skills

Chair: Jasmine Ernst[1]
[1]Purdue University

Integrative Statement:
Executive function (EF) skills are theorized to play a role in doing and learning mathematics, by enabling children to focus on the task at hand, remember and manipulate relevant information in the mind, and shift between aspects of a problem. Yet, most work to date has focused on the associations between EF and mathematics achievement broadly. Thus, this symposium takes a nuanced approach to understanding the intersection of EF and mathematics by unpacking the associations between EF and specific mathematical skills and the role(s) of EF in doing mathematical tasks. The first study focuses on the specificity of the concurrent and predictive associations between EF and six select numerical skills in preschool to third graders. The second study considers whether prior knowledge of whole numbers interferes with understanding fractions and the role of EF in the whole number bias in third graders. The third study examines the interrelations between three EF components and strategy selection and execution when solving multi-digit subtraction problems in a sample of fifth grade students. Together, this symposium aims to highlight some of the many ways EF contributes to mathematics in the early to middle childhood years, which can be used to inform instructional efforts to support mathematics learning.

Presentation 1: Concurrent and predictive associations between executive function and numerical skills in early childhood

Jasmine Ernst[1], Michèle Mazzocco[2], & Stephanie Carlson[2]
[1]Purdue University; [2]University of Minnesota

The importance of early numerical and executive function (EF) skills is well established, with each skill set positively and specifically predicting later mathematics, income, and postsecondary education. Less is known about the relations between EF and numerical skills, however. Therefore, we examined the concurrent and predictive relations between EF and numerical skills in early childhood. Participants (N=205, 4.67-8.75 years, 43.9% female, 51.2% White, non-Hispanic) completed EF, math, and verbal knowledge assessments at two time points (~1 year apart). An EF composite was created by averaging z-scores (Minnesota Executive Function Scale, Head Toes Knees Shoulders; rs=.40). Numerical scores included: nonsymbolic magnitude comparison (i.e., comparing dot arrays using the Panamath), numerical literacy (e.g., reading and writing digits), counting on (e.g., 10 and then comes…), verbal counting (i.e., count as high as you can), non-rote counting (e.g., set and dot enumeration, backwards counting), and numerical problem solving (e.g., story problems, nonverbal addition/subtraction). Regressions were conducted to examine concurrent and predictive (Time 1->Time 2) relations, while controlling for age, maternal education, and verbal knowledge. Robust standard errors and Benjamini-Hochberg adjustments were calculated. We found positive concurrent relations between the EF composite and all six numerical skills examined. After controlling for earlier levels of the same

skill, unidirectional predictive relations emerged between EF and later count on, numerical literacy, and non-rote counting and between numerical problem solving and later EF. Bidirectional relations emerged between EF and nonsymbolic magnitude comparison. Overall, this work can inform future interventions and experimental studies targeting EF and numerical skills.

Presentation 2: Testing the role of executive function in whole number bias

Dana Miller-Cotto[1], Josh Medrano[1], Clarissa Thompson[1], Brianna Devlin[2], & Morgan Shingledecker[3]
[1]Kent State; [2]University of Oregon; [3]University of North Florida

We aimed to understand the mechanistic role of executive functions in early math knowledge. Using whole number bias as a starting point, the current study seeks to test two predictions stemming from whole number bias: that executive function skills may predict fraction understanding and whether whole number knowledge interferes with fraction understanding. Third graders (N = 66) were presented with a fraction comparison task with congruent trials where fraction comparison rules are consistent with whole number knowledge and fraction comparison with incongruent trials where fraction comparison rules are inconsistent with whole number knowledge. Participants were also assessed on their executive functions: working memory and inhibitory control, whole number knowledge, fraction number line estimation, and reading. In the first session, children were administered two general math tasks: the whole number knowledge and the fraction number line task. These tasks were completed one-on-one on a computer-administered by research assistants. In the second session, children were administered the three domain-general tasks: the WJ-IV sentence fluency measure, our executive function tasks, and the relational reasoning task. In the last session, children were administered the fraction comparison task. Using a within-subjects design, all children were administered this task with a counterbalanced order. We also collected reaction times for each trial. Data collection is ongoing, and analyses will be conducted to determine if students perform worse on fraction trials inconsistent with entire number knowledge and whether inhibitory control is a unique predictor of performance by the time of the conference.

Presentation 3: Are strategy selection and execution in multidigit subtraction related to executive functions?

Stijn Van Der Auwera[1], Bert De Smedt[1], Joke Torbeyns[1], & Lieven Verschaffel[1]
[1]KU Leuven

We examined 150 fifth-graders' (Mage = 10y11m) selection and execution of direct subtraction (DS; e.g., 712–346=?; 712-300=412, 412-40=372, 372-6=366) and subtraction by addition (SBA; e.g., 712–346=?; 346+54=400, 400+300=700, 700+12=712 and 54+300+12=366) strategies to solve multi-digit subtractions, and whether these two strategy parameters were associated with their executive functions (EFs). Both strategy selection and execution were examined by means of the choice/no-choice method. Participants were offered ten subtractions in one choice condition (free choice between DS and SBA) and in two no-choice conditions (mandatory use of either DS or SBA). Strategy selection was examined in the choice condition, and strategy execution (in terms of accuracy and speed) in the no-choice conditions. Concerning the EFs, updating was measured using a 2-back task, inhibition by means of a Flanker task, and shifting via a Trail Making Task. Results showed that strategy selection was associated with updating, but not with inhibition and shifting. Concerning strategy execution, children's accuracy in the no-choice conditions was associated with updating and shifting, but not with inhibition. Furthermore, no associations were found between EFs and speed in the no-choice conditions. This study shows the different associations of EFs components with strategy selection and execution in the domain of multi-digit subtraction, and helps to unravel via which mechanisms EFs are associated with mathematical performance.

Discussion led by

Andrew Ribner[1]
[1]Chatham University

S7C: Arithmetical skills: Hierarchical nature, early predictors and effects of schooling and age

Chair: Tuire Koponen[1]
[1]University of Jyväskylä

Integrative Statement:

It is well known that significant differences in mathematical skills exist at the start of school, and unfortunately, the gap between low-performing and typically achieving children is more likely to widen than narrow during the school years. Understanding early mathematical pathways is essential for developing more efficient educational support to improve mathematical achievement for all learners. However, due to the lack of longitudinal research, knowledge is scarce regarding the hierarchy between mathematical skills, underlying developmental mechanisms, and contributing factors.

The objectives of the symposium are to provide novel insights into factors that are relevant when trying to understand the complexity of arithmetic skill development. The first presentation addresses the question of to what extent children's early arithmetic and its predictors in this age period are driven by maturational changes or by changes in their exposure to formal schooling. The second presentation covers findings regarding the early numerical predictors of arithmetic fluency at school and the stability and hierarchy among the predictors. The third presentation presents findings regarding the hierarchical nature of arithmetic skills and similarities, as well as differences between arithmetic operations regarding numerical and non-numerical cognitive predictors. The discussant will highlight and integrate the contributions of each study.

Presentation 1: Disentangling schooling and age effects on children's early arithmetic skills

Floor Vandecruys[1], Maaike Vandermosten[1], & Bert De Smedt[1]
[1]KU Leuven

An essential developmental milestone during early childhood is children's transition from preschool to primary school, where they learn to calculate. To date, it remains unclear to which extent children's early arithmetic and its predictors in this age period are driven by maturational changes or by changes in the exposure to formal schooling. One way to experimentally disentangle such maturational from schooling-related effects is the use of the school cut-off design, in which one compares the abilities of children whose date of birth falls shortly on either side of the cut-off date for school entry. This creates two groups of children who are similar in age, but different in the amount of schooling they receive. Previous school cut-off studies showed robust schooling effects with regard to reading-related skills. However, with regard to arithmetic, the few existing studies have revealed mixed evidence. The specific impact of schooling not only on arithmetic, but also on predictors of arithmetic remains particularly unclear. To this end, we conducted a longitudinal study with 144 5-year-olds, assessing them at two timepoints separated by one year. Our preliminary findings show that large age effects exist for early arithmetic and its predictors, as well as for general cognitive abilities. Conversely, large schooling effects were shown for early arithmetic and its predictors, but not for general cognitive abilities. These results suggest that schooling and age differentially impact important predictors of early arithmetic and general cognitive abilities during the transition from preschool to primary school.

Presentation 2: Early predictors of grade 2 arithmetic fluency

Tuire Koponen[1], Kenneth Eklund[1], Minna Torppa[1], & Jenni Salminen[1]
[1]University of Jyväskylä

It is well known that significant differences in mathematical skills exist at the start of school, and the gap between low-performing and typically achieving children is more likely to widen than narrow during the school years. This is partially attributed to a strong hierarchy in mathematical skills, where poor early numerical skills lead to weak learning skills in basic arithmetic. These foundational skills, in turn, are crucial for acquiring more advanced mathematical skills at school. Understanding the developmental hierarchy between early numerical skills and their long-term predictive effects on arithmetic skills provides important knowledge for early identification and information for developing early support. The present study examines 100 children followed from toddlerhood to 2nd grade, addressing the following questions: To what extent can Grade 2 arithmetic fluency be predicted by early number concepts and counting skills at 2.5–3.5 years? What is the stability between number skills from 2.5–3 years to 5–6 years, and to what extent does the model including number skills from both early ages explain the variance in Grade 2 arithmetic fluency? We will analyze the data by using age-adjusted numerical skill variables and path analysis.

Presentation 3: Hierarchical nature of arithmetic skills: Similarities and differences between operations

Jarno Rautiainen[1], Tuija Aro[1], Mikko Aro[1], Asko Tolvanen[1], & Tuire Koponen[1]
[1]University of Jyväskylä

Acquisition of arithmetic skills is pivotal for academic growth. Research indicates that early numerical skills form the foundation for mathematical achievement, and that arithmetic skills develop in a cumulative fashion. Nevertheless, there is a dearth of longitudinal studies examining the hierarchy of mathematical skills and the interplay of cognitions in hierarchical development. Skills such as verbal counting are known to predict mathematical achievement from kindergarten to secondary education, and another prominent view is that domain-general skills are critical for mathematical development. The present study is a part of a longitudinal research project comprising five points of assessment of arithmetic, reading, cognitive and motivational factors

from the first to the third grades. This study extends the understanding of hierarchical development using SEM framework. The models comprise latent factors (Numerical Abilities (NA), Serial Retrieval Fluency (SRF), Working Memory (WM), and General Cognitive Abilities [2nd grade fall]). Both the NA and SRF predicted the multiplication skill [3rd grade spring] in the baseline analysis. In the hierarchical models, the covariances of the predictive factors with the prior arithmetical (or reading) skills (addition, subtraction, and reading fluency [2nd grade spring]) were partialled out from the predictors. Addition fluency skill and WM predicted the multiplication skill in the addition fluency model. For subtraction fluency model, a novel pathway emerges (SRF) while the model remains in other respects on par with the addition fluency model. In the reading fluency model NA, SRF and reading predict multiplication skill. The results indicate domain-specificity to the hierarchical development of arithmetic.

Discussion led by

Lynn Fuchs[1]
[1]Vanderbilt University, American Institutes for Research

S7D: What's confidence got to do with it? Teaching efficacy in mathematics

Chair: Erica Lembke[1]
[1]University of Missouri

Integrative Statement:

In this session, participants will learn about 3 lines of research specific to teacher self-efficacy in mathematics, culminated by a lively discussion led by an international scholar interested in teacher self efficacy. In the first presentation, the value and measurement of self efficacy during the formative college years will be examined, as researchers examine mathematics efficacy in pre-service teachers. In the second presentation, self efficacy will be examined from the lens of elementary general education and special education teachers who are implementing an evidence-based, structured fraction intervention. This federally funded fraction intervention replication provides findings from the first large scale study to examine the use of the intervention when it is teacher implemented. In the final presentation, the researchers will report on middle school mathematics teacher's self efficacy when implementing data based individualization. Implementation for this middle school project is in the areas of data based decision making using weekly progress monitoring data, implementation of evidence based strategies in mathematics, and collecting and utilizing diagnostic data. Finally, in the discussion section, the discussant will raise key points from across the sessions related to teacher preparation, supporting teachers through ongoing coaching or peer support, and best practices in increasing self efficacy in mathematics. This discussion will be provided from an international lens, with a discussion of commonalities in self efficacy in both the US and Europe.Objective:1) Participants will be able to provide information on challenges and successes related to teacher self efficacy in mathematics.

Presentation 1: The influence of a mathematics methods course on pre-service teachers' mathematics teaching self-efficacy, mathematics values, and mathematics anxiety

Cassandra Smith[1], Emily Singell[1], Jessica Rodrigues[1], & Delinda Van Garderen[1]
1University of Missouri

Teachers' mathematics teaching self-efficacy, mathematics values, and mathematics anxiety can impact their mathematics instruction and student mathematics outcomes (Bates & Latham, 2011; Briely, 2012; Gresham, 2009). Research has shown that special education pre-service teachers (PSTs) experience elevated mathematics anxiety (Johnson & vanderSandt, 2011) and low mathematics teaching self-efficacy and mathematics values (Alazemi, 2018; Flores, 2014). However, the influence of mathematics methods courses on these factors for special education PSTs' is unknown (Gresham, 2010; Johnson & vanderSandt, 2011; Ray, 2008), which raises the question if these factors can be changed by university courses. This panel will share results from a study that examined the influence of a university mathematics methods course on special education PSTs' mathematics teaching self-efficacy, values, and anxiety. Special education PSTs completed a one semester mathematics methods course that addressed instructional teaching practices for students with disabilities. A pre/post online Qualtrics survey was administered to measure PSTs' mathematics teaching self-efficacy (MTEBI; □ = 0.88; Enochs et al., 2000), mathematics value (MVI; □ = 0.95; Luttrell et al., 2010), and mathematics anxiety (MAST; □ = 0.96; Ganley et al., 2019). PSTs also completed two Likert scale items about their plans and desire to teach mathematics and two open-ended questions concerning their beliefs about teaching mathematics to students with disabilities. Descriptive statistics, course artifacts, and open-ended responses will be provided. Results will provide insight into the influence of targeted mathematics teaching instruction on PSTs' mathematics teaching self-efficacy,

mathematics values, and mathematics anxiety. Implications and future research will be discussed.

