Team

**Principal Investigator**
Stephen Raudenbush, EdD, Professor, Department of Sociology and Chairman of the Committee on Education, University of Chicago

**Co-Principal Investigators**
Susan C. Levine, PhD, Professor, Departments of Comparative Human Development and Psychology and Chairman of the Committee, University of Chicago

Susan Goldin-Meadow, PhD, Professor, Departments of Comparative Human Development and Psychology and Chairman of the Committee, University of Chicago

Debbie Leslie, MAT, Associate Director for Direct Services, Center for Elementary Mathematics and Science Education (CEMSE), University of Chicago

Liesje Spaepen, PhD, Curriculum Developer, Center for Elementary Mathematics and Science Education (CEMSE), University of Chicago

**Team Members**
Raedy Ping, PhD, Postdoctoral Scholar, Spatial Intelligence and Learning Center, Department of Psychology, University of Chicago

Dominic Gibson, Doctoral Candidate, Department of Psychology, University of Chicago

Elizabeth Gunderson, Assistant Professor, Department of Psychology, Temple University

Marc Hernandez, PhD, Senior Research Scientist, Academic Research Centers, NORC, University of Chicago
# Table of Contents

Summary .................................................................................................................................................. 4

From the Classroom to the Lab and Back................................................................................................. 6
  Building children’s early numerical understanding ............................................................................ 6
  Building children’s early geometry and spatial thinking ................................................................. 8
  Teacher Work Circle ......................................................................................................................... 10

For Further Information ......................................................................................................................... 11

Related Papers ...................................................................................................................................... 11

References .............................................................................................................................................. 12
Summary

The overarching goal of *From the Classroom to the Lab and Back* is to integrate deep mathematical thinking into early childhood classrooms. Our approach to accomplishing this goal is to develop a coherent system of instruction that begins in pre-K and enables children of all social, ethnic, and linguistic backgrounds to attain high levels of academic achievement in elementary school and beyond. At the core of this system are statistically reliable assessments and instructional strategies that integrate research and practice and provide information to preschool teachers that is highly relevant to individual, group, and whole class instruction. Our approach is grounded in research demonstrating that early mathematics skills predict later achievement in mathematics (Duncan et al., 2007; Gunderson, Ramirez, Beilock & Levine, 2012; Jordan, Kaplan, Ramineni & Locuniak, 2009; Jordan, Glutting & Ramineni, 2010; Lee & Burkam 2002), but that children show marked individual differences in their mathematical knowledge at the start of school and these differences are often associated with children’s socioeconomic status (SES) (Jordan, Kaplan, Oláh, & Locuniak, 2006; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Lee & Burkam, 2002; Saxe, Guberman, & Gearhart, 1987; Starkey, Klein, & Wakeley, 2004).

Recent research suggests that math instruction and math-related interactions between adults and children can substantially enhance the development of children’s mathematical thinking (Clements & Sarama 2008; Griffin, Case & Siegler, 1994; Starkey, Klein & Wakeley, 2004; Gunderson & Levine 2011; Klibanoff, Levine, Huttenlocher, Vasilyeva & Hedges, 2006; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010). Further, we know that children from economically disadvantaged households seem to gain the most from high quality early childhood programming (ECE) (Barnett, 2008; Burger, 2010). However, we know that math instruction, let alone high-quality mathematics interaction, is rare in early childhood classrooms (Graham, Nash & Paul, 1997; Winton & Buysse, 2005).

We seek to change this state of affairs by clarifying instructional goals for early mathematics development in preschool settings. We will equip teachers with a system that will provide frequent, detailed information about individual children’s progress in acquiring different concepts and skills. By using the assessment itself, and through a professional development and support system, teachers will acquire an understanding of a) what the important mathematics content is for young children, b) how learning within the different content areas progresses from age 3 to 5, and c) how they might help children move along the learning trajectories. Over the past two years, we have conducted research and developed and piloted instructional strategies that help preschool children to learn the critical numerical, geometric and spatial skills that are measured in the assessment.
We are in an excellent position at the University of Chicago to accomplish this work, which requires ongoing collaboration between researchers and practitioners. We have an established team of early learning scholars from the Committee on Education, developers of mathematics early learning tools, from Center for Elementary Mathematics and Science Education, and practitioners from the University’s charter schools and other Chicago Public schools who bring considerable knowledge, experience, and skill to develop our assessment and instruction system.

