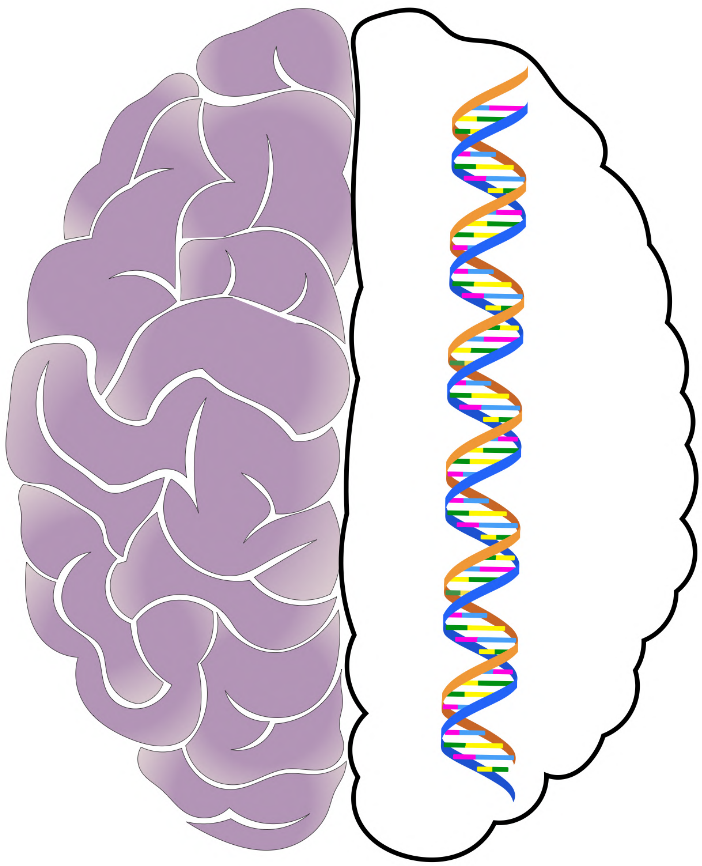
Is Math Ability Determined by DNA?

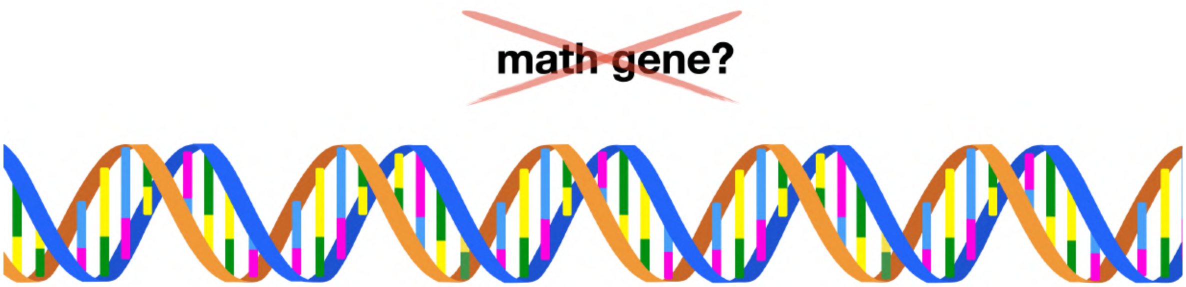
by DiBeos



"Young man, in mathematics you don't understand things. You just get used to them" – **John von Neumann**

Introduction

No one individual gene is responsible for math abilities. But the real question is: *do genetics influence your mathematical abilities?*



To answer that, we need to know if we're born with a sense of numbers or if it only starts to develop when we learn simple arithmetic. In order to answer this question, we have to go back to our infancy.

“Number sense”

In a 2016 study, researchers asked themselves: are babies born with a kind of “number sense” that will predict how good they will be at math later on? This gives you a clue as to whether there is any kind of inheritability of mathematical skill.

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Number sense in infancy predicts mathematical abilities in childhood

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Edited by Rochel Gelman, Rutgers, The State University of New Jersey, New Brunswick, Piscataway, NJ, and approved September 23, 2013 (received for review February 14, 2013)

Human infants in the first year of life possess an intuitive sense of number. This preverbal number sense may serve as a developmental building block for the uniquely human capacity for mathematics. In support of this idea, several studies have demonstrated that nonverbal number sense is correlated with mathematical abilities in children and adults. However, there has been no direct evidence that infant numerical abilities are related to mathematical abilities later in childhood. Here, we provide evidence that preverbal number sense in infancy predicts mathematical abilities in preschool-aged children. Numerical preference scores at 6 months of age correlated with both standardized math test scores and nonsymbolic number comparison scores at 3.5 years of age, suggesting that preverbal number sense facilitates the acquisition of numerical symbols and mathematical abilities. This relationship held even after controlling for general intelligence, indicating that preverbal number sense imparts a unique contribution to mathematical ability. These results validate the many prior studies purporting to show number sense in infancy and support the hypothesis that mathematics is built upon an intuitive sense of number that predates language.

analog magnitudes | approximate number system | cognitive development | mathematical cognition

Where does the uniquely human capacity for abstract mathematical concepts come from? What are the ontological building blocks that scaffold our ability for representing number symbolically and performing exact arithmetic? One hypothesis is that the preverbal, nonsymbolic numerical capacities exhibited by human infants in the first year of life serve as a conceptual basis for learning to count and acquiring symbolic mathematical knowledge (1, 2). Although many cognitive abilities contribute to math achievement, including working memory, inhibition, and other executive functions (3, 4), symbolic mathematics is commonly thought to build on a domain-specific nonverbal numerical representation (5). This system, the approximate number system (ANS), is an evolutionarily and ontogenetically ancient system that allows approximate representation of number without the need to count or rely on numerical symbols (2, 6).

Support for this hypothesis comes from a handful of studies that have shown a correlation between math ability and individual differences in ANS acuity. For example, ANS acuity in adolescence retroactively predicts math ability in elementary school (7) and ANS acuity in preschool-aged children correlates with their current and future math performance (8–12). In addition, children with dyscalculia, a severe deficit specific to math, have poorer ANS acuity than their typically developing peers (9, 11). These findings demonstrate that ANS acuity covaries with math ability, but the direction of this relationship remains unclear. One possibility is that ANS acuity guides the acquisition of the verbal counting system and symbolic math knowledge, such that children with greater ANS acuity learn to count earlier and have enhanced facility with spoken and written numerical symbols (13). Alternatively, learning the verbal counting system and early symbolic math concepts may refine ANS acuity, such that children with greater symbolic number knowledge end up with greater ANS acuity (13). To differentiate between these possibilities, it is necessary to investigate ANS acuity before children acquire the verbal counting system and before exposure to mathematics education. If the ANS is truly foundational for symbolic math, then early ANS acuity should inform children’s facility with written and spoken numerical symbols.

Can the acuity of the preverbal number sense in the first year of life, well before an infant can count and understand verbal or written numerical symbols, predict later developing math abilities? A major stumbling block for answering this question has been the lack of parametric measures available for studying infant cognition in the first year of life. Our understanding of number sense in preverbal infants comes primarily from studies showing that groups of infants repeatedly shown pictures of the same number of objects (e.g., 8 dots) look longer when arrays with a new numerical value are presented (e.g., 16 dots) (14–17). These studies provide binary information (i.e., success vs. failure to discriminate between different numbers) about behavior at the group level but do not provide parametric scores of numerical sensitivity at the individual level. The development of a numerical change detection procedure that yields preference scores modulated by the ratio between numerical values in a changing visual stream provides a solution to this disconnect between infant and adult measures of numerical discrimination (18, 19). In the numerical change detection paradigm, infants observe two streams of visual arrays, one of which alternates between two numerical values while the other stays numerically constant and only changes in dot size and arrangement (Fig. 1*A* and Movie S1). Infants’ preference for the numerically changing stream, as indexed

Significance

The uniquely human mathematical mind sets us apart from all other animals. How does this powerful capacity emerge over development? It is uncontroversial that education and environment shape mathematical ability, yet an untested assumption is that number sense in infants is a conceptual precursor that seeds human mathematical development. Our results provide the first support for this hypothesis. We found that preverbal number sense in 6-month-old infants predicted standardized math scores in the same children 3 years later. This discovery shows that number sense in infancy is a building block for later mathematical ability and invites educational interventions to improve number sense even before children learn to count.