Presentation 2: Elementary teachers' self efficacy when implementing a fraction intervention program

Leanne Ketterlin-Geller[1], Erica Lembke[2], & Sarah Powell[3]
[1]Southern Methodist University; [2]University of Missouri; [3]University of Texas at Austin

Teachers' self-efficacy, or their feelings about their ability to affect change in student learning (Dembo & Gibson, 1985), are positively related to both teacher- and student-outcomes. In a meta-analysis, Klassen and Tze (2014) found a strong positive effect for teachers' self-efficacy on their evaluated teaching performance; the effect on student achievement was smaller but still significant. Given these findings, we examined the self-efficacy of teachers delivering interventions to students experiencing difficulty. We administered a standardized measure of teachers' self-efficacy in mathematics before and after implementing interventions to Grade 4 students. Fifty-eight teachers were randomly assigned to implement an efficacious fraction-based intervention (36 30-minute lessons) or business-as-usual control. We tested two hypotheses: 1. Interventionists' self-efficacy improves for those implementing an efficacious intervention. 2. Changes in interventionists' self-efficacy mediates student outcomes. No statistically significant changes in teachers' self-efficacy were detected as a result of implementing the efficacious intervention. However, large positive gains were observed on students' fractions knowledge and their self-efficacy, as compared to the control group. Because there was no observed treatment effect on teachers' self-efficacy, we did not conduct the mediator analysis.In this presentation, we explore possible reasons for the observed findings, and discuss practical implications for teachers and students.Dembo, M. H., & Gibson, S. (1985). Teachers' sense of efficacy: An important factor in school improvement. The Elementary School Journal, 86(2), 173–184. https://doi.org/10.1086/461441Klassen, R. M., & Tze, V. M. C. (2014). Teachers' self-efficacy, personality, and teaching effectiveness: A meta-analysis. Educational Research Review, 12(2014), 59-76.

Presentation 4: Self efficacy of middle school mathematics teachers implementing data-based individualization

Erica Lembke[1], Leanne Ketterlin-Geller[2], & Sarah Powell[3]
[1]University of Missouri; [2]Southern Methodist University; [3]University of Texas at Austin

As part of a US Department of Education Research to Accelerate Pandemic Recovery in Special Education grant, our team is focusing on math and the educators who provide math support to students with disabilities in Grades 6, 7, and 8. In project STAIR (Supporting Teaching of Algebra: Individual Readiness), we propose to provide just in time support to teachers to help them address the needs of their students with math difficulties. We do this by providing professional development and coaching to teachers, utilizing practices tailored to teacher and student needs. We partner with several school districts across states to increase teacher use of (a) a data-based decision making framework, (b) evidence-based practices for math instruction, and (c) formative assessment data collection to make timely adaptations to math instruction. Teachers learn how to boost the math instruction within their current curriculum by integrating STAIR strategies into their math teaching. One of our primary aims for this project is to understand the effect of varying levels of STAIR coaching intensity on teacher - level outcomes (instructional practice, self-efficacy, and math knowledge for teaching). We will present data on teacher self-efficacy for year 1 as a result of participation in the STAIR. The primary data provided will be from the Mathematics Teaching Efficacy Belief Instrument (MTEBI), a valid and reliable 21 item assessment with two subscales: the Personal Mathematics Teaching Efficacy (PMTE) subscale and the Mathematics Teaching Outcome Expectancy (MTOE) subscale (Enchos et al., 2000). Implications for tailored coaching will be provided.

Discussion led by

Sara Caviola[1]
[1]University of Padova, Italy

S8A: Understanding perceptual influences on math cognition and learning

Chair: Avery Closser[1]
[1]Purdue University

Integrative Statement:

Perceptual cues in math problems (e.g., the color, arrangement, and spacing of numbers and operators) affect students' problem-solving interpretation, behavior, and performance (e.g., Alibali et al., 2018; Landy & Goldstone, 2010; Rivera & Garrigan, 2016). Such research prompts efforts to identify how perceptual processes can be leveraged in math education and learning technologies. This symposium will feature three presentations that describe new directions to expand our understanding of perceptual influences on math

cognition and learning in online contexts. Specifically, the first presentation will address how perceptual cues embedded in arithmetic problems affect problem-solving performance and proximal learning outcomes. The second presentation will delve into the underlying mechanisms behind how perceptual cues work as explored with eye tracking. The third presentation will consider whether the effects of perceptual cues occur earlier in math education and whether the effects generalize across two math content areas. Following these presentations, our discussant will share remarks and lead a discussion with the audience to identify themes, questions, and feedback related to the research presented. Alibali, M. W., Crooks, N. M., & McNeil, N. M. (2018). Perceptual support promotes strategy generation: Evidence from equation solving. British Journal of Developmental Psychology, 36, 153–168.Landy, D., & Goldstone, R. L. (2010). Proximity and precedence in arithmetic. The Quarterly Journal of Experimental Psychology, 63(10), 1953-1968. Rivera, J., & Garrigan, P. (2016). Persistent perceptual grouping effects in the evaluation of simple arithmetic expressions. Memory & Cognition, 44, 750-761.

Presentation 1: Examining the effects of spacing and color cues on middle school students' mathematical fluency with order of operations

Caroline Hornburg[1], Ji-Eun Lee[2], Avery Closser[3], Jeffrey Bye[4], Alena Egorova[2], Meagan Reinhardt[1], Isabel Valdivia[1], & Erin Ottmar[2]

[1]Virginia Tech; [2]Worcester Polytechnic Institute; [3]Purdue University; [4]University of Minnesota

Prior research has demonstrated general effects of individual perceptual cues on students' problem-solving performance (e.g., Harrison et al., 2020). The current experiment systematically examines the individual effects of perceptual cues by indicating higher-order operations (i.e., multiplication) by spacing symbols closer together or color-coding them, compared to no such perceptual cues. We investigate the effect of these manipulations on sixth-grade students' arithmetic performance, as well as examine potential moderators of these effects (e.g., students' prior knowledge, perceptual processing, math anxiety, and math value). We will present an analysis from a planned sample size of 600 U.S. middle school students, with 80% power to detect a main effect of $d > 0.20$ at $p < .05$. Analyses will include a series of regressions. We hypothesize that students in the two perceptual cue conditions (spacing and color) will perform better on problem solving (i.e., higher accuracy, shorter response times) and on an immediate posttest with cues no longer present, compared to students in the no-perceptual-cue condition. Furthermore, we hypothesize that students with lower prior knowledge, higher math anxiety, lower math value, or lower perceptual processing skills in mathematics will show a larger benefit from viewing perceptual cues than their counterparts. Results will add to our understanding of how to best support students' mathematical cognition through perceptual cues in an online learning environment. Harrison, A., Smith, H., Hulse, T., & Ottmar, E. R. (2020). Spacing out! manipulating spatial features in mathematical expressions affects performance. Journal of Numerical Cognition, 6(2), 186–203. https://doi.org/10.5964/jnc.v6i2.243

Presentation 2: Perceptual cues' influence on visual processing of order-of-operations problems

Alena Egorova[1], Jeffrey Bye[2], Aaron Wong[1], Caitlin Mills[1], & Erin Ottmar[1]

[1]Worcester Polytechnic Institute; [2]University of Minnesota

Learning to 'see' the underlying mathematical structure of arithmetic expressions is an important part of developing arithmetic and algebraic fluency, especially when solving left-to-right is invalid (e.g., when higher-precedence multiplication appears after addition, 2+3*4). Perceptual cues can be used to enhance this processing by emphasizing the multiplication and its operands as grouped together, or inhibit by emphasizing a lower-precedence operation (Marghetis et al., 2016). Our recent work using eye-tracking (Authors, under revision) found that U.S. undergraduates do not immediately fixate on higher-precedence operators, even when they are highlighted by superfluous brackets (i.e., brackets that do not change the order of operations, e.g., in "5+(2*3)-1"). Here, we extend this approach to measure how undergraduates process mixed-precedence arithmetic problems which use color or spacing cues to indicate the higher-precedence operator (multiplication). Unlike the use of brackets, these color and spacing cues are lower-level, non-mathematical perceptual cues that recruit object-based attention to facilitate grouping (Marghetis et al., 2016). We hypothesize that students receiving these cues (vs. no perceptual cues) will be faster to attend to the higher-precedence operator and operands (and thereby faster to correctly answer), especially when it appears in the middle or right position (i.e., the problem is not solvable left-to-right). Finally, since both color and spatial proximity have been demonstrated to strongly affect perceptual grouping (Quinlan & Wilton, 1998), we will compare the facilitative effects of color against the

effects of spacing in both guiding fixation and reducing solution time.

Presentation 3: Preliminary evidence on the effects of perceptual scaffolding on math performance and learning among elementary school students

Avery Closser[1], David Purpura[1], Connor O'Rear[2], Tamisha Thompson[3], Anthony Botelho[4], & Katherine Allen[1]
[1]Purdue University; [2]University of Notre Dame; [3]Worcester Polytechnic Institute; [4]University of Florida

Understanding relational concepts is foundational to progress from arithmetic to higher-level mathematics (e.g., Ching & Nunes, 2017; McNeil, 2014). However, students routinely perform calculations from left to right, compromising accuracy and efficiency on varied problem representations (e.g., McNeil, 2014). Since embedding perceptual cues within problems can affect secondary and postsecondary students' problem-solving behavior, creating differences in accuracy and efficiency, we question whether perceptual scaffolding in online materials improves performance and learning with younger students as well. In this presentation, we will describe and present results from two pilot studies with 2nd-4th grade U.S. students. The studies test the effects of perceptual scaffolding on students' performance, learning, and retention about (a) equivalence and (b) inverse operations. We hypothesize that students who view materials with perceptual scaffolding will demonstrate higher performance and learning gains from pretest to posttest than their peers who do not view perceptual scaffolding. This project will shed light on how perceptual scaffolding impacts learning earlier in math education and whether the effects generalize across two relational concepts. The findings will advance research on perceptual learning and provide recommendations for math classroom practice and content development in educational technologies.

Discussion led by

Nicole McNeil[1]
[1]University of Notre Dame

S8B: Numerical flexibility investigated from cognitive, neural, and educational perspectives

Chair: Michael Slipenkyj[1]
[1]Department of Psychology, Georgetown University, USA

Integrative Statement:

Symbolic numbers are a cornerstone of modern society. We use them in many everyday situations: from ordering daily tasks on a to-do list to comparing the price of two products. The ability to use numbers in flexible ways is one of their most useful features. Understanding the ways in which numerical processing is flexible and inflexible is important for mathematical cognition. In this symposium, we will detail cases of numerical and mathematical flexibility across several dimensions: First, Lilly Roth will discuss her research on Spatial-Numerical Associations being partly flexible (i.e., dependent on the numbers in the current task) and partly fixed. Second, Shawn Zhang will discuss the results of his spatial intervention study. Notably, they find short-term rigidity but long-term flexibility in mathematical skills. Third, Mike Slipenkyj will detail the results from his fMRI training study showing that the neural coding of artificial symbols and numbers are flexible across processing contexts. Fourth, Taylor-Paige Guba will share her research on the portrayal of mathematics problems in common US textbooks. Despite recommendations for presenting math problems in a variety of formats to encourage flexible thinking, her results show that textbooks persist in presenting math problems predominantly in a common form. In summary, this symposium aims to bring together several lines of research on numerical flexibility. Overall, the goal of this symposium is to demonstrate how numerical flexibility can be investigated from different perspectives and that this is necessary for researchers to develop a more comprehensive understanding of numerical and mathematical cognition.

Presentation 1: One and only SNARC? Spatial-numerical associations are partly flexible, relying on both absolute and relative magnitude

Lilly Roth[1], Annika Tave Overlander[2], John Caffier[2], Ulf-Dietrich Reips[2], Hans-Christoph Nuerk[1,3,4], & Krzysztof Cipora[5]
[1]Department of Psychology, University of Tübingen, Germany; [2]Department of Psychology, University of Konstanz, Germany; [3]LEAD Graduate School & Research Network, University of Tübingen, Germany; [4]German Center for Mental Health (DZPG), Germany; [5]Centre for Mathematical Cognition, Loughborough University, United Kingdom

Number magnitude is associated with space, as reflected by the SNARC effect (Spatial-Numerical Association of Response Codes; Dehaene et al., 1993), describing faster responses to small/large number magnitude with the left/right hand, respectively. Dehaene et al. (1993) and Fias et al. (1996) investigated the SNARC effect in parity judgment with different stimulus sets. Interestingly, numbers 4 and 5 were associated with the right in 0,1,2,3,4,5 vs. left in 4,5,6,7,8,9 (where they were the largest vs. smallest numbers). Thus, the SNARC effect seemed to adapt to relative magnitude within the stimulus set in a fully flexible manner. However, this important conclusion was drawn from the absence of evidence for the dependency on absolute magnitude in

frequentist analyses in underpowered studies. Two preregistered online replications were run: (1) with the original stimulus sets, (2) a conceptual one with 1,2,4,5 vs. 4,5,7,8, excluding the number 0 and potential confounds related to parity of numbers being used. Moderate Bayesian evidence was reached with 200 (direct replication) and 300 participants (conceptual replication). We found the SNARC effect in each stimulus set. The direct replication provided support for sole role of relative magnitude for the SNARC effect. The conceptual one showed that absolute magnitude had an impact as well. Although results from the original studies were replicated, our conceptual replication indicates they might be due to the special processing of number 0 and parity-related confounds in the direct replication. Spatial-Numerical Associations seem to flexibly adapt to relative magnitude, but partly rely on absolute magnitude as well.

Presentation 2: Mathematical flexibility in the immediate and long-term impacts of guided puzzle play in preschool children

Xiao Zhang[1] & Xinzhuo Zou[1]
[1]The University of Hong Kong, Hong Kong

Spatial cognitive training yielded significant transfer to mathematics skills in some studies but not all. Yet none of the studies included a delayed posttest at least one month following intervention. To fill this gap, the present study administered a guided puzzle play program in preschool children using a controlled pre-post-delayed-post design and tested its immediate and long-term effects on their spatial and arithmetic performance. Participants were 67 Hong Kong preschoolers (age: M ± SD = 56.67 ± 4.07 months), who were randomly assigned to the intervention or control groups within each school. Children in the intervention group participated in a guided puzzle play program comprising 12 weekly 25-min sessions in a small group setting (3 or 4 children). Children in the control group engaged only in regular preschool activities. In the pretest, immediate posttest, and delayed posttest (i.e., three months after the intervention), children were tested individually on their mental rotation and nonverbal calculation skills. The results showed immediate intervention effects on children's mental rotation but not on their nonverbal calculation. However, analyses of the delayed posttest data showed long-term effects on children's nonverbal calculation. The findings demonstrate the short-term inflexibility but long-term plasticity in mathematical skills and suggest that flexible mathematical thinking that arises from the enhancement of general cognitive skills such as spatial skills may have a delayed period of development. Further research should investigate why this delay occurs in a more granular fashion.

