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Children's Development of Mathematical Skills

Learning quantitative skills at an early age is important for children's cognitive development, academic achievement and life success. At the time of school entry, early math abilities are the strongest predictors of academic achievement, even more than reading skills.[1] Mastery of these fundamental computational skills has been associated with increased academic achievement and has also been associated with predicting future wage earnings.[2] Furthermore, a failure to teach basic skills in math seems to disproportionally affect disadvantaged children, thereby leading to an increase in the achievement gap.[3]

Despite increasing awareness of the importance of mathematics education for children, there remain many gaps in our knowledge of the underlying processes that influence the development of quantitative skills in children. The underlying skills that serve as building blocks for academic success remain largely unknown in the area of mathematics. Even less is understood about the relationship between math skills, reading abilities and general cognitive abilities.

The 2009 National Assessment of Educational Progress (NAEP) in mathematics[4] is a nationally representative assessment of the quantitative abilities of fourth and eighth graders. In 2009, only 39% of fourth graders and 34% of eighth graders scored at or above proficient levels in a range of mathematics content areas, including number properties and operations; measurement; geometry; data analysis, statistics and probability; and algebra. Of the fourth graders, 83% performed these skills at or above a basic level, while 73% of eighth grade students scored at or above a basic level. At the eighth grade level, these results reflect a continued improvement of scores, with 2009 scores higher than the results from 2007. However, fourth grade students' scores did not improve from 2007-2009, despite improvements from 1990-2007. Moreover, disparities by racial and ethnic group continued to persist at both grade levels despite the modest improvements in some scores.

In addition to the NAEP, the United States participates in two primary international measures of mathematics skills in students. Trends in International Mathematics and Science Study (TIMSS),[5] which was conducted most recently in 2007, looks at fourth and eighth graders' ability to perform math and science skills likely to have been part of a school curriculum. The Program for International Student Assessment (PISA)[1,6] focuses on children at the age of 15 and emphasizes quantitative literacy by considering the understanding and application of math skills to life scenarios. The most recent TIMSS assessment placed U.S. fourth and eighth graders just above the average score for the 36 participating countries. These 2007 scores represented an improvement over the initial 1995 TIMSS assessment for both grades. However, the U.S. has consistently scored below the PISA average in mathematics from 2003-2009.

National and international assessments of quantitative literacy demonstrate that U.S. students are not performing as well on measures of mathematic abilities as their peers in other countries. Given the importance of mathematics for school, employment and other aspects of daily life, policymakers, practitioners and parents have incentives to improve children's mathematic proficiency. However, less is known about which interventions can best improve quantitative literacy. In order to develop strategies to improve children's math skills, we first must understand the underlying skills necessary for mathematic competence and the factors that influence the development of these skills. Researchers at Case Western Reserve University are working to address this gap in knowledge.

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Through her research, Dr. Thompson seeks to understand how genetic code is translated into complex behavior at the level of brain function. Much of Dr. Thompson's work focuses on the development of cognitive skills, temperament and language from infancy through childhood. In addition to her ongoing collaborative research on the development of mathematical skills in children, Dr. Thompson and her colleagues are studying the environmental influences on the early development of reading skills in the same group of children.

Funded by the National Institute of Child Health and Human Development, a group of developmental scientists with Dr. Thompson are examining the genetic and environmental factors influencing mathematic abilities. The research involves over 400 pairs of twins living primarily in the state of Ohio and uses a quantitative genetic approach as a means of isolating genetic and environmental influences on complex behavior. Identical twins share 100% of their DNA and fraternal twins share about 50% of their DNA. By comparing the similarity of identical twins on specific traits or behaviors to the similarity of fraternal twins, estimates of the strength of genetic and environmental influences can be calculated using statistical models. Twins also provide a window on the relative influence of two broad classes of environmental influences on development, shared and nonshared. Shared environments make family members living together more alike. Neighborhood, diet, some parenting behaviors, culture and schools are examples of shared environmental influences. Nonshared environments are experiences that are unique to the individual and make family members living together dissimilar. For example, peers, accidents, illnesses, birth order, and differential parental treatment can contribute to nonshared environment. Furthermore, when several behaviors are measured and the twins are followed on a yearly basis, the influence of genes and environment on behavior can be explored for each age and as they change over time.

Building on the Western Reserve Reading Project

Reading ability and disability has been more extensively studied than math ability and disability. When research on the etiology of individual differences in reading was in its infancy, groups of typically developing readers were studied to identify fundamental reading processes. These processes were then assessed in families and twins where a wide range of reading ability was represented.

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Finally, in order to better understand the causes of reading disabilities and ultimately to develop effective interventions, information gained from the samples of typical readers was applied to twin samples where at least one member of each pair was diagnosed with reading disability. For their ongoing project on children's mathematical skills, Dr. Thompson and colleagues built on their previous work with the Western Reserve Reading Project ("WRRP"), and the study of reading in general, to investigate mathematics abilities in children.[7] Research on math development has begun to identify fundamental math processes and Thompson and her colleagues sought to characterize these math processes in a sample of typically developing twins. The next step in the research process will be to recruit twin pairs where at least one member is diagnosed with math disability.