Author contributions: A.S., M.E.L., and E.M.B. designed research; A.S. and M.E.L. performed research; A.S., M.E.L., and E.M.B. analyzed data; and A.S., M.E.L., and E.M.B. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

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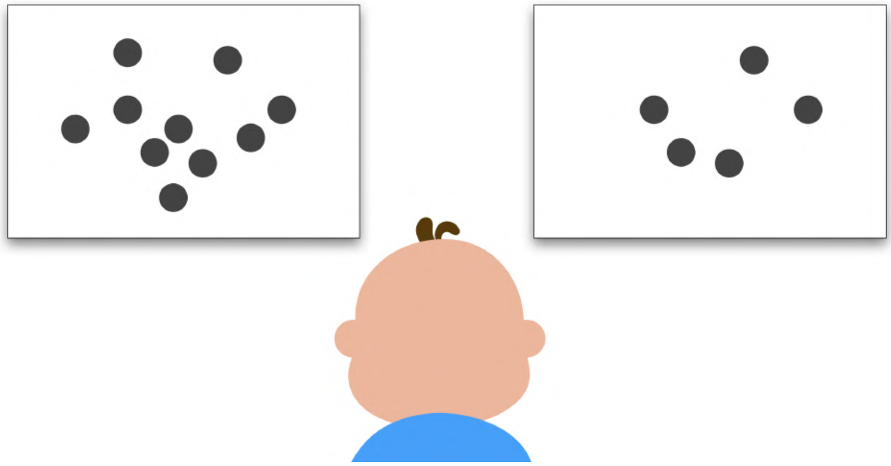
This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1302751110/-/DCSupplemental.

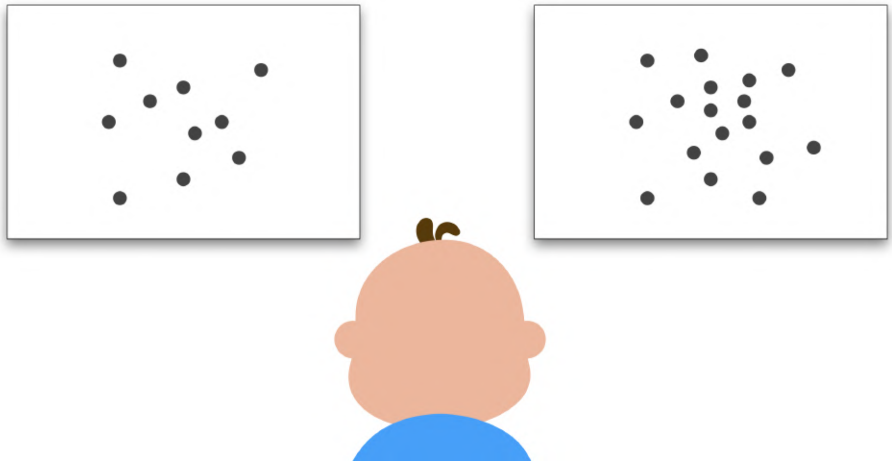
18116–18120 | PNAS | November 5, 2013 | vol. 110 | no. 45

www.pnas.org/cgi/doi/10.1073/pnas.1302751110

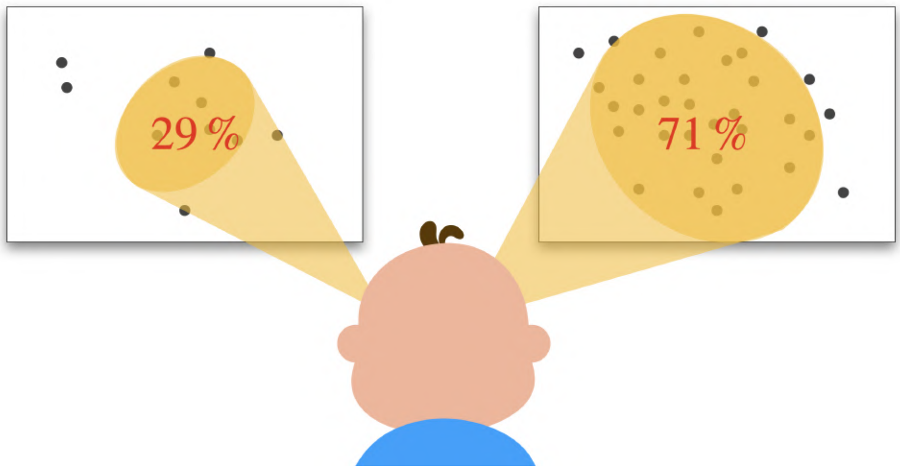
Researchers sat down 6 month old infants in front of two picture streams. On the left side, when each frame changed, the number of dots stayed the same every time (always 10 dots, though they varied in size and arrangement).



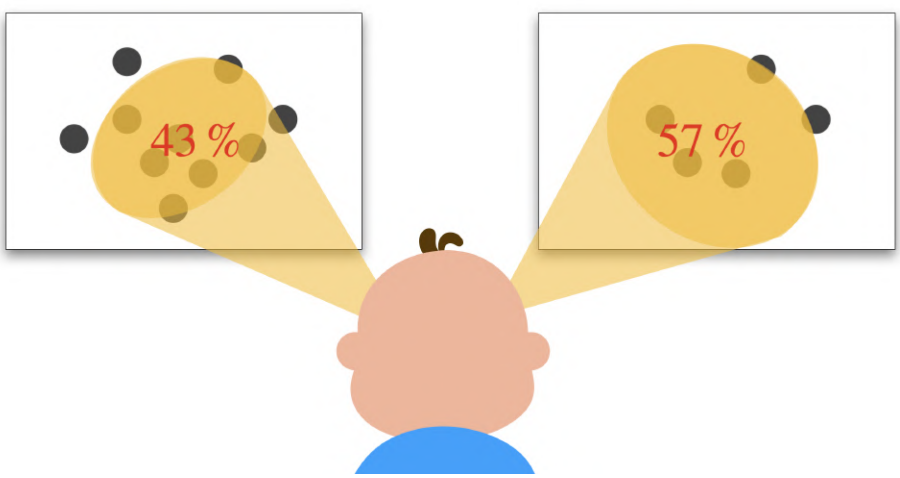
On the right side, the number of dots kept switching, and would also vary in size. Both sides flashed in rhythm, so the only difference was whether the number stayed constant or changed.



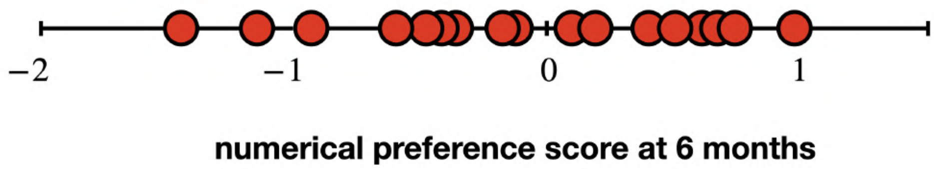
With special cameras, researchers would detect eye movement and the amount of time spent looking at each screen.



The thought was, if babies can sense changes in quantity, they should prefer looking at the side where the number keeps changing. The amount of extra time they spend looking at that side gives a numerical preference score, which is a measure of their **Approximate Number System** acuity (which we will call **ANS** acuity), or their "raw number sense".