Presentation 3: Flexibility in artificial symbols and numbers: Evaluating the impact of learning and computational context on the neural coding of abstract symbols

Michael Slipenkyj[1], Roma Siugzdaite[2], Jean-Philippe Van Dijck[3], Wim Fias[2,3], & Ian M. Lyons[1]
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Symbolic numbers (e.g., 1,2,3…) are foundational for modern society and human thinking. While symbolic numbers can be taught and processed in a variety of flexible ways, the impact that different acquisition and computational contexts can have on the resultant neural representations is unclear. To investigate this in the present research, two groups of participants underwent extensive behavioral training for a sequence of artificial symbols using either an associative (i.e., pairwise comparison) or positional (i.e., number line verification) training paradigm. Subsequently, both groups completed sequentially presented versions of their training task, and the other group's training (i.e., the transfer) task in an fMRI scanner with the artificial symbols and numerals. Univariate fMRI and representational similarity results during the anticipatory phase of the tasks revealed that the neural coding for the artificial symbols and numerals was remarkably dependent on the computational context, but largely agnostic to training group and symbolic format. Specifically, across fronto-parietal brain regions, the associative context was characterized by an inverse bi-anchor pattern, with increased activity for endpoint symbols. This pattern suggests a task-based neural response code. Conversely, the positional context generally showed a tri-anchor pattern, with decreased activity for the midpoint and endpoints symbols. This is consistent with position based neural coding. Representational similarity analysis revealed similar results, with structurally distinct patterns of coding and different theoretical model fits for each task. Broadly, this research demonstrates that the neural coding for abstract symbols is largely based on the computational context, rather than the training group or symbolic format.

Presentation 4: "High quality" US elementary math textbooks lack promotion of flexibility in equation and arithmetic understanding

Taylor-Paige Guba[1]
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Research has shown the importance of students' practice with non-traditionally formatted arithmetic problems (e.g., 5 = 2 + 3) for understanding the meaning of the equal sign, flexible problem solving skills, and progressing to higher-level math. It is unclear if current math textbooks are following this recommendation as a textbook analysis of this nature has not been published for more than a decade. In this study, eight common US math textbooks published between 2020 and 2023 were analyzed to determine what formats multiplication problems are presented in. US Common Core State Standards introduce multiplication in third grade, so third and fourth grade textbooks were selected in order to find out in what formats multiplication is introduced in the first year and how that changes once students are expected to have mastered the skill. A regression revealed that traditionally formatted multiplication problems are statistically significantly more common in the eight textbooks than non-traditionally formatted multiplication problems. Descriptively, there were four times as many traditionally formatted multiplication problems than non-traditionally formatted multiplication problems. Grade and textbook did not emerge as significant predictors of the amount of different problem types. This study revealed that, despite decades of recommendations for more non-traditional arithmetic practice, this sample of textbooks, which are highly rated in all categories on EdReports, lack appropriate variation of multiplication practice. Practical implications include the fact that more advocacy for non-traditional arithmetic format is needed in order to push towards curricula which include more of these types of arithmetic problems.

S8C: Multiplication fact knowledge: Integrating findings across multiple levels

Chair: Joanne Eaves[1]
[1]School of Psychology, University of Nottingham, UK

Multiplication fact fluency is believed to be foundational to more complex mathematical processes and key for mathematics success. However, we do not fully understand how multiplication knowledge helps with mathematics, how use of multiplication representations develop, and the role that cognitive skills play in learning and accessing multiplication facts. In this symposium, we present findings from four different labs that shed light on the importance of multiplication fact knowledge, students' interpretations of visual representations of multiplicative structures, and the cognitive skills that help to develop it. The first talk highlights the important role of multiplication fluency in developing a mature number sense in 9 – 13 year olds, and Talk 2 sheds light on how different multiplication models are perceived by children aged 8 to 11 years. Talks 3 and 4 both focus on interference between multiplication facts. Talk 3 models children's learning processes with adult participants, to track how interference develops between multiplication facts during learning, and Talk 4 investigates the cognitive skills and neural markers in multiplication performance in individuals of different fluency levels.Together these projects emphasise the substantial individual differences in multiplication fact knowledge; children differ in how they interpret visual representations of multiplicative structures, and adults differ in their ability to learn multiplication facts and fluently retrieve them. Part of this variability may stem from individual differences in cognitive skills.

Presentation 1: Elementary and middle school students' multiplication fluency is strongly correlated with their mature number sense

Kelly-Ann Gesuelli[1], Patrick Kirkland[1], & Nicole McNeil[1]
[1]University of Notre Dame, USA

Students exhibiting mature number sense make sense of both numbers and operations to flexibly solve problems. Despite being a key goal in mathematics education (NCTM, 1989), limited evidence exists on how students best develop mature number sense. In the present study, we aim to address this gap through the specific focus on multiplication fluency. We hypothesize that efficient production of multiplication facts reduces cognitive load, enhancing reasoning processes central to number sense (cf. Berrett & Carter, 2018). Building on Kirkland et al. (2024), who found a moderate correlation between multiplication fluency and mature number sense in elementary students, our research extends to a broader age range and larger samples. We analyzed two cross-sectional datasets: one of 154 3rd-5th graders (elementary dataset) and another of 274 6th- 8th graders (middle school dataset). Control variables included gender and underrepresented/minoritized (URM) status. Multiplication fluency was a statistically significant predictor of mature number sense in both elementary and middle school. Notably, in middle school, interactions between grade level and multiplication fluency ($\beta = .163$; $p < .001$) and grade2 and multiplication fluency ($\beta = -.136$; $p = .024$), suggest the strongest association may be in 7th grade. These findings replicate and extend Kirkland et al., indicating multiplication fluency is a key construct in mature number sense's nomological network. However, the causal mechanisms remain unclear, and some experts propose that number sense might boost multiplication fluency (Boaler, 2015). Future research will

explore these causal dynamics and the developmental trajectory of these important mathematics skills.

Presentation 2: The role of form and perceptual features in visual representations on children's interpretations of multiplicative structures in the third and fifth grades

Alison Tellos[1] & Helena Osana[1]
[1]Concordia University, USA

We examined children's interpretations of visual representations of multiplicative structures. Our objectives were to: (a) reveal which models of multiplication (equal groups, array, or product) are perceived by children as most representative of multiplication, (b) examine whether perceptual features of visual displays moderate the extent to which children interpret the representations as multiplication, and (c) investigate grade differences. Third graders (n = 40) and fifth graders (n = 16) were presented with whole-number multiplication expressions in symbolic form (e.g., 3 × 5) and visual displays of LEGO® bricks that either represented equal groups, array, and product. All children rated the extent to which the displays represented the target expression. Half of the visual representations used bricks as the lowest-level unit to represent the multiplication expression and the other half used studs as the lowest-level unit. The results revealed that all children rated the equal groups representations more representative of the expression than the array and the product forms. The results also showed that the third graders rated displays with studs as units as more representative of multiplication expressions than displays using bricks as units. The reverse pattern was revealed for the fifth graders. The results contribute to the literature by showing that children more readily associate multiplication with equal groups than arrays. Additionally, the younger children were more drawn to the studs on bricks than the older children, suggesting a need for future research on the role of inhibitory control in children's interpretations of visual representations of mathematical structures.

Presentation 3: Inhibitory control during the learning of multiplication facts

Camilla Gilmore[1], Joanne Eaves[2], & Lucy Cragg[2]
[1]Centre for Mathematical Cognition, Loughborough University, UK; [2]School of Psychology, University of Nottingham, UK

Models of number fact knowledge and retrieval suggest that number facts are stored in an associative network in which a number of possible solutions are activated when trying to retrieve an answer. This creates interference that needs to be resolved by a process known as inhibitory control. These models account for the skilled retrieval of number facts. However, there is no detailed model or direct empirical evidence of the role of inhibitory control as number facts are learned. In our pre-registered study, we are tracking 50 individuals as they learn a new set of multiplication facts and we are monitoring the cognitive interference between the facts as they are learnt. Our pilot work with 30 adults indicates that interference effects emerge early in the course of learning (when accuracy in retrieving the facts is low). Interference effects remain fairly stable throughout the learning, and are still present end of learning (when accuracy in retrieving the facts is high). We found no interference prior to learning. Our findings are the first to imply a need for inhibitory control in mathematics learning (not just performance), and we discuss the role inhibitory control might play at different stages of the learning journey. Our findings also inform teachers of the challenges children face; when learning multiplication facts, problems that are learnt at the same time generate interference and this interference persists over time. Children with insufficient inhibitory control skills will therefore struggle to develop multiplication fact fluency.

Presentation 4: Neural correlates of interference and problem size effects in single-digit multiplication: An fMRI study on varied fluency levels in Malaysia

Meh Ling Soh[1], Alejandro Estudillo[2], & Javier Garcia-Orza[3]
[1]University of Nottingham, Malaysia; [2]Bournemouth University, UK; [3]University of Malaga, Spain

This study investigates the neural mechanisms associated with interference and problem size effects in single-digit multiplication among individuals with diverse fluency levels in Malaysia. Drawing on recent findings, we examine the relationship between problem size (speed and accuracy in solving smaller problems) and interference effect (difficulty in retrieving high-interfering problems with feature overlaps from previously learned ones). Using a multiplication verification task paradigm adapted from De Visscher et al. (2015), we conducted functional magnetic resonance imaging (fMRI) scans with twenty-four participants evenly split between low and high-fluency groups. The fMRI data, analysed using a general linear model approach and paired t-tests, aims to identify multiplication-processing brain regions associated with visual problem-solving. Concurrently, behavioural data on attention, inhibition, and IQ reasoning were collected, confirming previous study findings. The present study will look into the neural signatures of interference and problem size effects,

providing insights into the neural mechanisms underlying numerical cognition and fluency differences.

S9D: Examining factors related to gender differences in early math development

Chair: Suzanne Varnelle[1] & Sona Kumar[1]
[1]Department of Human Development and Family Science, Purdue University, United States

Integrative Statement:

Prior work has shown gender differences in math achievement beginning in adolescence, with boys outperforming girls, making it important to explore early contributors to these differences. Across three papers, this symposium will explore different areas that have been theorized to impact math achievement, including parent expectations (Paper 1), the home math environment (Paper 2), and math anxiety (Paper 3). Papers 1 and 2 utilize parent report measures, whereas Paper 3 uses a direct report measure from children. Paper 1 examined differences in parent expectations for children's (3-5) math and literacy achievement between parents of boys and parents of girls, finding no gender differences in parents' expectations and value of math. Paper 2 explored differences in parent report of home math activities, math anxiety, and emotions while doing math with 6 to 12-year-olds. There were few differences in parent report of home math activities and related emotions by child gender, although parents of boys reported doing flashcards more than parents of girls. Paper 3 investigated differences in math anxiety and performance by child gender, finding higher levels of math anxiety for girls than boys across age (5-14). A discussant who is an expert in gender differences in math learning will bring together the ideas in this symposium. This symposium provides new information about gender differences in early math, suggesting that these differences may not be large (Papers 1 and 2). Additionally, Paper 3 highlights gender differences in math anxiety as a potential area of focus for decreasing gender disparities in math.

Presentation 1: Gender similarities and differences in parents' expectations and value of math and literacy for their young children

Suzanne Varnell[1], Sona Kumar[1], Siqi Zhang[1], & Sarah Eason[1]
[1]Department of Human Development and Family Science, Purdue University, United States

Situated expectancy-value theory posits that parents' child-specific beliefs, such as the value of math and expectations for their child's math achievement, can influence their child's beliefs and achievement in math (Eccles & Wigfield, 2020). Parents' beliefs about math have been shown to differ depending on their child's gender, with parents of girls seeing math as less valuable and having lower expectations for daughters' math achievement (Levine & Pantoja, 2021). In this study, we surveyed parents (N=587) of 3- to 5-year-old children about their expectations for their child's math and literacy success, the value of math and literacy for their child's future, and their concerns for their child not doing well in math and literacy. We hypothesized that parents of girls would have lower math expectations, values, and concerns than parents of boys. We ran multiple regressions with parents' ratings of math expectations, values, and concerns as the dependent variables and child gender, age, parent relation, and household income as the predictors. We also examined parents' literacy expectations, values, and concerns as a comparison. We found no child gender differences for math expectations, value, and concerns or literacy concerns. However, parents of girls expressed higher literacy expectations (β=.16, $p<.001$) and value (β=.10, p=.015) than parents of boys. This work sheds new light on parents' differing expectations for young children's math and literacy achievement.

Presentation 2: Investigating gender differences in the home math environment and its relation with child math outcomes

Nandrea Burrell[1] & Colleen Ganley[2]
[1]Department of Psychology, Florida State University; [2]Department of Psychology & Learning Systems Institute, Florida State University

The home math environment (HME) encompasses various math-related activities that parents engage their children in at home. Factors such as family composition, income, and parental beliefs regarding education influence the quality of the HME. Previous research has shown that as students get older, gender differences favoring boys increase in mathematics achievement (Cimpian et al., 2016; Mullis et al., 2000). The present study examines if there are differences in parents' report of the HME depending on their child's gender and if there are gender differences in the relation between the HME and children's math anxiety and skills. In a sample of 163 children and their parents, the HME was measured with a 17-item parent-report questionnaire gauging the frequency of home math activities and a 5-item survey assessing parents' emotions while aiding their child with math homework. Parents reported their child's math skills on a 0-100 scale and their child's math anxiety using a parent version of the Math Anxiety Scale for Young

Children-Revised. T-tests showed that parents of boys tended to use math flashcards more often. There were no gender differences in the frequency of other reported HME activities or in parents' emotions while helping with math homework. Structural equation models showed that more positive emotions during homework related to lower math anxiety and higher skills, but HME activity frequency did not, for both boys and girls. Our results suggest that both frequency and emotions involved in the HME, as well as their effects, seem to be similar by gender.

Presentation 3: Gender differences in math anxiety and math performance throughout childhood

Alex Silver[1], Andrea Quintero[2], & Lisa Feigenson[2]
[1]Department of Psychology, University of Pittsburgh; [2] Johns Hopkins University

Math anxiety and the associated negative feelings toward math are related to worse math performance around the world (Foley et al., 2017). Despite the large gender differences that have been identified for older children and adults, with females reporting higher levels of math anxiety than males (e.g., Hembree, 1990), studies of gender differences at younger ages have yielded conflicting results. Furthermore, previous work has often studied children using relatively small age windows, employing a variety of measures, and has often neglected to control for children's general anxiety or has used different measures for math versus non-math anxiety. Thus, it remains unclear how gender differences in math anxiety develop over time and how these relate to children's math performance. Here we examined math anxiety and general anxiety using a single measure, along with math performance, in 257 children ranging from 5 to 14 years of age (121 females). We found that, controlling for general anxiety, at all ages females reported more math anxiety than males, $F(1, 256)=12.78$, $p<.001$. Critically, this gender difference in math anxiety did not significantly change with age. Furthermore, the link between math anxiety and math performance did not differ for males and females; higher math anxiety was associated with worse math performance for all children, and this association did not significantly change with age. These findings suggest that gender differences in math anxiety, and links between math anxiety and math performance, are present even at the entry to formal schooling and remain stable throughout development.