Between 2011 and 2013, with funding from the McCormick Foundation and the Chicago Mercantile Exchange Foundation, we:

- Collaborated with teachers to explore ways to implement research findings in the classroom and create instructional activities
- Developed and tested a specific learning activity designed to target the numerical skills of cardinality and the successor function and piloted the activity with approximately 300 preschool children
- Developed a learning activity to promote understanding the attributes of a particular shape and piloted the activity with approximately 180 preschool children
- Conducted a study to investigate the role of language in children’s misconceptions regarding early geometric concepts
- Completed two pilot studies investigating the relative benefits of action vs. gesture as a way to improve mental rotation ability

Between 2013 and 2015, *From the Classroom to the Lab and Back* will move forward in several ways:

- We will conduct new lab studies that test the strategies in new content areas
- We will identify successful strategies and incorporate them into prekindergarten and kindergarten math lessons
- We will begin to merge our math strategies and our assessment work by linking the strategies and lessons to specific skills, thereby providing teachers with activities to advance the development of that skill
From the Classroom to the Lab and Back

The specific goals of *From the Classroom to the Lab and Back* are to collaborate with teachers to develop instructional strategies for teaching preschoolers fundamental numerical and spatial skills, and to empirically test these strategies. Establishing number understanding is critical for all later mathematics learning. Number understanding undergoes substantial development in the preschool years and shows large individual differences such that children from disadvantaged backgrounds tend to be behind. Strong spatial thinking has been underemphasized in the early math curricula, but is a significant predictor of children’s entry into STEM (science, technology, engineering, and mathematics) disciplines and is highly responsive to instruction (Wai, Lubinski & Benbow, 2009). In the domain of early numeracy, we focused on developing instructional strategies that build young children’s understanding of cardinal number (e.g., understanding that the number “three” represents sets of three items), the cardinal principle (i.e., understanding that the last number reached when counting a set represents the size of the whole set) and the successor function (i.e., understanding that for every number, the next number in the count list represents a set that is one larger). In the domain of geometry and spatial thinking, we focused on developing instructional strategies for teaching children about shape categories and angles, as well as instructional strategies that utilize technology to build children’s spatial visualization skills. We also completed a summer work circle with teachers in 2012, where we shared the results of our research, discussed ways to implement findings in the classroom, and worked together with teachers to begin creating instructional activities.

**Building children’s early numerical understanding**

We have developed and tested a specific intervention designed to target the numerical skills of cardinality and the successor function. The intervention takes the form of a game where children give puppets the number of objects the puppets like to have, and, along with the experimenter, count and label the objects and discuss the relations between different numbers of objects. As part of our design process, we met with expert preschool teachers and discussed our ideas for the intervention. We asked each teacher to try out the intervention with a preschool-aged child, and then met as a group to talk about their impressions of the task and how to improve it. Based on teacher feedback, we modified the intervention to be more interactive and more cognitively engaging for the child.

We piloted the intervention task with approximately 300 children attending five large preschools with children from low-income families. We randomly assigned children within classrooms to the intervention or control condition. The results from the pilot were very promising. Of those children who had not yet learned the cardinal principle, half of the children improved from pre-test to post-test on their cardinal number knowledge, resulting in an overall improvement in children’s knowledge. Based on these promising pilot results, we carried out an experimental study comparing children in the intervention condition to a control condition that involved only
counting, but does not involve labeling the number of objects or discussing the relations between numbers. We chose to use counting as our control condition because this is the type of interaction that typically occurs in preschool classrooms, and thus it allowed us to determine whether our intervention results in more learning than “business-as-usual.” We measured children’s understanding of the successor function using an ordering task, where children were asked to put cards in order, where the cards represented the numbers 1-7 using Arabic numerals, dots, and hand shapes. For children who already learned the cardinal principle (CP-knowers), we found that our experimental condition resulted in significantly more learning of the successor function than the control condition, controlling for pre-test ordering accuracy and age. In contrast, we did not see this effect for 3- or 4-knowers, children who understood the cardinal meanings of 3 or 4 number words but had not yet learned the cardinal principle. These findings have important implications about the sequencing of instruction for foundational number concepts.