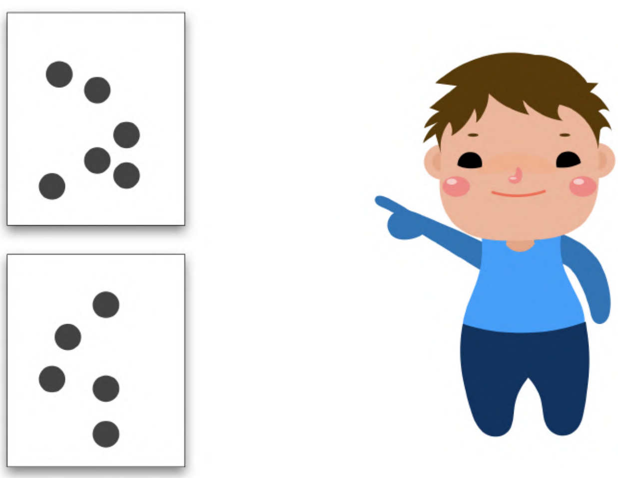


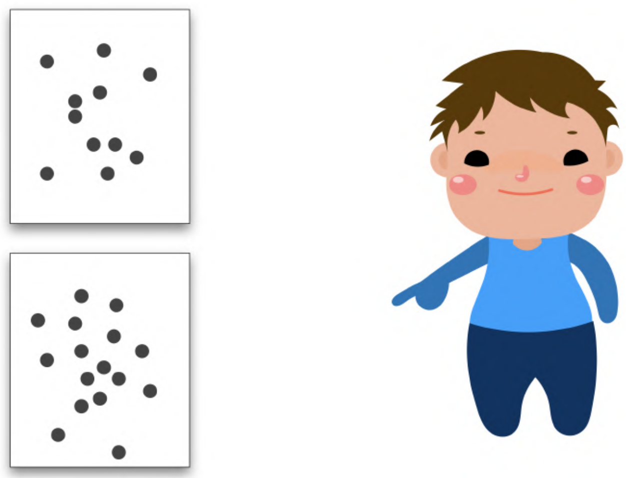
After completing the test, they were given scores. If a baby stared more at the "changing numbers" stream, they got a higher *positive* score. If they didn't really notice or preferred the "constant" stream, their score was closer to *zero* or *negative*.



The assumption was that the children with a higher score will be better at math when they age. Let's see if this hypothesis was confirmed...

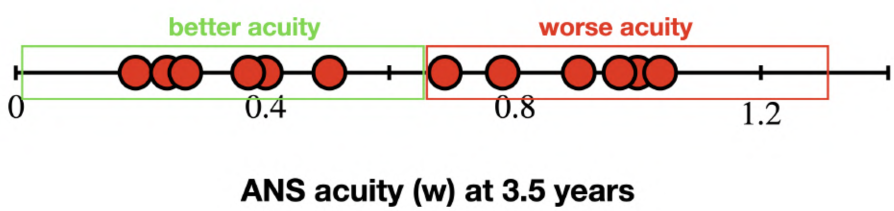
They came back to the children when they were 3.5 years old, and had them take two more tests to see whether their prediction was correct. In the first, they saw two dot groups and had to choose which had more dots, and got a score expressed as a **weber fraction** (**w**).



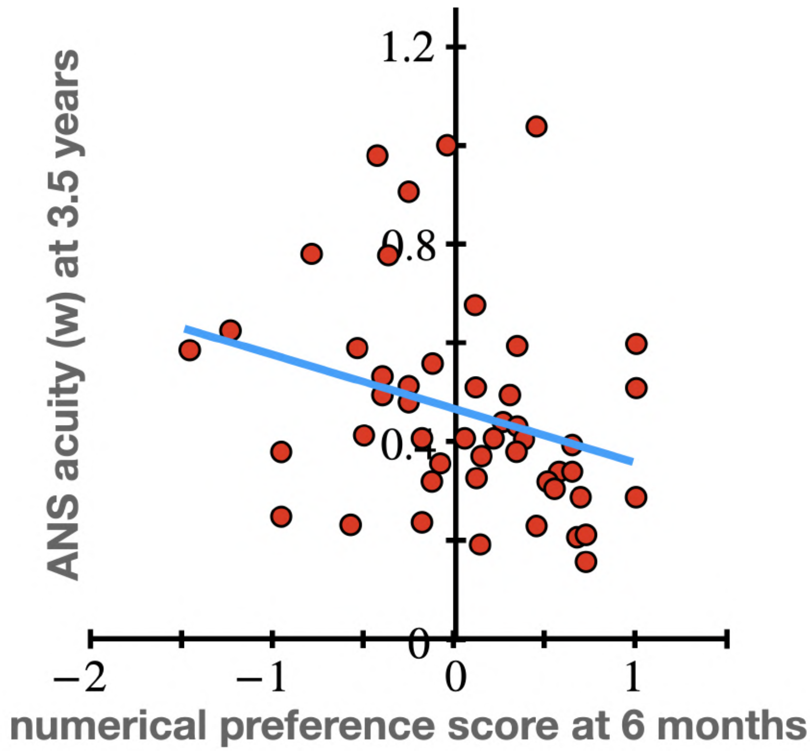


A small **w** (or closer to 0) means they could tell apart even very similar quantities (e.g., 10 vs 12). Which means that they had better acuity.

A large **w** (or closer to 1) means they only noticed big differences (e.g., 10 *vs* 20), so had worse acuity. So essentially *lower numbers = sharper number sense*.

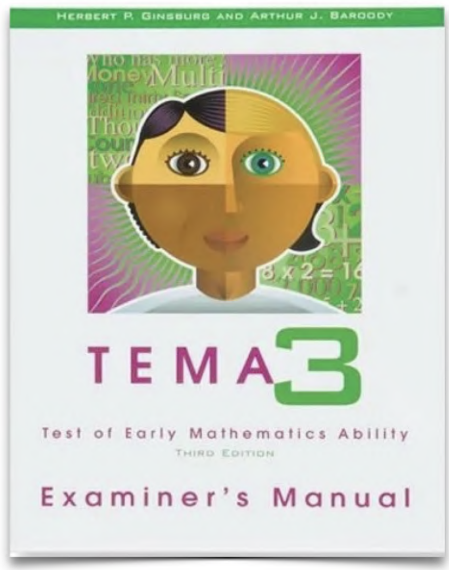


The graph below shows their scores combined. Remember, on the *x*-axis, the more positive, the better their perception. And on the *y*-axis, the lower, the better their math scores at 3.5 years old. This line tells us that on average, the better a baby's number sense, the stronger their later math skills.

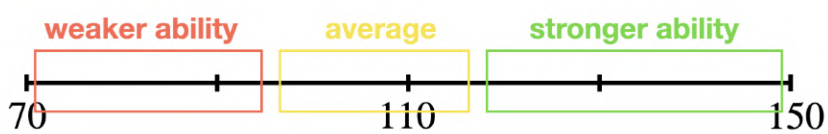


We'll come back to this graph later, but first we'll tell you about the second test. The children took the **Test of Early Mathematics Ability** (**TEMA-3**), which is a widely used standardized math exam for preschoolers.

Test of Early Mathematics Ability

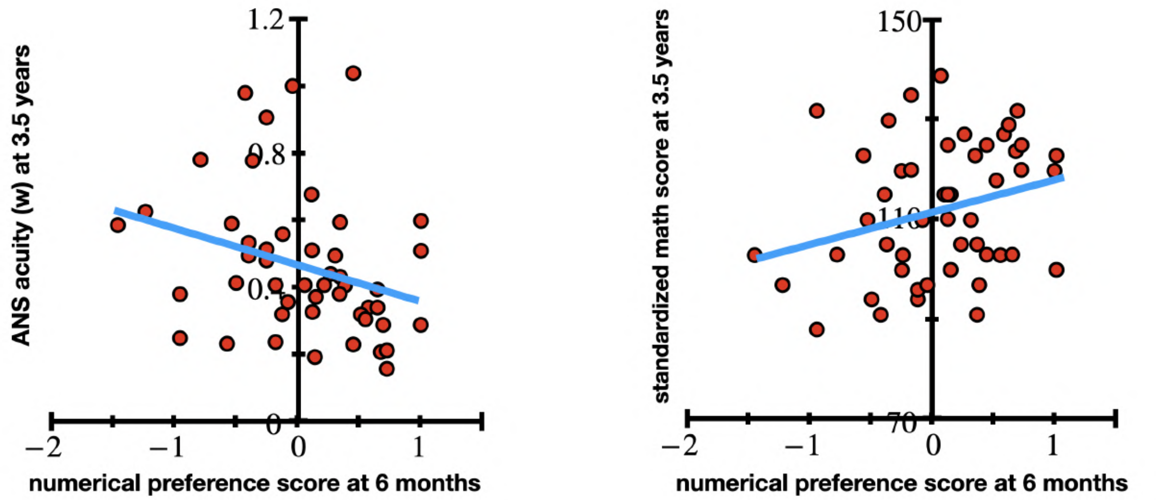


The raw results are converted into a standardized score. Scores around 100 means average for that age.