Discussion led by

Colleen Ganley[1]
[1]Department of Psychology & Learning Systems Institute, Florida State University

S9A: Training children's numerical skills in elementary school: From counting to arithmetic fluency

Chair: Catherine Thevenot[1] & Jérôme Prado[2]
[1]University of Lausanne , SSP, Institute of Psychology; [2] Centre de Recherche en Neurosciences de Lyon (CRNL), INSERM U1028 - CNRS UMR5292, Université de Lyon, France

Integrative Statement:

In today's rapidly evolving technological landscape, fostering strong numerical skills in children has become more crucial than ever. The ability to comprehend and manipulate numbers is not only foundational for success in STEM fields but also serves as a fundamental life skill. Recognizing the pivotal role of numerical proficiency in shaping the future of our young learners, we have organized the present symposium comprising three presentations delving into innovative approaches aimed at enriching and accelerating the development of early numerical skills in children. From exploring the impact of finger counting training (Marie Krenger) to delving into the efficacy of enhancing early numerical skills through a tablet-based intervention (Marianne Cottin) and dissecting the dynamics of game-based learning (Catherine Thevenot), our symposium covers a spectrum that includes both traditional teaching methods and contemporary digital interventions. The symposium will conclude with Terry Wong, who will provide a summary of the key findings and insights from each presentation and a cohesive overview of the content covered, fostering further discussion on the future of early numerical skill development.

Presentation 1: Finger counting training in young learners

Marie Krenger[1] & Catherine Thevenot[1]
[1]University of Lausanne, SSP, Institute of Psychology

In a study involving more than one hundred kindergarteners and first graders, aged between four and seven years, we show that children who do not calculate naturally on their fingers and receive finger counting training exhibit improvement in their addition skills from pre- to post-test compared to both a passive control group and an active control group engaged in rote learning of addition. In addition to assessing arithmetic skills, we also conducted pre- and post-tested to evaluate broader numerical abilities. This was done by examining counting principles in kindergarten and numerical decomposition skills in first grade. Our goal was to investigate whether, beyond its impact on arithmetic skills, finger counting can support the acquisition of the number concept.

Presentation 2: Enhancing early numerical skills through a tablet-based intervention combining domain-specific training with individualized feedback

Marianne Cottin[1], Ludovic Arnold[2], Marie-Line Gardes[3], & Jérôme Prado[1]

[1]Université de Lyon, Centre de Recherche en Neurosciences de Lyon (CRNL), INSERM U1028 - CNRS UMR5292; [2]Association Agir pour l'Ecole, Paris, France; Marie-Caroline Croset, Université Grenoble Alpes, Laboratoire d'Informatique de Grenoble; [3]Haute école pédagogique (HEP) Vaud, Lausanne

Math learning is incremental, with early knowledge providing the foundation for later math skills. While this implies that young children with weak number knowledge are likely to experience difficulties later on, it also suggests that early foundational numeracy might be a target for interventions. Yet, effects of short-term early math interventions are limited and often fade over time. A challenge for these interventions is also the heterogeneity of children's numerical skills, which makes it difficult for teachers to tailor instructions. Computerized interventions may address some of these issues, as they could maximize effects through repeated practice and allow for individualized feedback to teachers. To test this hypothesis, we examined the effectiveness of a 10-week large-scale tablet-based intervention in kindergarten. Through the tablet, children were presented with a series of activities fostering cardinal understanding, transcoding, number decomposition, arithmetic transformation, and problem solving. These activities were practiced three times a week in 30-minute daily sessions. Teachers, who monitored each child's progress through a dedicated application, were instructed to engage in a weekly tablet-free 30-minute math instruction session tailored to children's needs. Children's math skills were evaluated before and immediately after the intervention through one-on-one assessments. Data were analyzed using hierarchical mixed-level modeling. Compared to a business-as-usual group (n=423), children who benefited from the intervention (n=462) showed enhanced overall learning (0.2SD). Because teachers in the intervention group reported spending less math instruction time than teachers in the control group, these findings suggest that the intervention was particularly efficient in fostering early number knowledge.

Presentation 3: Enhancing arithmetic fluency in children: A comparative analysis of mathador training with and without teacher guidance

Catherine Thevenot[1], Céline Poletti[1], Valéry Layeux[2], Mélinée Chanard[2], & Georges Nivoix[2]

[1]University of Lausanne, SSP, Institute of Psychology; [2]Ministère Française de l'Education Nationale, Réseau Canopé

During a four-week period, a total of 161 ten-year-old children participated in an arithmetic training program. Within this program, a subgroup of 38 children engaged in a game resembling Count-Down, known as Mathador, by playing individually on a tablet for 10 minutes every school day. The objective of the game was to achieve a target number by creatively combining five given numbers, incorporating various arithmetic operations such as addition, subtraction, multiplication, and division. The study compared the improvement in performance on an arithmetic fluency test between the Mathador group and a control group exposed to a vocabulary game (N = 40). Additionally, two other groups were included: one where children were taught specific Mathador calculations by a teacher (N = 41) and another where children both played Mathador and received instruction from a teacher (Mathador + Teacher). When focusing solely on children who demonstrated improvement in the Mathador game itself, those in the Mathador + Teacher group exhibited higher improvement compared to the Vocabulary control group. However, Mathador alone did not yield this positive effect. Furthermore, the performance improvement in the Mathador + Teacher group did not surpass that of the Teacher alone group, indicating that the tablet-based game did not provide additional value to the pedagogical sequence centered around Mathador and guided by the teacher.

Discussion led by

Terry Wong [1]

[1]The University of Hong Kong

S9B: The development of foundational mathematics skills across the life span

Chair: Shuyuan Yu[1]

[1]Department of Cognitive Science, Carleton University

Integrative Statement:

Mathematics is hierarchically built on foundational skills (e.g., informal and formal knowledge of numbers and relations). Thus, the acquisition of foundational skills is crucial to educational and professional success. Four papers in our symposium demonstrate the development of these fundamental skills over a wide age range. Speakers will address how early foundational mathematics skills are built on informal knowledge (Paper 1), how early (Paper 2) and more advanced (Paper 3) numeracy knowledge co-develops during elementary school, and how foundational math skills change with old age (Paper 4).Paper 1 provides evidence that informal

fraction knowledge in Grade 1 predicted unique variance in math achievement in Grade 2, after controlling for whole number knowledge and general cognitive skills. Paper 2 shows the longitudinal contribution of ordering skills in Grade 2 to subsequent arithmetic in Grade 3 for not-at-risk math learners and suggests challenges among at-risk students in forming arithmetic fluency from numerical knowledge. Paper 3 explores the development of arithmetic and equivalence from Grade 4 to Grade 5 for Chinese students, showing that the influence of arithmetic on equivalence fluency is initially stronger, but the cross-lagged contributions were equal in strength by the end of Grade 5. Finally, Paper 4 shows that arithmetic retrieval skills show the strongest decline with age, and this decline is partially mediated by age-related declines in hippocampal volumes. Together, these papers explored the path of foundational mathematics skill development throughout life, offering valuable insights for interventions to teach and maintain math skills across the lifespan.

Presentation 1: First graders' informal fraction knowledge predicts math achievement two school years later

Alexandria Viegut[1], Ilyse Resnick[2], Christina Barbieri[3], Nora Newcombe[4], & Nancy Jordan[3]

[1]Department of Psychology, University of Wisconsin–Eau Claire; [2]Faculty of Education, University of Canberra; [3]School of Education, University of Delaware; [4]Department of Psychology, Temple University

Young children show some informal knowledge of fraction-related ideas, like equal sharing and the word "half", years before learning about them in school (Begolli et al., 2020). In our previous study with 103 U.S. first graders, children's fall informal fraction knowledge significantly predicted their spring math achievement, controlling for numerical and cognitive skills (Viegut et al., 2023). In the current study, we followed up with these children to test how informal fraction knowledge and errors changed one year later, and to examine if their first grade fraction understanding continued to predict math achievement. We tracked informal fraction knowledge at three time points over two school years (i.e., first grade fall and spring, second grade spring) with a subset of the original sample (n = 80). We also measured numerical and cognitive skills in first grade and standardized math in spring of second grade. Children showed consistent improvement across all time points on all aspects of informal fraction knowledge, even though math instruction focused almost exclusively on whole numbers. Extending our previous findings, regression showed that early fraction knowledge at the start of first grade explained significant variance in math achievement at the end of second grade ($\beta = 0.37$, $p = .006$), controlling for first grade whole number knowledge and several general cognitive skills. We also present error analyses examining change in children's misconceptions about fractions over the first two years of primary school. We discuss implications for strengthening and building on children's early fraction skills to support later understanding.

Presentation 2: Co-development of comparison, ordering, and arithmetic skills in 7- to 8-year-old students

Shuyuan Yu[1], Heather Douglas[1], Rebecca Merkley[1], & Jo-Anne LeFevre[1,2]

[1]Department of Cognitive Science, Carleton University; [2]Department of Psychology, Carleton University

Number comparison and order judgement are both foundational skills for arithmetic development in early elementary years. Previous cross-sectional studies have shown a developmental shift in the contribution of these skills to arithmetic, with order judgement emerging as a stronger predictor over number comparison with development. However, the reciprocal influence of early arithmetic on later magnitude processing has been overlooked. In the current research, we examined the co-developmental pattern longitudinally. Students (N = 9034, Mean age = 7.41 y) completed number comparison (identifying the larger of two numbers), order judgement (assessing whether a triad of numbers is in order), and arithmetic fluency (addition and subtraction) as part of a larger numeracy screening at the beginning of Grade 2 and Grade 3. Multi-group cross-lagged panel models revealed different developmental patterns between not-at-risk versus at-risk math learners (i.e., those within the bottom 25% of the screening score). Among not-at-risk students, ordering processing at Grade 2, but not number comparison, predicted arithmetic one year later. Conversely, among at-risk learners, neither number comparison nor ordering significantly predicted later arithmetic, suggesting challenges in leveraging cardinal and ordinal associations to form arithmetic associations. Importantly, for both groups of students, arithmetic fluency predicted subsequent number comparison and ordering, indicating a bidirectional relationship. Notably, the cross-lagged longitudinal contribution from arithmetic to comparison and ordering was stronger compared to the reversed direction. Our research highlights the interactive nature of early math development and provides insights into interventions focusing on

establishing connections between numerical and arithmetic skills, particularly among at-risk.

Presentation 3: Standard arithmetic and equivalence fluency: A longitudinal investigation of their co-development from grade 4 to grade 5

Lisa Jane Rodgers[1], Chang Xu[1], Sabrina Di Lonardo Burr[2], Judith Wylie[1], Jiwei Si[3], Bijuan Huang[4,5], & Hongxia Li[3]
[1]Queen's University Belfast; [2]The University of Sheffield; [3]Shandong Normal University; [4]Shandong First Medical University; [5]Shandong Academy of Medical Sciences;

Children's understanding of the equal sign, which is fundamental to understanding relations between quantities, develops gradually throughout the elementary school years. In the present study, Chinese children (N = 935, Mage = 9.3 years) completed measures of standard arithmetic and equivalence fluency across four time points (first and second terms of Grades 4 and 5). Additionally, they completed a nonverbal reasoning measure at the beginning of Grade 4. For standard arithmetic equations, the operands always appeared to the left of the equal sign (e.g., 15 + 28 = __, 43 – 29 = __) whereas for equivalence, which was measured using non-standard arithmetic equations, the position of the equal sign varied across equations (e.g., 9 + __ = 14; 6 = 9 - __; 10 + 7 = __ - 2; __ - 35 = 9 + 50). We found that standard arithmetic and equivalence performance co-developed over time, with the correlations between these measures becoming progressively stronger. Cross-lagged panel analysis, controlling for children's non-verbal reasoning skills, further revealed that, up until the first half of Grade 5 (Time 1 to Time 3), the influence of standard arithmetic on the development of equivalence fluency was greater than the reverse. However, by the end of Grade 5 (Time 3 to Time 4), the bidirectional relations between the two measures were equal in strength. This longitudinal research provides insights into the bidirectional development of these fundamental mathematics skills and highlights the need for early introduction of arithmetic equations in various formats.

Presentation 4: Age-related declines in hippocampal volumes explain strong age-related declines in simple math-fact retrieval

Jana Reifegerste[1], Michael Ullman[2], & Ian Lyons[3]
[1]Department of Neurology, Georgetown University; [2]Department of Neuroscience, Georgetown University; [3]Department of Psychology, Georgetown University

Maintaining basic math skills is important for maintaining quality of life in aging. A key math skill is arithmetic fluency—the ability to answer arithmetic problems quickly, reliably, and accurately. Central to arithmetic fluency is the capacity to efficiently retrieve arithmetic associations from memory. Prior work suggests that, despite relying more on retrieval when solving simple arithmetic problems, older adults are less efficient than younger adults. Independent research indicates that the hippocampus, which is important for memory retrieval, declines substantially in aging. We tied these two lines of research together. We propose that hippocampal declines lie at the heart of age-related declines in arithmetic fluency, by undermining arithmetic fact retrieval. In a cross-sectional sample of 92 healthy adults (age range 19-82, mean=48yrs), we found the strongest association between increasing age and longer solution times on problems most likely to be solved via direct retrieval (controlling for solution times on other types of arithmetic problems, sex, education and processing speed). Reduced efficiency on these same problems was linked to declines in hippocampal volumes, controlling for both prefrontal and parietal volumes. Further, hippocampal-volume declines partially explained (mediated) age-related declines in arithmetic fact-retrieval efficiency. Together, these results support the hypothesis that age-related hippocampal declines lead to difficulties with arithmetic fact retrieval in aging. Broadly, our data suggest that math skills that rely most on memory retrieval are most susceptible to age-related declines. Conversely, such age-related declines might be partially offset by interventions that shift older adults' arithmetic strategies away from hippocampal-dependent memory retrieval.