Math Study Design

One of the hallmarks of the current study were the one-on-one home-based assessments of mathematics and reading ability, which were conducted over seven years and which provided an in-depth look at the skills of the research participants. This study design allows questions to be answered about the etiology of individual differences in reading and math ability and how they change across development during the early school years where change occurs very rapidly in terms of physical and cognitive development. Measuring reading and math ability in the same children may also shed light on the puzzling finding that while many children with math disability are also diagnosed with reading disability, many are not; suggesting that subtypes of reading and math disability exist. Thompson and her colleagues hope to pinpoint where processes are shared and where they are distinct across math and reading skills.

The math study was part of the WRRP, an ongoing longitudinal study of twins in Ohio. Pairs of twins were recruited through schools, the media and birth records. The twins were all about six years old at the time of initiation into the study. Researchers conducted home visits to assess a range of areas of math ability, including calculation, fluency, problem-solving and mathematics knowledge. Calculation represents a child's ability to perform mathematical computations such as addition, subtraction, multiplication and division. Fluency is a child's ability to answer a set of computation problems in a timed period. Problem-solving is a child's ability to analyze an applied problem and correctly use mathematics concepts and operations in response.

Findings & Conclusions

Evidence for both genetic and environmental influences on children's math skills was found. More specifically, the extent of environmental influence relative to genetic influence varied across different measurement times and different math skills. For example, when twins were younger, there seemed to be more shared environmental effects on the fundamental math skills involved in calculation, applied problem solving and quantitative concepts; perhaps reflecting a period of skill acquisition through formal classroom instruction. As the twins acquired these foundational skills and started using them in more advanced applications, the impact of the shared environment decreased and genetic influence became stronger. In contrast, math fluency appears to be consistently influenced by genetic factors which are largely distinct, affecting only math fluency and not other cognitive skills. This is an important finding for understanding differences in the etiology of learning disabilities.

The relationship between math skills, reading skills and general cognitive abilities was also examined. Researchers found genetic and environmental overlap between mathematics, reading and general cognitive abilities, depending on the particular measure of math or reading used. For example, when the researchers considered calculation in the model as the math factor, they found no genetic overlap between reading and general cognitive abilities, but instead found evidence of connections between math and cognitive abilities that suggested environmental influences. This is perhaps not surprising since children must be taught how to compute different types of math problems. Genetic overlap between the fluency measure of math skills and rapid automatized naming (RAN) was also found. RAN is a test in which children must name objects as quickly as possible and which has been connected to later development of reading abilities. The authors hypothesized that the timed component of both fluency and RAN was responsible for the significant overlap between them. Finally, strong genetic overlap and some environmental overlap between children's mathematical problem-solving skills and their reading and general cognitive abilities were noted.

In separate analyses with the WRRP data, Dr. Thompson and colleagues examined the links between general mathematics and reading performance and symptoms of attention-deficit/hyperactivity disorder (ADHD).[8] They found evidence for similar general genetic and shared environmental influences on ADHD symptoms, math and reading. This analysis is important because although ADHD has been strongly associated with difficulties in academic achievement, the underlying skills that are implicated are not yet well understood.

The results from the WRRP demonstrate that there is genetic and environmental overlap between math, reading and general cognitive abilities. However, as the more nuanced results discussed above indicate, the extent of this overlap depends on the type of measure used to gauge ability. The results also demonstrated individual genetic effects on mathematic abilities.

Implications for Policy and Practice

The ongoing research by Dr. Thompson and colleagues addresses a gap in our understanding of how children develop math skills. While the importance of quantitative abilities for academic success and later life is well recognized, less is known about exactly what cognitive skills are necessary for success in school, and what factors underlie these crucial abilities.

Increased reliance on technology cannot substitute for a basic understanding of mathematics that allows children to become quantitatively literate. While research, policy and practice have all sought to address the skills necessary for reading proficiency, much less has been invested in the development of quantitative literacy.[9] Given the implications and utility of mathematical proficiency for education, employment and daily life, emphasis on the development of early math skills in children has the potential to have long-lasting positive effects. The international and national emphasis on education performance, in which President Obama recently referred to Shanghai, China's superior performance in mathematics on the PISA as "our generation's sputnik moment"[10] reflects a broader shared acknowledgement of the importance of math literacy.

Dr. Thompson's work has implications for early identification of math disability. Currently, a consensus definition for identifying math disability does not exist, making it hard to design and implement early screening measures to identify children at risk for math disability. The work described here suggests that math fluency may be a good candidate as a screening measure. Math fluency appears to reflect skills that are specific to math outcomes and that are genetically influenced. Fluency tasks are quick and easy enough for young children to complete. Development of valid early screening measures will enhance the implementation of intervention.

A key implication of Dr. Thompson's work is that it debunks claims that math abilities are either entirely innate or entirely due to environment. Instead, the results of this ongoing study demonstrate that a complex mix of genetics and environmental factors are at play and, importantly, begins to tease out some of the nuances between different basic academic abilities. A further implication of Dr. Thompson's work is that genetic differences in math ability are not deterministic,[11] but that genetics and the environment interact to influence each individual's math performance. These results suggest an imperative to provide the most effective education and socialization opportunities possible to ensure that children can develop quantitative skills to the best of their abilities.

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