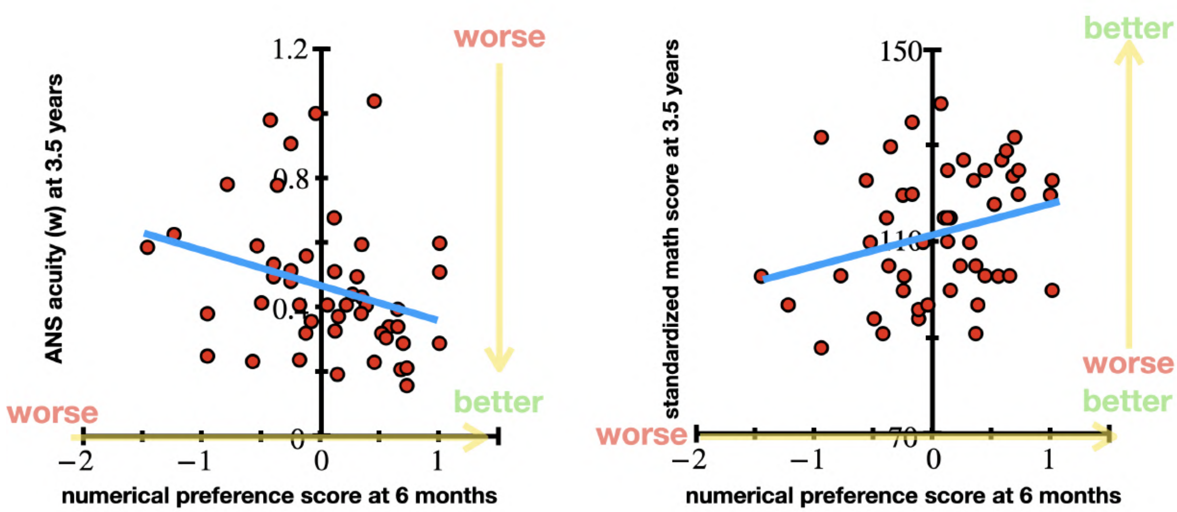


standardized math score at 3.5 years

Higher scores indicate stronger early math skills (like counting, number facts and basic arithmetic). And lower scores mean weaker math ability for their age. Essentially, *higher numbers = better math performance*. The graphs below show their scores combined.



The upward slope of the line means that the more a baby preferred number changes, the higher their math scores later.



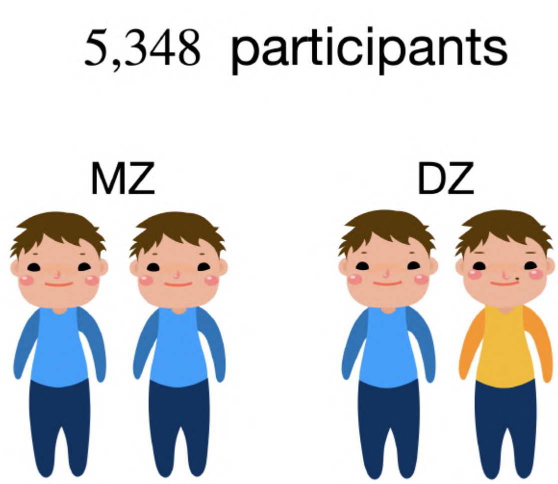
We can see that on average, the prediction of the researchers was true: the babies with a better number sense tended to be better in math later on. But the thing is, the tendency is not very strong, and even the researchers acknowledged that.

It’s very fair to say that some people are born with a sharper number sense, and on average those individuals are more likely to perform better in math as they grow up. But the thing is, this trend is pretty modest, and there are plenty of exceptions, because genetics is more of a contributing factor than a determinant.

But, has anyone ever tested how much genetics influence *mathematical ability* versus *environment*? Fortunately, yes, in a twin study that we’ll discuss now.

Genetics vs Environment

The nice thing about twins is that *identical twins* (which the study labeled **MZ**) share $\sim$ 100% of their DNA. *Fraternal twins* (labeled **DZ**) share $\sim$ 50% of their segregating DNA. The final results included the participation of $5,348$ individuals, all of whom were 10 years old.



The hypothesis was that if identical twins are more similar in math performance than fraternal twins, then there's a clear and significant influence of genetics.

All the twins took a math test aligned with the **UK National Curriculum**, which covered:

1. *"Understanding number"*: numerical and algebraic processes.

Example:

These three numbers are alike in some ways: 9, 36, 81.
Click on the two ways in which they are alike'

2. *Non-numerical processes*: mathematical processes and concepts such as rotational or reflective symmetry and other spatial operations.

Example:

Which is the longest drinking straw? Click on it

3. *Computation and knowledge*: calculation ability and recall of mathematical facts and terms.

Example:

Click on each even number.

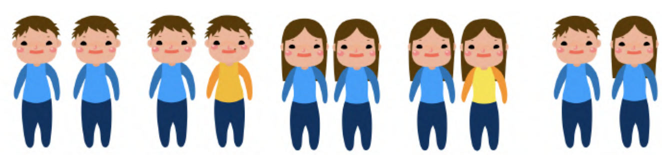
All four-sided shapes are called what?

Type in the answer: 149 + 785 = ?

And the results were summed into a

4. *Composite score.*

The table below shows the results of how similar the answers were between each set of twins in each subject. Remember **MZ m** stands for identical male twins, **DZ** for fraternal males. Same for the other but **f** for female, and **opp** means fraternal one male and one female. The n represents the number of twin pairs.



Variable	MZ m	DZ m	MZ f	DZ f	DZ opp
Understanding number	48 %	31 %	49 %	35 %	34 %
	$n = 120$	$n = 124$	$n = 143$	$n = 119$	$n = 248$
Non-numerical processes	42 %	42 %	39 %	40 %	35 %
	$n = 128$	$n = 130$	$n = 139$	$n = 115$	$n = 239$
Computation and knowledge	46 %	30 %	44 %	38 %	31 %
	$n = 135$	$n = 121$	$n = 131$	$n = 125$	$n = 239$
Composite	59 %	40 %	58 %	44 %	37 %
	$n = 123$	$n = 144$	$n = 135$	$n = 117$	$n = 239$

In general, identical twins had higher concordance rates, which means they scored more similarly with each other than fraternal twins did.

Variable	MZ m	DZ m	MZ f	DZ f	DZ opp
Understanding number	48 % $n = 120$	31 % $n = 124$	49 % $n = 143$	35 % $n = 119$	34 % $n = 248$
Non-numerical processes	42 % $n = 128$	42 % $n = 130$	39 % $n = 139$	40 % $n = 115$	35 % $n = 239$
Computation and knowledge	46 % $n = 135$	30 % $n = 121$	44 % $n = 131$	38 % $n = 125$	31 % $n = 239$
Composite	59 % $n = 123$	40 % $n = 144$	58 % $n = 135$	44 % $n = 117$	37 % $n = 239$

So, the results were pretty similar, especially between identical twins. But what these tables don't tell us is how much of that similarity is because of their genes, and how much of it is because of their *shared environment* or *non-shared environment*. The results are obviously also influenced by the fact that the siblings were raised together.

The explanation of how that was measured is a teeny bit complicated, so we won't discuss the details here because that would take way too long. If you would like to know the precise answer, check out the research paper below. We will just discuss the final results here.