S9C: Pattern learning: Empirical research about interventions, parental beliefs, and links to mathematical competence in children

Chair: Nicholas Vest[1]
[1]Department of Psychology, University of Wisconsin-Madison

Integrative Statement:

Patterning (e.g., square-circle-circle-square-circle-circle) is a fundamental aspect of early mathematics education and lays a solid foundation for later math achievement. Although math is often said to be a language of patterns and regularities, patterning has received far less attention in early math education than domains such as numeracy. How are patterning skills related to other mathematical competencies? Are patterning skills malleable, and if so, can they be trained and improved through intervention? This symposium aims to answer these questions by bringing together studies with different research designs and in different cultural contexts. Specifically, the

symposium will present current research about the efficacy of single-session and multi-session lessons on improving children's performance with various patterning tasks (e.g., extend the pattern, abstract the pattern) in the US as well as consider the bidirectional relation between patterning skills and arithmetic competence in the Chinese children. Last, the symposium will present findings about the role of parents' pedagogical approaches to patterning and whether an intervention can change these approaches. This symposium underscores the importance of patterning skills in early math learning and showcases the promise of potential patterning interventions.

Presentation 1: Modeling the reciprocal relationship between patterning and arithmetic in Chinese preschool children: Between-person and within-person perspectives

Chen Xueliang[1] & Xiao Zhang[1]
[1]Faculty of Education, The University of Hong Kong

Atterning and arithmetic are two critical domains of early mathematics learning and are closely related with each other. This study investigated reciprocal relations between three types of patterns (i.e., repeating, growing, and rotating patterns) and Chinese preschool children's arithmetic skills. A total of 138 Cantonese-speaking children (68 girls; Time 1 M age: 4.98 years; SD = .33) were assessed on patterning and arithmetic tasks three times, spaced six months apart, between ages 5 and 6. Across both between-person (i.e., the cross-lagged panel model) and within-person (i.e., the random-intercept cross-lagged panel model) approaches, repeating and rotating patterns predicted arithmetic skills from ages 5 to 5.5, while arithmetic skills predicted almost all patterning skills from ages 5 to 6, even after strong controls (i.e., receptive vocabulary, working memory, and spatial ability) were considered. These findings suggest potential bidirectional relations between patterning and arithmetic skills and could enrich existing theories of pattern-math associations. Furthermore, this study also revealed that the children performed better on the rotating pattern task than on the growing pattern task, suggesting children's patterning skills as currently conceived may have been underestimated and that there is a need to consider additional patterns such as rotating patterns in preschool.

Presentation 2: Does focusing on the unit of change help children extend and abstract shape and number patterns?

Nicholas Vest[1], Lauren Anthony[1], Kendall Callery[1], Alyssa Shack[1], Christine Becerra[1], Pragati Maheshwary[1], & Martha Alibali[1]
[1]Department of Psychology, University of Wisconsin-Madison

Patterning skills in early childhood are associated with numerical skills, and number knowledge in kindergarten is an important predictor of future academic and career success. In an online study with a pretest-lesson-posttest design, we examined whether a brief lesson focusing on the pattern unit (i.e., the unit of increase or decrease) would help children (Grades K-2, N = 85) learn to extend and abstract growing patterns. The pretest and posttest included both shape items (e.g., ooo ooooo ooooooo oooooooo) and number items (e.g,. 3 5 7 9). Children were asked to identify the next item in the pattern or to choose a similar pattern from a set of four response options, and they were asked to explain their choices. For the lesson, children were randomly assigned to receive either (1) a Pattern Unit lesson with simple visuals, (2) a Pattern Unit plus Perceptual Support lesson with enhanced visuals that highlighted the pattern unit, or (3) a control lesson about mental rotation. Both pattern unit lessons focused on identifying the unit of increase or decrease in growing shape patterns and using that unit to extend the patterns. Children in both lesson conditions showed greater gains in accuracy on shape extension items from pretest to posttest than children in the control condition, and they also showed greater increases in mentioning the pattern unit on those items. However, children did not transfer their learning to number patterns or to pattern abstraction items. Analyses of children's strategy use are ongoing.

Presentation 3: Malleability of various patterning skills in 5- and 6-year-old children

Tongyao Zhang[1] & Emily Fyfe[1]
[1]Department of Psychological and Brain Sciences, Indiana University

Patterning skill is an important precursor of children's math achievement, and previous theories pointed out its domain-general role under multiple learning contexts. To test whether patterning skill is a malleable cognitive ability, we provided 43 children between 5 and 6 years old with a two-day training on various patterning activities (e.g., extending, abstracting, and identifying core units). Before and after the training, children completed pretests and posttests that contained four different types of tasks: missing item (e.g., filling "A" into ABAB_B), extension (continuing ABAB__ with "AB"), abstraction (using CDCDCD to show the same kind of pattern like ABABAB), and memory (making the same pattern after the given

pattern is taken away). Results showed that children's patterning accuracy and response time significantly improved through training, Accuracy $t(42) = 2.94$, $p = .003$, Cohen's $d = .45$; Response Time $t(42) = 5.85$, $p < .001$, Cohen's $d = .89$. Exploratory analyses showed improvements on all types of pattern tasks except the memory items. We conclude that patterning skill is malleable even under brief training in childhood. The current data is part of a larger on-going intervention study where the type of training differs across conditions. Further analyses will focus on whether the type of training impacts learning outcomes of both patterning and numeracy.

Presentation 4: Pedagogical approaches to home math support: The effect of a parent patterning intervention

Camille Msall[1], Faith Logan[1], Brooke Poston[1], Ashli-Ann Douglas[1], & Bethany Rittle-Johnson[1]
[1]Department of Psychology & Human Development, Vanderbilt University

Parents play a crucial role in shaping their children's math development, with parents' beliefs influencing the support they provide (Mutaf-Yildiz et al., 2020). Parents' pedagogical approach encompasses the broad approach for math support they consider most important and the approach they use most often. Previously, parents reported most often incorporating math during daily routines but reported believing direct teaching to be most important (Msall et al., 2023). Interventions have increased parents' engagement in numeracy activities (e.g., Linder. & Emmerson, 2019) and their beliefs about the importance of math (Holtzman et al., 2023), but not the malleability of parents' pedagogical approaches. Furthermore, despite evidence for the importance of early patterning knowledge for later math development (e.g., Rittle-Johnson et al., 2017), these interventions have primarily focused on numeracy. The current study examines the impact of an intervention on pedagogical approaches. Participants were 51 Nashville parents (84% mothers; 65% college-educated) of 4-year-olds (56% girls). The intervention consisted of a 15-minute information session on repeating patterning skills and suggestions for incorporating these skills into daily routines and activities their children enjoy. Parent surveys prior to the intervention showed that parents most often incorporated math in daily routines (51%) and believed this approach to be most important (55%), contrasting with previous findings (Msall et al., 2023; Deflorio & Beliakoff, 2015). There were no significant changes in pedagogical approaches post-intervention, potentially due to the intervention encouraging parents to incorporate math into daily living. We will discuss potential explanations and implications.

S10A: From games to gains: Enhancing early numeracy through play and technology

Chair: Francesco Sella[1]
[1]Loughborough University, UK

Integrative Statement:

This symposium gathers a series of insightful talks that explore innovative interventions bringing unique perspectives and findings on how playful learning and games can effectively improve mathematical understanding and competence among young learners. This includes examining the effectiveness of playful activities in teaching complex concepts like fractions, understanding the role of specific cognitive skills in mathematical development, and leveraging technology to track and enhance learning. The first talk (Guo) investigates the effectiveness of playful math games in teaching fractions to elementary students by comparing simultaneous and sequential equivalent fraction representations. The second talk (Redican) evaluates the effectiveness of fraction training based on concreteness fading to help children connect fraction concepts with fraction symbols. The third talk (Wong) examines the impact of digital game-based interventions targeting number-magnitude mapping, symbolic numerical skills, and place-value understanding on first-graders' mathematical competence. The final talk (Siddiqui) analyses the use of educational app data to understand the influence of symbolic and non-symbolic number comparison on counting and arithmetic skills in children aged 5-7. These talks aim to contribute to a deeper understanding of how playful learning can be strategically used to enhance early numeracy skills, providing valuable insights for educators, researchers, and policymakers in the field of early childhood education.

Presentation 1: Examining the effectiveness of playful math games on adding fractions

Siling Guo[1], Kreshnik Begolli[1], Lourdes M. Acevedo-Farag[1], Jesse Giovanni Sanchez[1], Katherine Rhodes[1], June Ahn[1], Lindsey Richland[1], Andres S. Bustamante[1], & Drew H. Bailey[1]
[1]University of California, Irvine, School of Education

Fractions are difficult for elementary students and hinder learning advanced mathematics. Playful games based on the science of learning can be a promising approach to addressing this challenge. We created two fraction games: Fraction Ball (basketball) and Fraction Bottle Caps (tabletop shuffleboard). Our first aim was to

examine the effectiveness of combining the two games. Our second aim was to test game design features to optimize fraction learning. We drew from the literature on comparing and contrasting representations and examined two game versions. In one condition students were shown equivalent fraction representations simultaneously (e.g., fourths next to eighths), and in the other condition the representations were shown sequentially (e.g., first fourths, then eighths). We compared the simultaneous (n = 87) versus sequential (n = 79) game conditions within seven treatment classrooms. Students were randomized within classrooms to either condition across four math periods. Three comparison classrooms (n = 75) only took the pretest and posttest. Our pre-registered analyses showed significant impacts when comparing the treatment groups (both conditions combined) to the control group (b = .15, p < .01), but not when comparing the treatment groups to each other (b = .02, p = .66). We found a marginal effect for untimed fraction addition with unequal denominators (b = .21, p = .05), favoring the simultaneous condition. Finally, students with higher pretest performance benefited more from the simultaneous condition and vice versa (HigherPretest X Simultaneous b = .27, p = .002). Our work presents an effective fraction learning intervention.

Presentation 2: Effects of playful learning activities on first graders' early fraction knowledge

Eva Redican[1], Dominique Lopiccolo[1], Alexandria A. Viegut[2], Ilyse Resnick[3], Nora S. Newcombe[4], & Nancy C. Jordan[1]
[1]School of Education, University of Delaware, US; [2]Department of Psychology, University of Wisconsin-Eau Claire, USA; [3]Department of Education, University of Canberra, AUS; [4]Department of Psychology and Neuroscience, Temple University, USA

Children's informal fraction knowledge develops before formal instruction and predicts later fraction and general number knowledge (Viegut et al., 2023). However, there are substantial individual differences at first-grade entry. Our goal was to test the effectiveness of training activities in building understanding of key fraction concepts. The training uses concreteness fading to help children connect fraction concepts (e.g., when there are more shares, they are smaller) with fraction symbols in a playful, digital environment. In a pretest-training-posttest design, first-graders are randomly assigned to a fraction training or reading control group. Both groups are completing five 15-minute activity sessions 1-on-1 with an experimenter. Pretests and posttests measure early fraction skills (Viegut et al., 2023), whole number knowledge, vocabulary, and proportional reasoning (Möhring et al., 2016). We hypothesize that the experimental group will outperform the control group on early fraction and numeracy skills. ANCOVA is being used to compare conditions on fraction skills and whole number knowledge, controlling for pretest. Accounting for 5% attrition, 86 children per group yields 80% power to detect a meaningful effect size (g = .25). The study analyses will be completed by the conference. If the experimental group shows significant gains compared to the control group, this suggests young children may be prepared to learn foundational fraction concepts, which will help pave the way to later success with formal instruction. Follow-up analyses will explore comprehension check performance to examine learning during the activities. We also explore whether different cognitive skills (e.g., proportional reasoning) moderate training effectiveness.

Presentation 3: Examining the effects of game-based domain-specific cognitive skills training on children's mathematical competence

Terry Wong[1]
[1]Department of Psychology, University of Hong Kong

Although various math-specific cognitive skills, such as number-magnitude mapping, symbolic numerical skills, and place-value understanding, have been found to have robust relations with children's mathematical competence, not many intervention studies have been done to test these potential causal relations. Given the successful attempts to improve children's mathematical competence through digital gamified interventions, the current study aims to examine whether digital gamified interventions targeting the aforementioned math-specific cognitive skills can improve children's mathematical competence through a randomized controlled trial. A total of 240 first graders (around 6 years of age) have been recruited and randomly assigned to one of the five conditions: (1) number-magnitude mapping, (2) symbolic numerical skills, (3) place-value understanding, (4) visuospatial working memory, and (5) literacy skills. The latter two conditions serve as control conditions. Children in which of these conditions will play two digital educational games that target the relevant construct for a total of 160 minutes. Before and after the interventions, children will be tested on their mathematics achievement and the relevant cognitive factors to examine the effectiveness of the interventions. Data from approximately half of the participants will be ready before the conference. ANCOVAs will be conducted to examine the potential group differences in post-test performance after controlling for the relevant pre-test performance. The findings will not only inform researchers about the

potential causal relations between the targeted math-specific cognitive skills on children's overall mathematical competence but also provide educators with a cost-effective means to improve children's mathematical competence.

Presentation 4: The use of log data from an educational maths app to understand developmental pathways of counting and arithmetic for children aged 5-7 years old

Zahra Siddiqui[1], Laura Outhwaite[2], & Jo Van Herwegen[1,2]
[1]Department of Psychology and Human Development, IOE - UCL's Faculty of Education and Society, UK; [2]Centre for Education Policy and Equalising Opportunities, IOE - UCL's Faculty of Education and Society, UK

Symbolic number comparison and non-symbolic dot comparison abilities are highlighted as key predictors of future mathematical development. Previous research often employs association or correlational studies to investigate how predictive these abilities are for more complex outcomes, such as counting and arithmetic abilities. The present study explores how response to training of both magnitude comparison tasks predicts counting and arithmetic outcomes in children aged 5-7. It also showcases the use of educational apps to collect intervention training data at multiple timepoints across various abilities in a broad sample of children. This pre-registered study analyzed back-end log data from the educational math app Funexpected. 274 children aged 5-years-old and 270 children aged 7-years-old were participants in the study. Multiple linear regression was conducted with counting as the outcome measure, and again with arithmetic as the outcome measure. Preliminary analysis for the counting outcome with the 5-year-old sample suggests that symbolic comparison average score is a significant predictor for the counting outcome measure; $F(5,264) = 2.221$, $p = 0.0374$, $R2 = 0.008$). Similar results were also found for the 7-year-old children counting model. For the arithmetic outcome measure, neither the symbolic nor non-symbolic predictors were significant. However, the counting outcome measure was a significant predictor of the arithmetic outcome measure; $F(6,300) = 10.4$, $p < .001$, $R2 = 0.155$). Again, similar results were also found for the 7-year-old children arithmetic model. The discussion will consider how characteristics of maths apps can support the development of counting and arithmetic.

S10B: What do we Know About Children's Knowledge of Base-Ten Numeration?