In addition, we found that children who had not yet learned the cardinal principle (also referred to as “subset-knowers” since they know only a subset of the number words in their count list), showed greater cardinal number knowledge in gesture than in speech. This was especially true of children who knew the cardinal meanings of fewer than 3 number words. We gave children two tasks where we showed them a picture of a certain number of objects (e.g., 3 boats) asked them “What’s on this Card?” In one task, children were asked to show the answer with their fingers (WOC-Manual), and in the other, with their words (WOC-Verbal). Our results show that children who had not yet learned the cardinal principle were significantly more accurate on the WOC-Manual task than on the WOC-Verbal task for sets of size 2 and 3. In other words, the same child who, when shown a picture of 3 boats, would say an incorrect number like “five” was able to correctly show the number of boats using three fingers.

When they were shown larger sets of objects (5-10), subset-knowers gave responses that were closer to the correct number on the WOC-Manual than on the WOC-Verbal task, indicating that they were better able to approximate the number of objects in gesture than in speech.

We also examined the occurrence of simultaneous gesture-speech mismatches on the WOC tasks. Gesture-speech mismatches occur when a child raises a certain number of fingers and, at the same time, says a different number word. We found that mismatches were more likely in response to set sizes for which children had not already learned the cardinal word meaning, and that children’s gesture responses were more accurate than their verbal responses during these mismatches. These findings raise the interesting hypothesis that children’s gesture-speech mismatches can be regarded as an index of their readiness to learn the meaning of the next number in their count list, a hypothesis we plan to explore during the next funding period.
In the current phase of this work, we are exploring whether it is more effective for children to engage with multiple examples of small numbers (e.g., repeated examples of 1, 2, and 3) or to engage with examples of large (4, 5, 6) numbers, where set size cannot be perceptually ascertained but must be assessed by counting.

Building children’s early geometry and spatial thinking

In the domain of geometry/spatial thinking, our efforts were aimed at going beyond typical early mathematics curricula, which focus almost entirely on teaching children to name 2-dimensional shapes. We collected data on a study where we use analogy, widely established in the cognitive and developmental psychology literatures as a powerful learning tool, to help children to learn the defining attributes of the shape category “triangle”. We also collected data for a study that uses language to help very young children to understand the concept of “angle”—a concept that is not introduced into typical curricula until second grade. We also worked on developing instructional strategies that enhance children’s spatial visualization skills—skills that are important but are not typically covered by early math curricula. Since feedback from teachers indicates that they find game play and gesture to be easy-to-implement learning tools, our interventions focus on the possible relative benefits of both iPad technology and gesture in improving spatial visualization skills.

Improving children’s shape-related concepts. Young children’s representations of geometric shape categories (e.g., triangle) tend to be centered on familiar, prototypical exemplars of shape categories. Children typically have a prototype (e.g., an equilateral triangle with a horizontal side at the bottom), and when determining whether other exemplars are a member of the category, they simply use visual similarity to the prototype, rejecting non-canonical members of the category. This leads to rejection of atypical exemplars, e.g., scalene triangles or triangles with the horizontal side at the top, as members, and acceptance of non-members, e.g., a three sided but not enclosed shape, as members (Satlow & Newcombe, 1998)—these misconceptions persist late into development (up to age 9 for many children). However, shape category membership is determined by defining attributes (e.g., a triangle is an enclosed shape with three straight sides). We developed an intervention that uses comparing typical and atypical exemplars, and contrasting exemplars with non-exemplars to foster learning the attributes of the shape category “triangle”, and collected data with over 180 3.5 – 5 year old children. Our findings suggest that contrastive examples (e.g., “This is a triangle, this is not a triangle”) may be more effective than comparing two examples, (e.g., “This is a triangle and this is a triangle”). In fact, contrasting two shapes that are perceptually identical, except for one necessary attribute, leads to the best understanding of the shape category. For example, contrasting two forms, i.e., a scalene triangle (“this is a triangle”) and an identical form that is missing part of one side (“this is not a triangle”), helps children to learn the rule “triangles have enclosed sides”. This type of contrast is also effective at teaching children the rule that triangles must have exactly three of those enclosed sides. This intervention was most effective at moving children away from a prototype-based or ill-
defined triangle category to a category defined by necessary attributes. Notably, the effectiveness of contrastive examples ran counter to teachers’ intuitions that positive examples would be most effective in teaching children the triangle concept.