The Genetic and Environmental Etiology of High Math Performance in 10-Year-Old Twins

There are 3 categories of influence: *Genetic* (DNA), *Shared Environment* (same parents, same housing, etc), and *Non-Shared Environment* (different teachers, friends, hobbies, etc).

	Genetic (A)	Shared Environment (C)	Non-shared Environment (E)
Understanding number	$a^2 = .52$	$c^2 = .14$	$e^2 = .34$
Non-numerical processes	$a^2 = .09$	$c^2 = .44$	$e^2 = .47$
Computation and knowledge	$a^2 = .42$	$c^2 = .18$	$e^2 = .40$
Composite	$a^2 = .53$	$c^2 = .25$	$e^2 = .22$

Overall, genetics alone explained about **half of the variance** in *Understanding Number* ($a^2 = .52$), *Computation & Knowledge* ($a^2 = .42$), and the overall *Math Composite* ($a^2 = .53$).

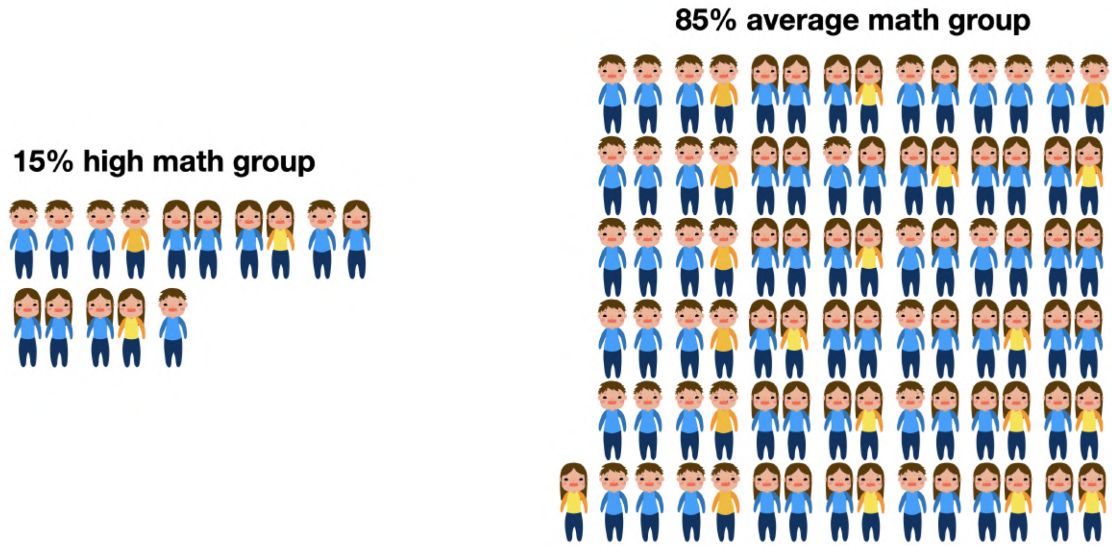
For *Non-numerical processes*, genetics was very small ($a^2 = .09$) and not statistically significant. So spatial-like reasoning is a lot more influenced by your environment.

The shared environment was significant for *Non-numerical processes* ($c^2 = .44$) and the *Composite* ($c^2 = .25$). But it was not significant for *Understanding Number* ($c^2 = .14$) or *Computation & Knowledge* ($c^2 = .18$).

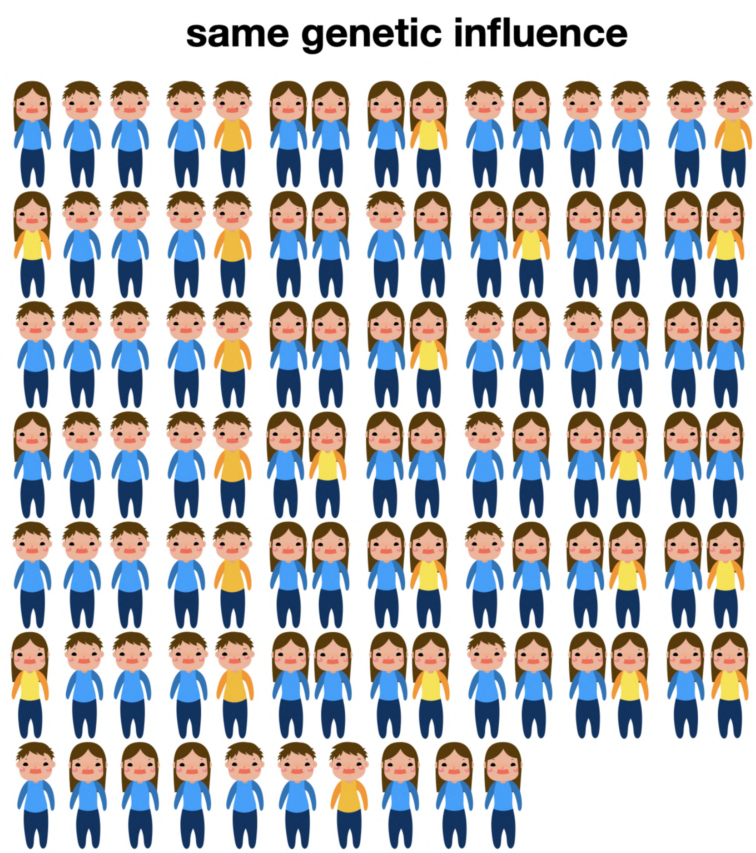
And the *Non-shared environment* (including error) was significant for all outcomes.

Ok, we've given you a lot of numbers, but essentially the conclusion is this: in general, both genetics and environment play an important role in your math level. But here's an interesting detail:

The kids were separated into those that scored better than 85% of the others. Is there any difference between them and the others? Whether genetic or environmental?



No, there was no meaningful difference in influence. So the outcome is that everyone, whether they're good in math or not, are influenced by the same proportions of genetics and environment.



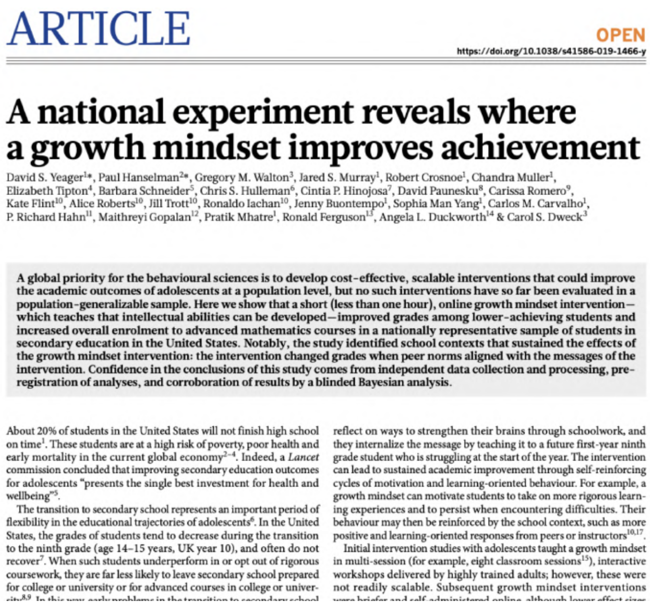
This study is the first of its kind, so it serves as an indicator of what determines our math abilities. To answer our initial question, whether genetics influence our math ability, the answer is yes, they do, to an extent.

If you watched the video and you like math, chances are your genetics probably favor it, since you enjoy it. In terms of success in the field of math, remember that only some of it is genetics. That leaves the other part up to the environment, and up to your effort.

Does Hard Work Actually Matter?

None of these studies showed the influence of hard work and the effect it had on their math skills. It mostly measured genetic influence, without any extra effort. So none of these actually compare hard work with natural talent.

There are many studies that show that with enough determination, anyone can succeed in becoming better at a subject, despite possible disadvantages.