Chair: Helena P. Osana[1] & Kelly S. Mix[2]
[1]Concordia University; [2]University of Maryland

Integrative Statement:

Base-ten numeration is at the core of school mathematics. Research on children's numeration is central to understanding mathematical development and has important implications for the teaching and learning of the big ideas that span the K-12 mathematics curriculum. In a pioneering article, Fuson (1990) described the conceptual structures that are required for a relational and inter-connected understanding of the base-ten numeration system. Fuson's model has been used to delineate what children need to learn about the base-ten system, inform the design of instructional approaches, and guide researchers' assessments of children's base-ten knowledge. Since the appearance of the conceptual structures model, research has advanced what is known about children's numeration and how it develops. Various individual components of children's knowledge have been investigated, such as approximate and syntactic place value, transcoding (i.e., the reading and writing of numbers), number magnitude, and multi-unit coordination. This symposium will bring together researchers who have studied different aspects of children's knowledge of base-ten concepts. The goal of the symposium will be to examine theoretical connections between the researchers' approaches to studying children's base-ten numeration in an effort to evaluate progress in the field since the introduction of Fuson's model. The symposium will generate recommendations for future research in the development of children's base-ten understanding and approaches for evaluating their numeration knowledge in research and educational contexts.

Presentation 1: Beyond task accuracy: How kindergartners' "smart" errors in place value tasks predict later multidigit calculation performance

Corinne A. Bower[1], Kelly S. Mix[2], Lei Yuan[3], Gregory R. Hancock[2], & Linda B. Smith[4]
[1]California State University, Los Angeles; [2]University of Maryland; [3]University of Colorado, Boulder; [4]Indiana University

Place value (PV) notation (e.g., "24" stands for [2 x 10] + [4 x 1]), plays a crucial role in children's mathematical understanding and early PV comprehension predicts later multidigit calculation skills. This study delves into longitudinal and causal associations by examining both accuracy and evidence of structural understanding in children's place value learning. Here, we focus on two "smart errors" in children's place value learning: (1) unconventional unit-boundary shifts in Base-Ten Counting, labeled as 'inventing counting errors', and (2) expanded errors on Transcoding. Unconventional shifts

during Base-Ten Counting indicate a partial understanding of base-ten structure, while Transcoding errors involve adding zeroes for better alignment between written and spoken versions of multidigit number names. Kindergartners who produce either or both of these smart errors may be at a transitional stage of place value understanding, and thus may be better prepared to learn multidigit calculation and score higher on multidigit calculation assessed in second grade than their peers who are equally incorrect, but produce random errors rather than smart errors.Kindergartners (N=279) completed two PV tasks, and smart errors were recorded. Two years later in second grade, the Comprehensive Math Assessment Tool (CMAT) measured multidigit calculation skills. Results suggest that kindergartners who made invented counting errors alone showed stronger multidigit calculation skills in second grade compared to those who made neither error, p =. 007. Thus, these smart errors reflect partial structural knowledge of place value that is a potentially important developmental contributor to learning multidigit number meanings.

Presentation 2: Can children and adults coordinate units in base ten?

Mélanie Barilaro[1], Helena P. Osana[1], & Anne Lafay[2]
[1]Concordia University; [2]Université Savoie Mont Blanc

The ways in which units are related in a multidigit number is a central feature of the base-ten system. Specifically, a multidigit number consists of various levels of units that are characterized by powers of 10 (e.g., 100, 101, 102). Higher-level units are composites of lower-level units (e.g., there are 10 tens in 100), and lower-level units can be disembedded from higher-level ones. Knowledge of units coordination in base ten supports place-value understanding and flexible strategy use in arithmetic. We investigated the types of errors produced by first graders (n = 138) and undergraduates (n = 96) when coordinating levels of units in three-digit quantities represented visually. Participants either indicated the number of hundreds in the quantity, which required composing tens, or the number of tens, which required decomposing hundreds. Results showed that both children and adults were able to work with tens as composite units when interpreting visual displays of base-ten quantities. Nevertheless, children produced a larger proportion of unit errors than adults, meaning that they did not fully coordinate across all units. Despite adults' relatively stronger units coordination, over a third still struggled to coordinate units in base ten. The finding that young children are capable of unitizing collections of objects aligns with previous research and provides a solid foundation upon which to build their conceptual structures in the classroom. That more than a minority of adults struggle to understand the multiunit structure of base-ten numeration underscores the importance of explicitly targeting units coordination in elementary mathematics instruction.

Presentation 3: Exploring the spatial pathway to early place-value understanding

Winnie Wai Lan Chan[1] & Terry Tin-yau Wong[2]
[1]Education University of Hong Kong; [2]University of Hong Kong

Understanding the representational system of multi-digit numbers, or the place-value concept, is important for later mathematical development. Although formal instruction on the place-value concept typically starts in Grade 1, kindergarteners have already started to make sense of multi-digit numbers in daily life. Understanding the early building blocks of the place-value concept would help educators find ways to support children's mathematical development. This study particularly focused on exploring how early spatial skills could be related to the place-value understanding. Sixty-nine children in Hong Kong were assessed for their spatial working memory, count-on skills, nonverbal reasoning, and number line estimation when they were in the final year of kindergarten (Time 1) and were assessed again for their place-value understanding in Grade 1 (Time 2). Results showed that, after controlling for nonverbal reasoning, there was a significant mediation pathway from spatial working memory, through count-on skills and then number line estimation (all measured at Time 1), finally to place-value understanding at Time 2. This suggests that early spatial skills lay the foundation for place-value understanding through supporting count-on skills and the spatial representation of magnitude on a number line. Such findings help us better understand the role of spatial skills in place-value understanding. They also provide useful implications for nurturing children's foundational skills for later mathematical learning.

Discussion led by

Karen C. Fuson[1]
[1]Northwestern University

S10C: Diverse methodologies to explore parental involvement in children's math learning

Chair: Rebecca McGregor[2] & Yuchen Song[1]
[1]University of Georgia; [2]University of Pittsburgh

Integrative Statement:

Parents play a key role in nurturing children's math development across preschool and elementary school. As such, different types of parental involvement may encourage or discourage math learning, such as using praise and criticism during math conversations, helping with math homework, and talking about math during everyday routines. Examining these diverse types of parental involvement contributes to our understanding of the real-life interactions that parents and children have about math. To this end, the symposium explores parental involvement in children's math learning from cognitive, socio-motivational, and emotional perspectives through the use of diverse methodologies including focus groups, surveys, and naturalistic observations. The first paper examines patterns in parents' constructive and unconstructive behaviors during an informal math activity using latent profile analysis. The second paper investigates the mediating effect of parenting self-efficacy on the reciprocal association between math anxiety and parents' affect during homework help. The third paper investigates the role of routines in family math engagement through focus groups with families about their typical routines and observations of families engaging in a daily routine. The fourth paper examines the impact of an intervention promoting math talk during family routines on trajectories of parent-child math talk across four timepoints. Together, these four papers emphasize the ways in which parents' math-related beliefs, emotions, and behaviors contribute to children's math learning and illustrate the need to use diverse methodological approaches to explore parental involvement in parent-child math interactions.

Presentation 1: A latent profiles analysis of parental practices during informal math activity

Yuchen Song[1], Michael Barger[1], & Eva Pomerantz[2]
[1]University of Georgia; [2]University of Illinois - Urbana Champaign

Prior research relying on variable-centered approaches has documented that parents' praise, autonomy-support, value communication, and positive affect contribute to children's math adjustment (e.g., Li et al., 2023), whereas criticism, control, and negative affect undermine children's success in math (e.g., Silinskas & Kikas, 2019). Synthesizing parenting behaviors that have been examined separately in variable-centered research, the present observational study sought to reveal combinations of parental practices during dyadic math interaction using a person-centered approach. Latent profile analysis yielded three distinct profiles that described 305 parents of children 7 to 8 years old: Moderately supportive parents (81%), demotivating parents (14%), and motivating parents (5%). Compared to moderately supportive parents, motivating parents used substantially more praise and value communication. Demotivating parents, compared to moderately supportive and motivating parents, used significantly more criticism and parental control, coupled with significantly less praise and autonomy-support. For affect, moderately supportive and motivating parents showed slightly elevated levels of positive affect accompanied by minimal negative affect, whereas demotivating parents displayed slightly elevated affect on both positive and negative scales. It must be noted, however, that even parents classified as "motivating" displayed parental control in almost one third of our observational segments. This implied that parental control, although deemed unconstructive, may be necessary for parents of young children to provide sufficient guidance. Instead of less frequent parental control, what distinguished motivating parents from the majority is the amount of praise and value communication they engaged in, which may counterbalance the detrimental effects of controlling behavior on children's math learning.

Presentation 2: Parents' math anxiety and affect: The mediating role of efficacy in helping

Carolyn MacDonald[1], Jiawen Wu[1], & Eva Pomerantz[1]
[1]University of Illinois - Urbana Champaign

Parents' math anxiety appears to undermine children's math achievement via their parenting (e.g., Oh et al., 2022). For example, the more parents are math anxious, the more negative affect they report in helping children with math homework (e.g., DiStefano et al., 2020), which is predictive of poorer math achievement (e.g., Wu et al., 2022). We examined why this might be the case in a 3-wave longitudinal study of American parents (N = 615; 80% mothers, 53% white) of young elementary school children (Mage = 7.17 years; 50% girls) who reported on their math anxiety, affect when assisting with math homework, and efficacy in helping with math homework. A subset (n = 353) also reported on these constructs daily for 12 days. Cross-lag panel model analyses revealed that heightened math anxiety among parents predicted more negative and less positive affect while assisting with math homework 18 months later, adjusting for parents' earlier affect, βs = .23 and −.19, ps < .001. These pathways were mediated by parents' efficacy in helping, βs = .08 and −.11, ps < .001, such that the more math anxious parents were, the less self-efficacious they were over time, βs = −.40 and −.38, ps < .001, which in turn predicted more

negative and less positive affect during homework over time. Analyses of parents' daily reports replicated this pattern. These findings highlight the importance of parents' efficacy beliefs in the transmission of math anxiety to parents' positive and negative affect when assisting with math homework.

Presentation 3: Caregiver-child math engagement during family activities and routines

Mary DePascale[1], Yilin Liu[1], & Eric Dearing[1]
[1]Boston College

Much of young children's math learning occurs at home (Eason et al., 2022). While societal inequities create obstacles to supporting early math for many, researchers increasingly reject the notion that family deficits are to blame. Instead, attention is being given to family assets and strengths that can be leveraged to promote math learning in the face of disadvantage (Bustamante & Hindman, 2020). Family routines may be a case in point, serving both practical and cultural purposes while being rich with math learning chances. We conducted two studies to examine opportunities for math engagement and learning in the routines of lower-income Arabic-, English-, and Spanish-speaking families of young children (age 3-5 years). In study 1, we conducted five semi-structured focus group interviews with caregivers (n = 29). Questions addressed typical family routines and the goals of and perceived influences on these routines. Preliminary thematic analyses highlight a range of routines that (a) provide opportunities for math learning (e.g., bath time, bedtime, outdoor walks) and (b) caregivers' beliefs that these activities support learning goals and other priorities (e.g., becoming independent, treating others well). In study 2, families (data collection ongoing for n = 50) audio recorded a daily routine with their child and completed surveys of their beliefs about math. Transcripts of family routine recordings will be coded for use of math talk and talk related to caregivers' other learning goals. Findings will be used to help guide the design of interventions that leverage family routines for young children's math learning.

Presentation 4: Longitudinal growth in parents' and children's math talk from a family math intervention

Rebecca McGregor[1], Diana Leyva[1], & Melissa Libertus[1]
[1]University of Pittsburgh

Parent-child conversations about math are critical for preschool children's math development. Thus, many family interventions have focused on improving these conversations. Yet, few studies have examined intervention effects on parent-child math talk longitudinally beyond more than two timepoints, which allow researchers to examine patterns of change over time rather than identifying differences in amount of math talk. The current study examined trajectories of parent-child math talk across four timepoints in a pilot study of Math Made 4 Me (MM4M), an intervention promoting math talk during families' routines. Participants were 76 mostly White, middle-income parents and their four-year-old children (M age = 53.32 months; 45% girls) in the U.S. Dyads were randomized into MM4M or a business-as-usual control condition. At four timepoints about two weeks apart across the intervention period, dyads were videotaped completing picture-sharing and free-play tasks and their utterances were transcribed and coded for math content. Results indicated significantly greater rates of change in math talk for parents ($B = 7.20$, $SE = 1.35$, $t = 5.32$, $p < .001$) and children ($B = 4.29$, $SE = 1.04$, $t = 4.14$, $p < .001$) in the MM4M condition compared to the control condition. These results show that dyads in the MM4M condition had faster growth in parent-child math talk compared to those in the control condition. Future research examining math talk at multiple timepoints is needed to better model patterns of change in parent-child math talk.

S11A: Innovations in the science of mathematics instruction: Three randomized controlled trials with struggling learners

Chair: Lynn Fuchs[1]
[1]Vanderbilt University and American Institutes for Research

Integrative Statement:

Despite impressive strides over the past 20 years, state-of-art intervention science for treating mathematics difficulty fails to meet the needs of 25%-45% of affected children. For this reason, a pressing need exists to expand the framework for mathematics intervention science with innovative approaches. This session includes three randomized controlled trials (RCTs) designed to move mathematics intervention science forward by testing three innovations: (a) intervention designed to facilitate cross-domain transfer among second-grade children with comorbid difficulty across word-problem solving and reading comprehension; (b) intervention designed to support success with multi-step word problems while promoting pre-algebraic understanding via single and multi-step equations among fourth-grade children with mathematics difficulty; and (c) dual-focus (math + reading) intervention designed to improve calculations and word-reading outcomes in coordinated fashion (while keeping intervention time constant across dual-focus

coordinated intervention, math-only intervention, and reading-only intervention) among first-grade children with comorbid calculations and word-reading learning difficulty. Each speaker will present the motivation for the RCT, its design, findings to date, and contribution toward moving math intervention science forward. The discussant will comment on each study and discuss connections among the studies and links to other ideas for expanding the framework for mathematics intervention science. The objectives of the symposium are to provide participants up-to-date information on innovative advances and generate discussion about future directions.