Improving children’s understanding of “angle”. We investigated the role of language in children’s misconceptions regarding the early geometric concept of angle. When making judgments about the size of angles, children often incorrectly rely on erroneous properties such as the overall size of the angle-figure (Lindquist & Koubu, 1989; Clements & Battista, 1989). One possibility is that this misconception stems from the whole object bias -- the tendency to assume that a novel label refers to an object as a whole rather than to its parts or features (Markman, 1994). By this account, when presented with a canonical angle figure (two line segments meeting at a point), children may believe “angle” refers to the entire figure and therefore think that a “bigger angle” is a larger figure and not a figure with a larger measure of rotation. Given another constraint on word learning, mutual exclusivity, we hypothesized that children would be more likely to attach the correct referent to the word “angle” if they were first given a label for the overall angle shape (e.g., “toma”).

To test this, we carried out a study of preschool children using a single session pretest/training/post-test design. During piloting and the study itself we ran a total of 61 participants, although only 30 of these participants completed the final version of the study (mean age: 4.86 years, SD: 0.53 years). At pretest, children showed evidence of the whole-object misconception. After training, children who were given a novel-word label for the whole object improved significantly more than those trained on the meaning of “angle” alone. These results suggest students’ angle misconceptions are not due to perceptual or representational limits, but rather they are due to the misleading language typically used to describe angles. This opens the possibility that the concept of angle could be introduced far earlier in school as long as these barriers are addressed.

Improving spatial visualization and spatial language. Young children’s dynamic spatial visualization skills such as mental rotation are related to later spatial and math abilities, predict academic performance and entry in the STEM (Science, Technology, Engineering, and Mathematics) disciplines over the lifespan, and importantly, can be improved. We are assessing the effectiveness of a variety of instructional strategies that use technology to improve young children’s mental rotation abilities. We have completed two pilot studies, one investigating the relative benefits of action vs. gesture on tangible manipulatives as a way to improve mental rotation ability, and one investigating the relative benefits of action vs. gesture on virtual manipulatives (dynamic geometry objects) as a way to improve mental rotation ability. The findings of these studies indicate that, although action is effective at improving mental rotation ability, gesture may be even more effective. We believe this may occur because gesture encourages children to visualize the rotation in a way that actual action does not, since children are able to see the results of an action but are not able to see the results of a gesture. We have recently designed a new study
bridging the gap between these two pilot studies, which will help us understand the mechanisms behind possible relative benefits of spatially dynamic actions and gestures. Four-year-old children will receive instruction in mental rotation with a computer game. Our plan is to investigate the relative benefits of different types of action with virtual manipulatives (touch screen rotation and gesture about rotation), to see which kinds of action are best for young learners. We have created the dynamic geometry apps that will allow us to carry out these studies and we have begun piloting our procedures.

Teacher Work Circle

In summer 2012, fourteen Pre-Kindergarten and Kindergarten teachers joined researchers for a two-day long work circle. The work circle started with overviews of early math followed by a discussion of instructional dilemmas teachers face. Teachers reported needing help in deciding which topics to teach during math, given a lack of common core standards and curricula in pre-K. During each day, professors, post-doctoral researchers, graduate students, and research assistants gave informal presentations of lab research in topics like numeracy, measurement and estimation, angle learning, math anxiety, and spatial visualization. Each presentation was followed by a 45-minute breakout session, where teachers and researchers brainstormed instructional dilemmas and strategies for solving them, based on the empirical research presented. At the end of each day, teachers worked in groups to come up with instructional activities for the classroom. At the end of the final day, teachers shared their instructional activities with one another. Teachers then received a file with notes from the instructional activities they had created.
For Further Information, please contact:

Stephen Raudenbush, Project PI, Professor, Department of Sociology and Chair, Committee on Education, University of Chicago, raudenb@uchicago.edu

Susan C. Levine, Project Co-PI, Professor, Departments of Psychology and Comparative Human Development; Committee on Education, s-levine@uchicago.edu

Susan Goldin-Meadow, Project Co-PI, Professor, Departments of Comparative Human Development and Psychology; Committee on Education, sgm@uchicago.edu

Liesje Spaepen, Project Co-PI, Curriculum Developer, Center for Elementary Mathematics and Science Education, University of Chicago, liesje@uchicago.edu

Debbie Leslie, Project Co-PI, Senior Curriculum Developer, Early Childhood Specialist, Director of Science Companion Projects, Center for Elementary Mathematics and Science Education, daleslie@uchicago.edu

Related Papers


References