ARTICLE

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https://doi.org/10.1038/s41586-019-1466-y

A national experiment reveals where a growth mindset improves achievement

David S. Yeager[1]*, Paul Hanselman[2]*, Gregory M. Walton[3], Jared S. Murray[1], Robert Crosnoe[1], Chandra Muller[1], Elizabeth Tipton[4], Barbara Schneider[5], Chris S. Hulleman[6], Cintia P. Hinojosa[7], David Paunesku[8], Carissa Romero[9], Kate Flint[10], Alice Roberts[10], Jill Trott[10], Ronaldo Iachan[10], Jenny Buontempo[1], Sophia Man Yang[1], Carlos M. Carvalho[1], P. Richard Hahn[11], Maithreyi Gopalan[12], Pratik Mhatre[1], Ronald Ferguson[13], Angela L. Duckworth[14] & Carol S. Dweck[3]

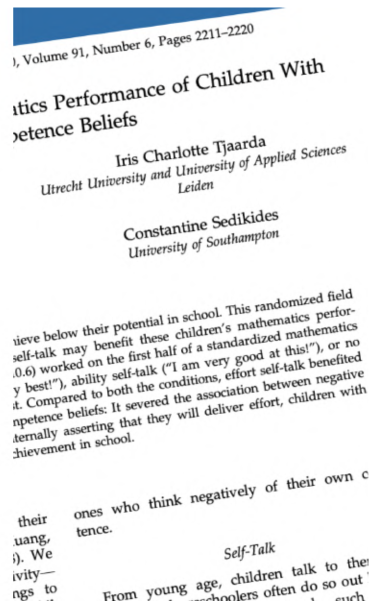
A global priority for the behavioural sciences is to develop cost-effective, scalable interventions that could improve the academic outcomes of adolescents at a population level, but no such interventions have so far been evaluated in a population-generalizable sample. Here we show that a short (less than one hour), online growth mindset intervention—which teaches that intellectual abilities can be developed—improved grades among lower-achieving students and increased overall enrolment to advanced mathematics courses in a nationally representative sample of students in secondary education in the United States. Notably, the study identified school contexts that sustained the effects of the growth mindset intervention: the intervention changed grades when peer norms aligned with the messages of the intervention. Confidence in the conclusions of this study comes from independent data collection and processing, pre-registration of analyses, and corroboration of results by a blinded Bayesian analysis.

About 20% of students in the United States will not finish high school on time[1]. These students are at a high risk of poverty, poor health and early mortality in the current global economy[2–4]. Indeed, a *Lancet* commission concluded that improving secondary education outcomes for adolescents "presents the single best investment for health and wellbeing"[5].

The transition to secondary school represents an important period of flexibility in the educational trajectories of adolescents[6]. In the United States, the grades of students tend to decrease during the transition to the ninth grade (age 14–15 years, UK year 10), and often do not recover[7]. When such students underperform in or opt out of rigorous coursework, they are far less likely to leave secondary school prepared for college or university or for advanced courses in college or univer-

reflect on ways to strengthen their brains through schoolwork, and they internalize the message by teaching it to a future first-year ninth grade student who is struggling at the start of the year. The intervention can lead to sustained academic improvement through self-reinforcing cycles of motivation and learning-oriented behaviour. For example, a growth mindset can motivate students to take on more rigorous learning experiences and to persist when encountering difficulties. Their behaviour may then be reinforced by the school context, such as more positive and learning-oriented responses from peers or instructors[10,17].

Initial intervention studies with adolescents taught a growth mindset in multi-session (for example, eight classroom sessions[15]), interactive workshops delivered by highly trained adults; however, these were not readily scalable. Subsequent growth mindset interventions



), Volume 91, Number 6, Pages 2211–2220

atics Performance of Children With
petence Beliefs

Iris Charlotte Tjaarda
Utrecht University and University of Applied Sciences Leiden

Constantine Sedikides
University of Southampton

ieve below their potential in school. This randomized field
self-talk may benefit these children's mathematics perfor-
.0.6) worked on the first half of a standardized mathematics
y best!"), ability self-talk ("I am very good at this!"), or no
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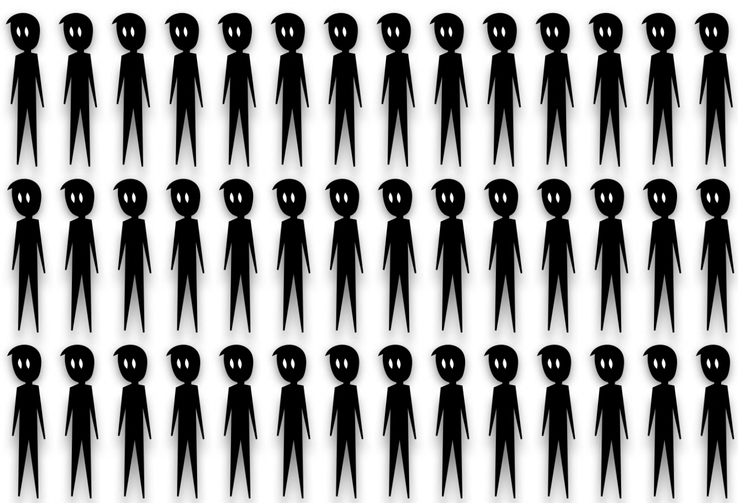
Self-Talk

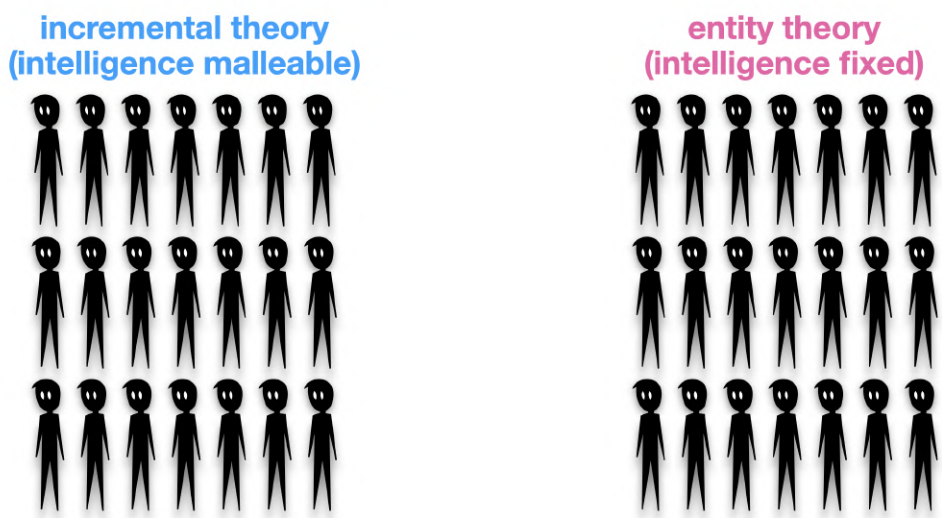
From young age, children talk to the

But in any case, did you know that it actually matters whether you believe that you can become better at math, or if you believe that the outcome is fixed?

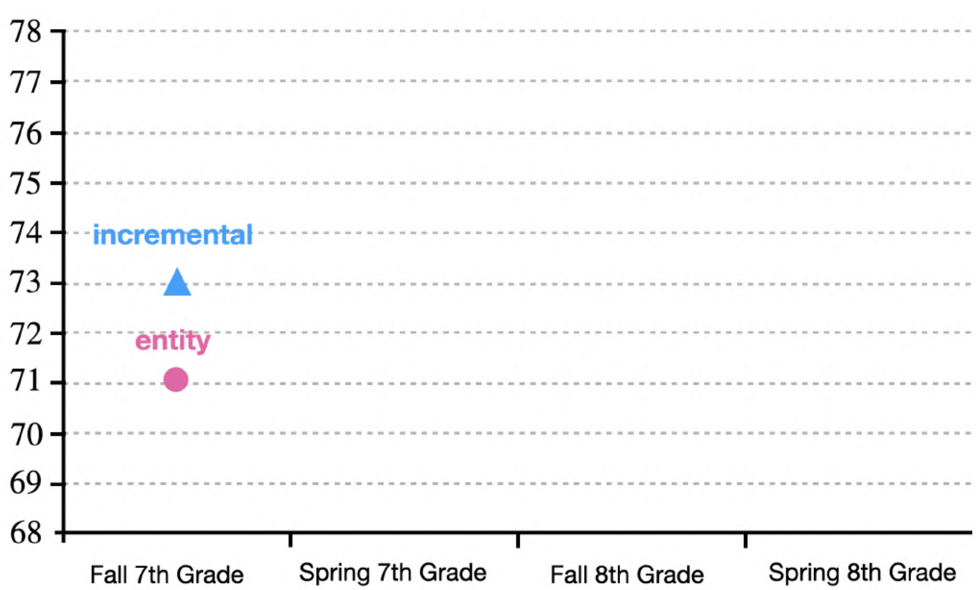


In one study, researchers followed 373 students across 7th and 8th grade. One group believed that intelligence is malleable (called **incre-**

mental theory), the other, that it is fixed and predetermined (or **entity theory**).