Presentation 1: Intervention to promote transfer between word-problem solving and reading comprehension

Lynn Fuchs[1]
[1]Vanderbilt University and American Institutes for Research

Prior studies conducted with students who experience comorbid reading and math difficulty focus on effects of intervention in one or the other domain without regard for students' co-occurring reading and math needs. This is a troubling omission from the intervention literature because challenging schedules and costs of supplemental intervention decrease the chances of schools providing more than one intervention per student. Reading intervention usually takes priority over math intervention, leaving many of these students underserved. This RCT's intervention conditions were designed to improve math word-problem solving (WPS) or reading comprehension (RC) in ways that support transfer to the other domain, such that intervention in one domain improves outcomes in both domains. The linking focus between domains was text structure: parallels between change word problems and cause-effect reading passages and parallels between compare word problems and compare-contrast reading passages. 207 second graders with comorbid WPS and RC difficulty were randomly assigned to innovative WPS intervention; innovative RC intervention; or the control group (the school's standard program with school intervention). Multilevel analyses indicated that WPS intervention produced significant effects favoring WPS intervention over control on WPS outcomes, while RC intervention produced significant effects favoring RC intervention over control on RC outcomes. Of greater interest, with explicit but limited instruction to support transfer to the other domain, reciprocal effects occurred in which WPS intervention students outperformed control on RC outcomes while RC intervention students outperformed control on WPS outcomes. Effects were mediated by children's text-structure knowledge in passages with and without numbers.

Presentation 2: Two approaches to students' multi-step word-problem solving

Sarah Powell[1]
[1]University of Texas at Austin

In the late elementary grades, students are asked to solve single-and multi-step mathematics word problems. However, many students are inadequately prepared to set up and solve these word problems, particularly problems with multiple steps. This RCT focused on testing the efficacy of two approaches to multi-step problem solving. In the first approach, students learned to use an equation for each step of the word problem, resulting in two equations for two-step problems or three equations for three-step problems. In the second approach, students learned to use a single equation representing the entire multi-step word problem. In this RCT, 259 Grade 4 students (ages 9-10) who experienced difficulty with word-problem solving (i.e., <25th percentile on a word-problem screener) were randomly assigned to (1) participate in word-problem intervention with the first approach, (2) participate in word-problem intervention with the second approach, or (3) control (i.e., no word-problem intervention with the research team). The word-problem intervention included 36 individual lessons implemented 3 times a week for 30 min each session. In this session, we report the findings from the first two years of data collection in which students in both word-problem intervention conditions outperformed students in the control group on measures of word-problem solving. We will also shed light in whether one approach to multi-step word-problem solving is more advantageous than the other.

Presentation 3: Coordinated dual-focus intervention to address the needs of first-grade children with comorbid calculations and word-reading difficulty

Douglas Fuchs[1]
[1]Vanderbilt University

This RCT addresses a subset of the learning disabilities population with a distinctive set of needs: children with comorbid difficulty across calculations and word reading. This subgroup experiences weaker outcomes in both domains and poorer response to mathematics and reading intervention than do children with difficulty in just one of these domains. Guided by a framework that identifies opportunities for strengthening early

calculations and word reading in coordinated fashion, this RCT is designed to extend understanding about connections between early mathematics and reading, test coordinated treatment's effects, and investigate mechanisms by which effects of coordinated treatment occur. Comorbid first-grade children are randomly assigned to four conditions: a control group, coordinated treatment across math and reading, math-only treatment, and reading-only treatment. Coordinated treatment's effects on math and reading are tested against the control group. Non-inferiority testing is conducted to evaluate comparability on math outcomes between coordinated treatment and math-only treatment and evaluate comparability on reading outcomes between coordinated treatment and reading-only treatment. In this session, we report findings to date on coordinated treatment's math and reading effects and results of analyses assessing whether improved calculations skill mediates coordinated treatment's effects on word-reading outcomes and whether improved word-reading skill mediates coordinated treatment's effects on calculations outcomes.

Discussion led by

Tuire Koponen[1]
[1]University of Jyväskylä

S11B: What is going on with number ordering? The role of eye-movements, emotions, and familiarity in ordinality and the reverse distance effect

Chair: James Vellan[1]
[1]Department of Psychology, Carleton University, Canada

Integrative Statement:

Over the past several decades, research has shown the important role of numerical ordering skills in mathematical cognition. Recent research has highlighted the potential role that sequence familiarity plays in number ordering. In particular, familiarity for adjacent ordered sequences (e.g., 1-2-3) has been argued as the source of the reverse distance effect (RDE). However, the complete role of familiarity is unclear, and more research is needed to understand the processes involved in and the factors that may influence number ordering. This symposium addresses this need by bringing together cutting edge research on ordinal number processing, including the use of behavioral and eye-tracking methods, as well as emotion priming. Each talk aims to unpack the ordinality judgment task performance and the resultant RDE from different angles. The first presentation will discuss relations between eye movements and self-reported strategy use in ordinality judgment. The second presentation will discuss findings related to the effects of emotional priming on order judgment performance. The third presentation will discuss differences in an observed familiarity effect and RDE at both the individual and group level. Finally, the fourth presentation will discuss alternative cognitive mechanisms which may explain the RDE in a broader range of contexts. Overall, each talk in this symposium will examine the different aspects of ordinality with the goal of developing a clearer picture of the processes involved in judging the order of symbolic numbers. So what is going on with number ordering? Let's find out.

Presentation 1: Strategy use in order judgment: evidence from eye-tracking

James Vellan[1], Seyeon Kim[1], Liza Kihwaji[2], Alexander Kirby[1], Jules Lavoie[2], & Jo-Anne LeFevre[1,2]
[1]Department of Psychology, Carleton University, Canada; [2]Department of Cognitive Science, Carleton University, Canada

When people decide if sequences of numbers are in order, they respond faster to ordered counting sequences with differences of 1 (e.g., 1-2-3) than to sequences with larger inter-element distances, regardless of whether these other sequences are ordered or unordered (e.g., 2-4-6 or 3-1-2). This effect has been labelled the reverse distance effect (RDE). In studies where people were asked to describe their strategies in the order judgment task, they reported more use of memory retrieval when judging sequences with differences of 1 versus more use of other strategies (particularly decomposition) when judging sequences with greater distances. We hypothesized that self-reported strategy use will be reflected in patterns of eye movements during order judgment. Adults (N = 60) completed an order judgment task and at the end of each trial were asked to report the strategy they used to make the judgment. Their eye movements were tracked from stimulus onset until response. We manipulated mean inter-element distance and order violation locations to examine their effects on fixation times, scan paths, and the number of fixations during judgments. We used mean response times to calculate participants' RDEs. In addition to the expected RDE, participants most frequently reported using decomposition to judge sequence order. We also compared scan paths for trials where different judgment strategies were used. We discuss the implications of these differences in eye movements for order judgment generally and compare our findings to other numerical cognition tasks where eye tracking was used.

Presentation 2: Influences of the emotions on the symbolic number ordering judgment

Natalia Dubinkina[1] & Patrick Lemaire[2]
[1]Centre for Mathematical Cognition, Loughborough University, United Kingdom; [2]Aix-Marseille University, Faculty of Arts, Letters, Languages and Human Sciences

To decipher key mechanisms underlying number ordering judgment performance, several experimental manipulations have been undertaken and shown a few factors that modulate participants' performance. Here, we tested the role of emotions, as previous studies showed that emotions influence several numerical judgment task performance, including tasks that participants accomplish fairly automatically. Although effects of math anxiety on symbolic number order judgment performance (Dubinkina et al, 2023) suggest that emotions influence number order judgments, no studies examined this influence directly. Using an affective priming paradigm, we asked participants to determine whether ordered and non-ordered triplets varying in between-element distances are presented in order or not. Data showed poorer performance under negative emotion, especially when order number judgments were the hardest (e.g., non-ordered trials). Also, interestingly, emotions modulated magnitudes and directions of distance effects usually found in ascending and non-ordered trials (i.e., faster performance on smaller-distance relative to larger-distance trials; e.g., 3-4-5 vs; 3-6-9). In addition to how emotions influence number ordering judgment and possibly other numerical judgment tasks, the present findings speak to mechanisms underlying robust (e.g., distance, order) effects when people are asked to judge whether series of numbers are in order or not.

Presentation 3: The role of familiarity in number order processing

Declan Devlin[1], Korbinian Moeller[1,2], Iro Xenidou-Dervou[1,2], Bert Reynvoet[3,4], & Francesco Sella[1,2]
[1]Centre for Mathematical Cognition, Department of Mathematics Education, Loughborough University, UK; [2]Centre for Early Mathematics Learning, Department of Mathematics Education, Loughborough University, UK; [3]Brain & Cognition, KU Leuven, Leuven, Belgium; [4]Faculty of Psychology and Educational Sciences, KU Leuven, Kortrijk, Belgium

In order processing, consecutive sequences (e.g., 1-2-3) are generally processed faster than non-consecutive sequences (e.g., 1-3-5) (also referred to as the reverse distance effect; RDE). A common explanation for the RDE is that order processing operates via a memory-based associative mechanism whereby consecutive sequences are processed faster because they are more familiar and thus more easily retrieved from memory. However, the RDE is often absent. A possible explanation for these absences is that familiarity may vary both within and across sequence types; therefore, not all consecutive sequences are necessarily more familiar than all non-consecutive sequences. Accordingly, under this familiarity perspective, familiar sequences should always be processed faster than unfamiliar sequences, but consecutive sequences may not always be processed faster than non-consecutive sequences. To test this hypothesis, we used a comparative judgement approach to measure familiarity at the individual sequence level. Using this measure, we found that although not all participants showed a reverse distance effect, all participants displayed a familiarity effect. Notably, this familiarity effect appeared stronger than the reverse distance effect at both the group and individual level; thus, suggesting the reverse distance effect may actually be a specific instance of a more general familiarity effect.

Presentation 4: When it comes to explaining the reverse distance effect, we're going to need a bigger boat

Ian M. Lyons[1] & Michael Slipenkyj[1]
[1]Department of Psychology, Georgetown University, United States of America

There is growing debate over the source of the reverse distance effect (RDE) when judging ordinal sequences. This debate is not dissimilar to that over the mechanisms underlying the canonical distance effect (CDE) that arises when comparing two numerosities. Recent evidence indicates that the CDE is underlain by different mechanisms in different contexts. Here, we suggest that multiple mechanisms may contribute to the RDE as well. In contrast, recent work has asserted that the RDE is primarily – or even exclusively – the product of direct memory retrieval. We review multiple sources of evidence that challenge this assertion: (1) The RDE is more robust for numerical sequences that are unlikely to be retrieved, (2) the RDE obtains in non-numerical contexts where retrieval is an unlikely strategy, (3) the magnitude of the RDE is relatively constant across elementary school grades. We conclude by suggesting that, while retrieval contributes to the RDE in some contexts, alternative mechanisms are needed to explain the RDE across the broader range of contexts in which it is observed. Further, we suggest that the notion of 'retrieval' in the current debate has been under-defined, and a more precise definition can lead to clearer hypotheses about the contributions of specific memory mechanisms to ordinal processing. In sum, when it comes to explaining the RDE, considering a broader range of contexts and mechanisms is likely to be both necessary and fruitful – in other words, we're going to need a bigger boat.

S11C: Why does storybook reading matter?: Influences of storybook reading on STEM disciplines

Chair: Eylül Turan[1]
[1]KU Leuven

Integrative Statement:
There is abundant research showing that storybook reading has positive impacts on young children's language development (Noble et al., 2019). A recent line of research has indicated that the benefits of storybook reading further extend to different areas of STEM disciplines. For this symposium, we will be presenting three studies that investigated the use of storybook reading in different disciplines (i.e., science, math, literacy). These studies differ in terms of the characteristics of the books provided to the children, and the context in which the effectiveness of the books have been assessed. The first study examines storybook reading in a science context, and asks whether certain elements of storybooks (i.e., language type and character diversity) are critical to increase children's science interest. The second study investigates storybook reading in a math context, and explores whether specific mathematical language in storybooks promotes numeracy skills in a linguistically diverse sample. Finally, the third study employs storybook reading to promote literacy and numeracy skills, and specifically focuses on children from lower socioeconomic backgrounds. At the end of the presentation, our discussant will evaluate important components of shared book reading sessions and will highlight future directions of this research.

Presentation 1: The impact of visual and linguistic cues in a STEM storybook on children's STEM Interest

Sona C. Kumar[1] & Kathleen H. Corriveau[2]
[1]Purdue University; [2]Boston University

Prior work suggests storybook reading as one way to increase children's STEM engagement (e.g., Leech et al., 2020). Additionally, action-based language (e.g., "Let's do science) has been shown to increase young children's science interest compared to identity-based language (e.g., "Let's be scientists"; Lei et al., 2019). After reading a STEM storybook varying by language type and character diversity, experimenters invited children to rate science interest. In Study 1 (N = 95, Mage = 77 months, SDage = 10 months, 51 female) storybooks featured White, boy characters; half used action-based language, half used identity-based language. Study 2 (N = 94, Mage = 77 months, SDage = 10 months, 51 female) was identical to Study 1, but storybooks featured primarily girls and characters of color. Children in the action-based language conditions expressed greater science interest than children in the identity-based language conditions ($\beta S1 = -1.52$, SE = 0.44, $p < 0.001$; $\beta S2 = -1.03$, SE = 0.40, $p = 0.01$). Study 3 (N = 40, Mage = 77 months, SD = 12 months, 25 female) investigated the effect of storybook reading compared to no input on interest. Results indicated an interaction between storybook (none or diverse characters) and language such that in the identity-based condition, but not the action-based condition, children who read the storybook expressed greater science interest than children who did not (Fintx (1, 130) = 7.36, $p < 0.001$). Findings suggest storybooks as a tool for adults to increase children's science interest, especially when discussing science as an identity.

Presentation 2: Causal associations between mathematical language and mathematical abilities in dual-language-learners

Eylül Turan[1], Suzanne Splinter[1], Bert De Smedt[1], & Joke Torbeyns[1]
[1]KU Leuven

Children's understanding of mathematical language is causally associated with their numeracy skills (Purpura et al., 2021). The existing intervention studies on mathematical language have mainly focused on single language learners (SLLs), neglecting the diverse educational reality of dual language learners (DLLs). To address this research gap, 163 preschoolers (M = 4 years 6 months) who differed in their language backgrounds were randomly assigned to a mathematical language intervention group or a business-as-usual group. Each group included an equal amount of SLLs, DLLs who spoke Dutch at home frequently, DLLs who spoke Dutch at home less frequently, and DLLs who did not speak any Dutch at home. Over the course of three weeks, preschool teachers implemented a dialogic reading intervention focused on quantitative mathematical language (i.e., words such as more, less, few), and at posttest children were assessed on their quantitative language and numeracy skills. Results revealed that after controlling for demographic variables (i.e., age, sex, socioeconomic status) and children's pretest general language and quantitative language, children in the intervention group significantly outperformed the children in the comparison group on quantitative mathematical language. Yet, children's language status was not related to the effectiveness of the intervention. The intervention did not result in any positive effects in children's numeracy skills. The current results suggest that quantitative mathematical language can have positive

impacts on DLLs' language skills, yet more research is needed to understand how mathematical language interventions can be effective for both SLLs' and DLLs' numeracy skills.