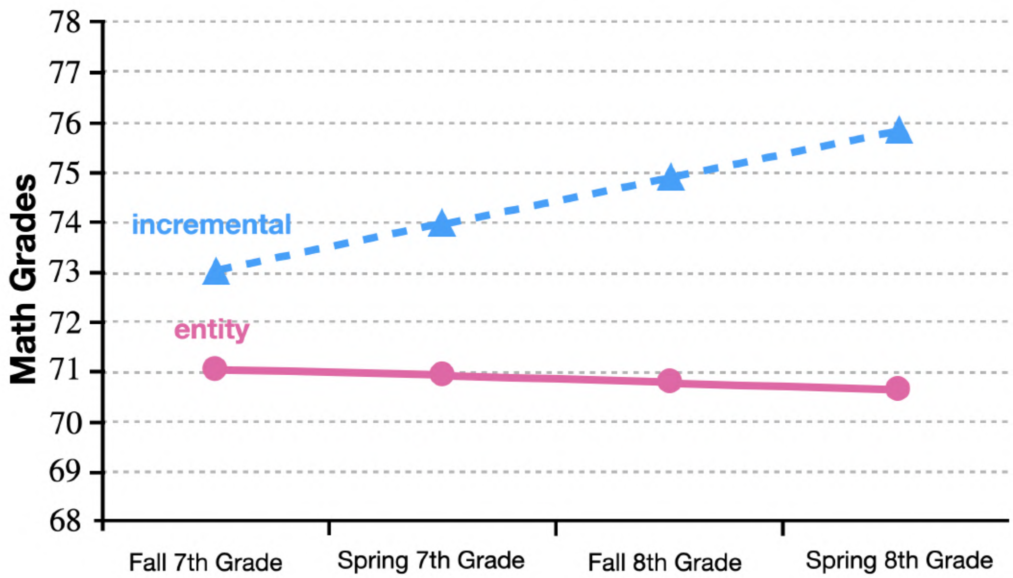


Both groups started out at similar grade levels. Each point represents the average for each group.



The y-axis represents their math grades in %. The x-axis is the time from the fall of 7th grade, through the spring of 8th grade, a total of 2 years.

Watch how they progressed:

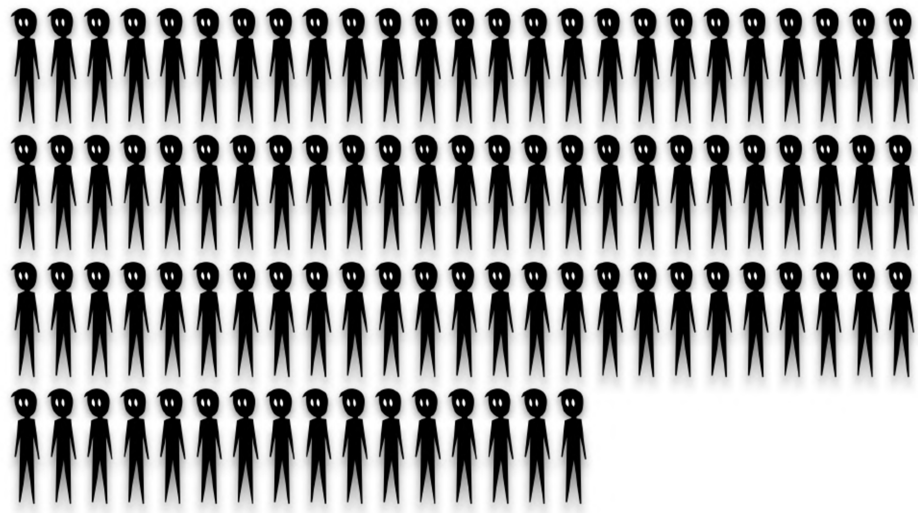


The Incremental group (or the growth mindset group) steadily increased their average across 7th and 8th grade, ending around 76%.

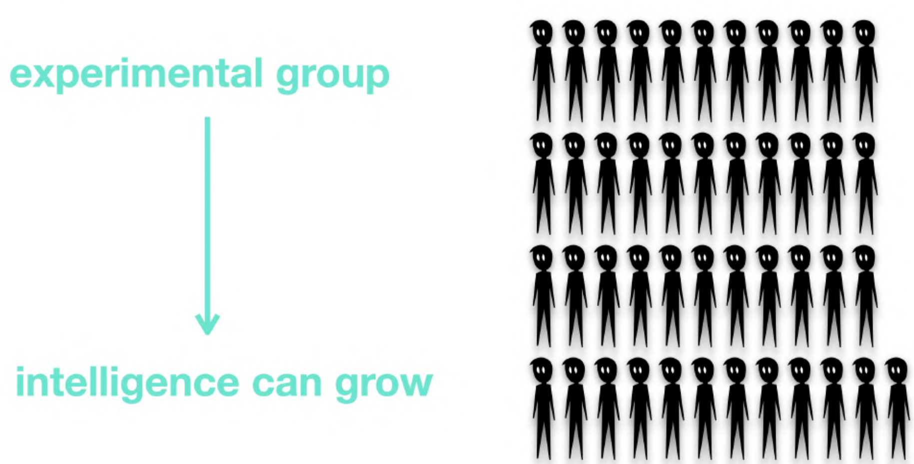
Entity groups (or the fixed mindset) had their grades stay flat or even slightly decline, ending around 71%.

Essentially this tells us that: If you believe intelligence can grow, you keep improving. But if you believe that intelligence is fixed, you actually decline. And that's not all.

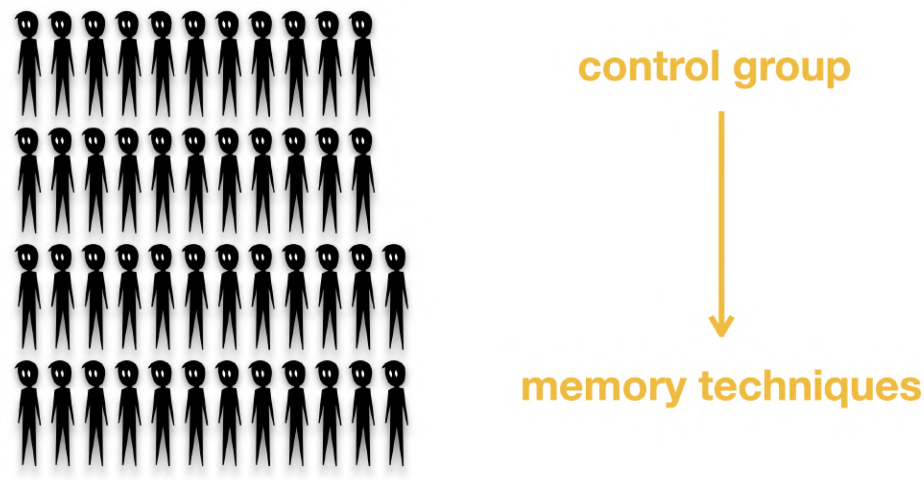
In a second study, the same researchers randomly assigned 91 students to two groups, and held one session a week with them for a total of eight weeks.



The Experimental group was taught that intelligence can grow through effort (via lessons, activities, and discussions like "You can grow your intelligence"). And the Control group learned about memory techniques, like note-taking strategies, organization skills and test preparation tips.