Presentation 3: Leveraging shared book reading in the community to examine the connection between literacy and numeracy

Michelle L. Luna[1], Alina R. Boada[1], Beverly Stankiewicz[1], Alcides Argueta[1], Jill M. Pentimonti[1], & Nicole M. McNeil[1]
[1]University of Notre Dame

Print awareness and numeracy are important kindergarten readiness skills (Duncan et al., 2007). Although these domains are distinct, they both function as systems of abstraction and symbolic representation, where individual elements (letters, objects) form larger entities (words, sets). Notably, children from lower socioeconomic backgrounds often demonstrate lower levels of performance in these areas due to educational opportunity gaps. To address this issue, we partnered with preschools serving children from lower socioeconomic backgrounds to provide 1:1 structured shared book reading sessions that promote print awareness and numeracy through evidence-based practices. Following participation in 17 sessions on average, our initial cohort of 35 preschoolers exhibited growth in these skills beyond the program's typical growth. Children who demonstrated any print awareness had higher numeracy than those who did not demonstrate print awareness, $t(33)=2.45$, $p=.02$. Interestingly, children's baseline level of print awareness did not predict growth in either domain, whereas growth in print awareness uniquely predicted growth in numeracy. In contrast, baseline numeracy levels uniquely predicted growth in both numeracy and print awareness. We are currently investigating these patterns in a cohort of 97 4-5-year-olds in Head Start, including 59 children participating in a 24-week structured shared book reading program. Baseline data show a similar correlation between print awareness and numeracy. Midtests and posttests are being collected this semester. This research is poised to contribute to our theoretical understanding of the link between print awareness and numeracy, while also providing practical benefits for our community partners who seek to prepare preschoolers for kindergarten.

Discussion led by

María Inés Susperreguy[1]
[1]Pontificia Universidad Católica de Chile

WITHDRAWN SUBMISSIONS

The following submissions were submitted and accepted as a part of the peer-review process but were unable to be presented at the conference. Additional submissions that were withdrawn are noted in the abstracts above.

The relationship between math achievement, math self-beliefs, and the cognitive and affective aspects of math anxiety in recent junior high-school graduates [Poster]

Caroline Biegel[1], Manuela Foster[2], Franziska Felder[2], Sascha Schneider[2], Christian Ruff[2], Silvia Brem[2], Nora M. Raschle[2], Ruth O'Gorman Tuura[1], Elisabeth Moser Opitz[2], & Karin Kucian[1]

[1]University Children's Hospital Zurich, [2]University of Zurich

Developmental dyscalculia (DD) is a neurodevelopmental disorder, which is characterized by deficits in number processing and calculations. DD and poor numeracy are associated with negative consequences from young age into adulthood. However, to date, there is a lack of interventions for adults with dyscalculia. Our research project aims to develop a support program for adolescents and adults with DD and to evaluate its effectiveness regarding behavioural and neuronal changes. We plan to recruit 30 adolescents and young adults between 14 and 27 years of age with DD as well as 30 matched controls. Participants with DD will receive 12 units of an individually tailored educational intervention. Before and after the intervention math performance will be measured. Furthermore, brain activity during resting state, a magnitude judgement task, and a place value task as well as brain structure will be assessed by means of magnetic resonance imaging (MRI). To evaluate long-term effects, additional behavioural and MRI measurements will be conducted at a follow up point of 14 to 28 weeks after the intervention took place. The project not only helps to get a better understanding of learning processes in DD but also provides concrete support to affected adolescents and young adults. In the future, this might lead to increased opportunities in education and professional career as well as a better well-being for affected people.

Supporting mathematics teaching and learning in early childhood settings: The role of wellbeing and mathematics anxiety among educators [Lightning Talk]

Katherine Canobi[1]

[1]University of Melbourne, Australia

Introduction: Despite a growing recognition of the importance of ECEC (early childhood education and care) educators in supporting young children's numeracy, surprisingly little is known about their mathematics views and teaching practices. However, some research points to a lack of confidence among ECEC educators in relation to mathematics and links their wellbeing to children's mathematics achievements. This study explored educators' reports of mathematical experiences in ECEC, their mathematics anxiety and key aspects of their attitudes and beliefs toward mathematics teaching and learning (perceptions of comfort, benefits and challenges) and important professional-wellbeing factors (sense of community belonging, safety and security, and professional identity). Method: Eighty-five Australian ECEC educators completed an online survey comprising established scales of ECEC professional wellbeing, mathematics anxiety and attitudes and beliefs about ECEC mathematics, along with open-ended questions. Eight survey respondents also participated in focus groups. Results: The results indicate that educators' mathematics anxiety and professional identity predict the extent to which they view ECEC mathematics teaching and learning as beneficial along with their degree of comfort with ECEC mathematics teaching and learning. In addition, educators' mathematics anxiety and sense of community and belonging in the workplace predict the extent to which they view ECEC mathematics teaching and learning as challenging. Qualitative findings highlight the rich and varied practices and methodologies of ECEC educators in designing and facilitating opportunities for young children to recognise and explore mathematical concepts. Conclusions: Together, the findings provide new insights into ways to assist ECEC educators to support children's numeracy learning.

The saliency of the base component in comparisons of exponential expressions [Poster]

Ami Feder[1], Mariya Lozin[1], Nadav Neumann[1], & Michal Pinhas[1]

[1]Ariel University

Exponential expressions represent series that grow at an unfixed growing pace such as carbon pollution and the spread of disease. Despite their importance, people tend to struggle with these expressions. In two experiments, participants performed numerical comparisons, where they were tasked to choose the larger of two exponential expressions as quickly and accurately as possible. In both experiments, we manipulated the distance between the base/power components and their compatibility. In base-power compatible pairs, both the base and power of one expression were larger than the other (e.g., 23 vs. 34), while in base-power incompatible pairs, the base of one

expression was larger than the base in the other expression but the relation between the power components of the two expressions was reversed (e.g., 32 vs. 24). Moreover, while in the first experiment, the larger power always led to the larger result, in the second experiment we introduced base-result congruent pairs as well. Namely, the larger base led to the larger result. Our results showed a base-power compatibility effect, which was also larger for larger power distances (Experiments 1–2). Moreover, participants processed the base-result congruent pairs faster and more accurately than the power-result congruent pairs (Experiment 2). These findings suggest that both the base and power components are processed when comparing exponential expressions, though the base is more salient during processing. This exemplifies a lack of understanding of the syntax of exponential expressions, where the power, even though physically smaller, has a larger mathematical contribution.

Are number words special? The impact of making a biased comparison [Poster]

Javier García-Orza[1], & Ismael Gutiérrez-Cordero[1]
[1] Universidad de Málaga, Spain

The phenomenon termed Stimulus Type Effect on Phonological and Semantic errors (STEPS), by which many aphasic patients make more phonological errors with words (e.g., tale → lale) and more semantic errors with numbers (e.g., forty-two → thirteen) has been considered as an evidence of number words having a special status in language production. The current work offers an alternative account of the effect based on interactive models of language processing taking into account (a) the properties of number words compared to the words with which they are usually compared, and (b) the existence of subtle differences in the way the production of words and number-words are assessed. Two patients with conduction aphasia, whose speech errors are predominantly phonological, were assessed in three production tasks with multi-digit numbers, and color sequences varying in frequency. We found that high-frequency color sequences, like multi-digits numbers, were produced with more semantic errors, while the phonological errors emerge again with low-frequency color sequences. These findings support that number words are not special. The STEPS seems to be the result of the combination of both the intrinsic properties of number words (made of sequences of very high frequency lexemes) and the evaluation context (usually semantically heterogeneous context for words but homogeneous for number words) during clinical assessment. The present study holds significant importance in the current discussion on language and number production models, the understanding of speech error mechanisms in aphasia, and the assessment of number transcoding in clinical settings.

Exploring the role of perceptual size in different-length multi-digit number comparison [Poster]

Ismael Gutiérrez-Cordero[1], & Javier García-Orza[1]
[1] Universidad de Málaga, Spain

The leftmost-digit congruity effect describes the fact that number comparison is faster for congruent pairs (such as 2384–107) than incongruent pairs (such as 2675–398), where the leftmost digit of the 3-digit number is larger than the initial digit of the 4-digit number. A non-solved issue is whether participants choose the number with more digits by exactly computing the number of digits in the string (e.g., 3 vs. 4) or whether they simply choose the perceptually larger item. To address this question, we showed 3- vs. 4-digit number pairs to a sample of 74 participants using the classical paradigm. However, they were encouraged to decide which number started with the larger digit. Under this condition an interference effect from the number length was expected (e.g., 2384–107 faster than 2675–398). More critically, in a second condition, differences in length between 3- and 4-digit numbers were obscured by including a letter at the end of the shortest multi-digit (e.g., 2384–107M and 2675–398M). In this letter condition we hypothesized that if participants automatically compute the exact number of digits in the string, the congruity effect would be similar to that in the no-letter condition; on the contrary, if length estimation is based on the amount of space occupied by the string no congruity effects would arise. Our results confirmed this second hypothesis, evidencing an automatic processing of perceptual size, and supporting that this factor is used as a proxy to solve the comparison of different length numbers.

The relationship between math achievement, math self-beliefs, and the cognitive and affective aspects of math anxiety in recent junior high-school graduates [Poster]

Min Hsiao[1], Chin-Yuan Chang[1], Wen-Chi Chiang[1]
[1]Chung Cheng University

Numerous studies have examined the math anxiety—math performance link and generated various hypotheses. According to control-value theory, math anxiety (MA), achievement emotion towards mathematics, is reciprocally linked to math achievement in students, and intermediately influenced by their math-

related self-beliefs. Some recent studies have emphasized distinctions in math-beliefs, between self-concept (SC) and self-efficacy (SE), and in MA, between cognitive and affective components (i.e., worrying thoughts versus negative emotional reactions). To address such issues in non-Western cultures, our study tested a group of Taiwanese junior-high-school graduates who recently underwent a standardized national achievement assessment (CAP). We measured the participants' basic cognitive abilities (short-term and working memory) by forward and backward recall of verbal/visuospatial items, math attitudes (math-SC, math-SE, and MA) by respective PISA questionnaires and a questionnaire measuring cognitive and affective MA separately, and achievement in mathematics and reading (indexed by CAP Grades), and then applied the hierarchical regression method, with cognitive vs. affective MA as the outcome variable, math-SC vs. math-SE as the second-step predictor, and all other factors as the first-step predictors. It was revealed that math achievement consistently predicted MA of both types, even after math-SE was added into the models. The same pattern was found with math-SC, but only in the model for affective MA. For cognitive MA, however, math-SC replaced math achievement as the sole predictor once added. These results are consistent with previous findings in support of differentiation between cognitive and affective MA, but also suggest cultural differences in the patterns of factors linked to MA.

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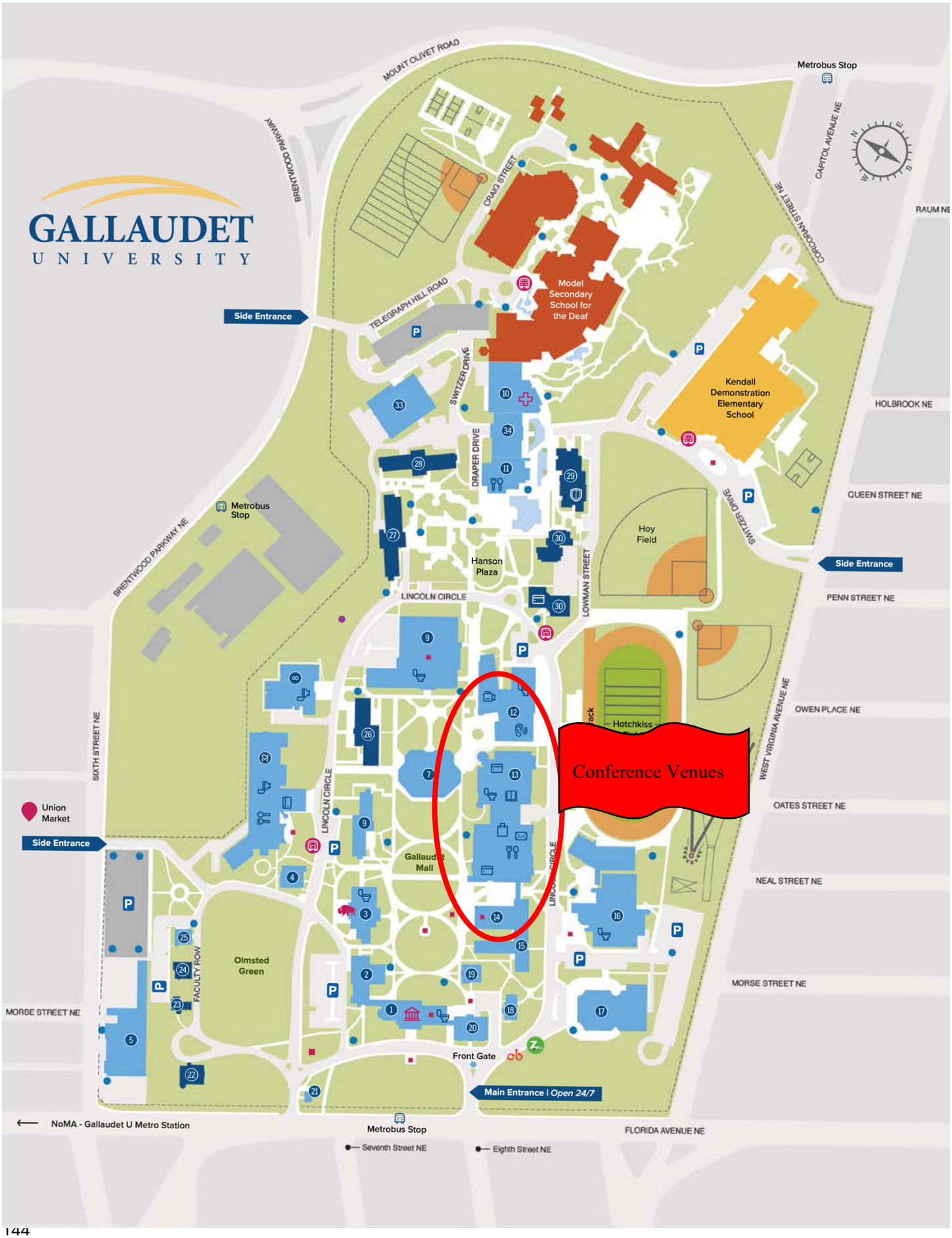
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