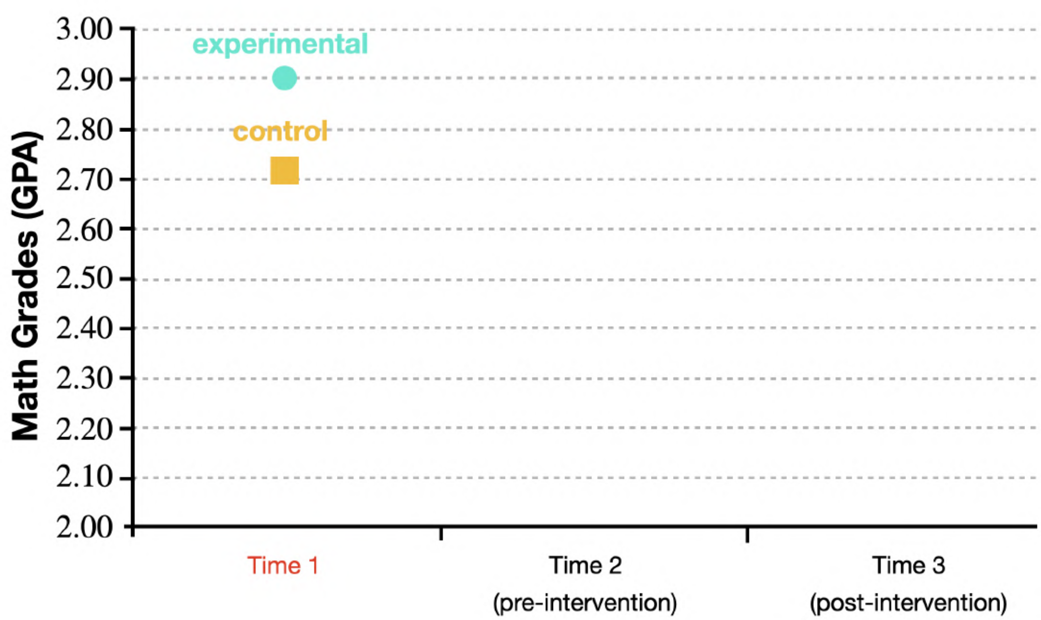


Notice that these skills don't challenge students' beliefs about intelligence. They assume intelligence is fixed, and the best you can do is manage your study habits.

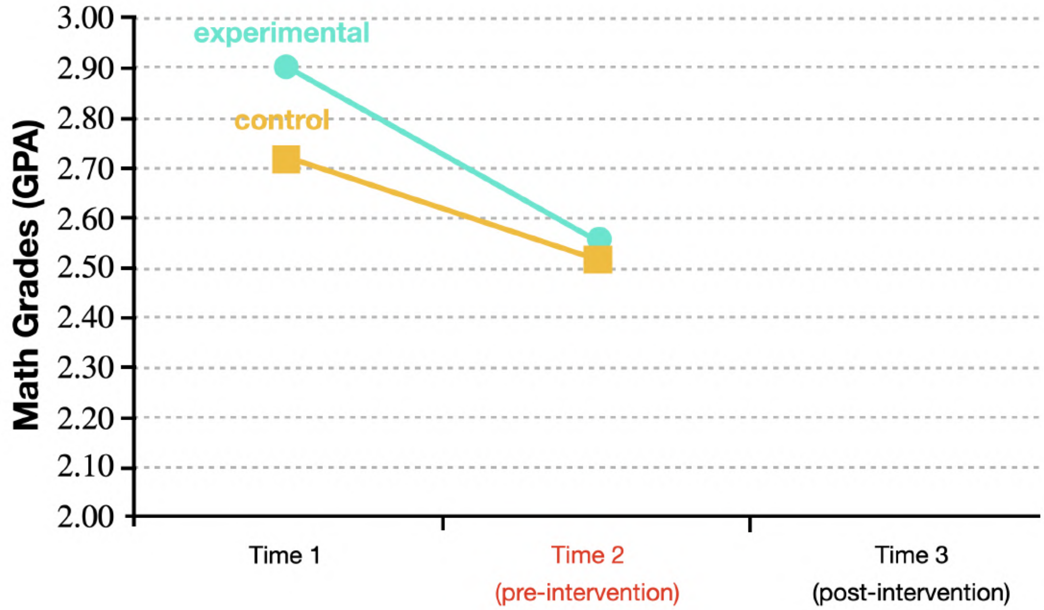


Well, here are the results:

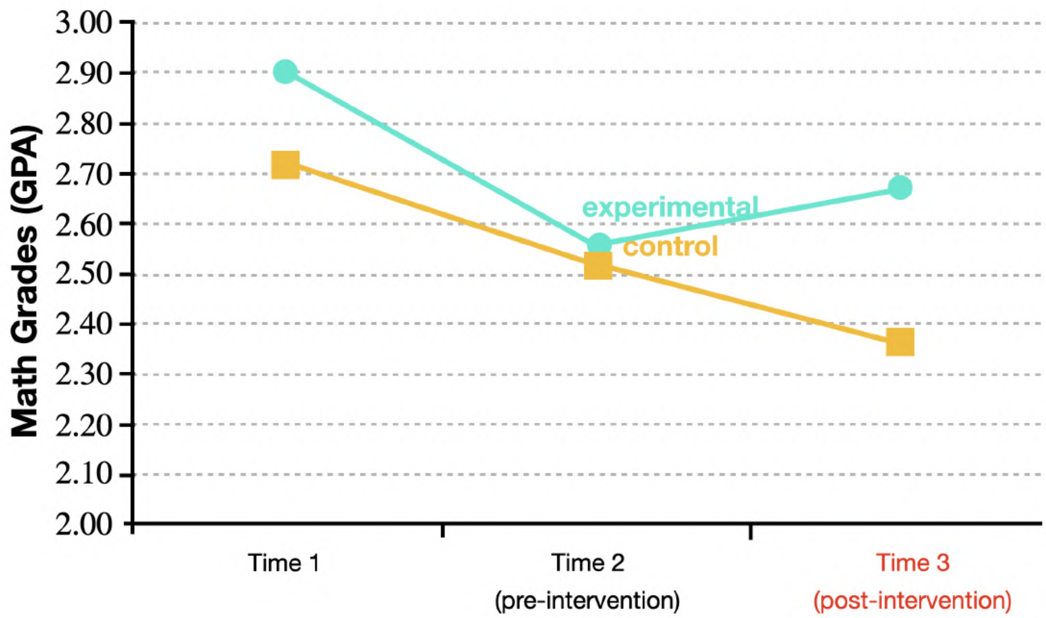
In the y-axis were the students' actual math grades (on the GPA scale). On the x-axis we have **Time** 1, which is what the grade point average was when they started, before intervention.



Time 2 represents a check of how they were doing right at the beginning of intervention (before starting the first class). The average of both groups' grades decline slightly, but that's actually a normal trend in middle school.



And by **Time 3**, after the intervention, the experimental grades rose, while the grades of the control group actually kept going down.



The conclusion from both studies is that just believing that doing the hard work can make you better in math actually makes you better in math, whether you're originally good at it or not.

To give you guys an expression, even if you aren't born a Mozart, or a genius, it doesn't mean you can't play the piano. With enough practice, you may become just as great.

In any case, modern math doesn't progress because of geniuses. Advancements in math come from decades, sometimes centuries of cumulative achievements of thousands of mathematicians. And if you enjoy doing it, it's worth doing it even just for that alone. Not to mention all the benefits your brain will be reaping from it.

If you found this document useful let us know. If you found typos and things to improve, let us know as well. Your feedback is very important to us. We're working hard to deliver the best material possible. Contact us at: dibeos.contact@gmail.com

Sources:

Number Sense in Infancy Predicts Mathematical Abilities in Childhood

The Genetic and Environmental Etiology of High Math Performance in 10-Year-Old Twins

Implicit Theories of Intelligence Predict Achievement Across an Adolescent Transition: A Longitudinal Study and an Intervention