

Math, SES, and democracy: Why are they so related?

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Executive summary

- Differences in math performance based on *socioeconomic status* (SES) are greater than SES differences in other areas of knowledge. The SES-based knowledge gap begins prior to school entry and widens over time.
- Mathematics is a way of thinking in which reason and appropriate arguments are essential. Mathematical knowledge gives adults the tools to understand the topics discussed in political campaigns and analyze information necessary for civic participation. For this reason, mathematical education is a key factor for strengthening democracy.
- Deficiencies in mathematical understanding make adults more vulnerable to political campaigns based on false or misleading information.
- Improving math ability in school (when it is easier to do) should be considered a particularly important part of a social equity policy to strengthen democracy.

A snake biting its own tail

We know, from our experience as teachers, that not all children learn equally well. The effectiveness of formal education is hindered by several factors such as genetic differences and socioeconomic status (SES) of households, among others. SES has been proposed as one of the best predictors of children's educational achievement, but the degree to which this association is genetically mediated remains unclear. However, the SES of families has been recognized as a major factor explaining academic achievement differences. In most countries, the socially determined nature of learning outcomes seems to be a disease that has come to stay. It appears we have few ideas about how to change this and ensure education contributes to social mobility rather than reflects social hierarchy.

Children from families with low SES get—on average—worse academic achievement compared with children from middle-class families. There are several longitudinal studies showing that the lower children's SES is, the worse their academic achievement, and this relation is consistent across ages of children^[1,23]. This gap starts from a very early stage. For example, toddlers from different socioeconomic groups have up to 80 words of difference at 18 months of age but the gap seems to grow at the age of 2 years old when the disparity in vocabulary development increases to 150 words^[2]. Something similar occurs in math knowledge. The household income gap in mathematics achievement is well documented in elementary school, where economically disadvantaged children have less extensive mathematical knowledge than their middle-income peers. This effect has been shown for different countries and seems to be specific for informal mathematical knowledge^[24]. However, these early SES-related differences in mathematical development are persistent and conceptually broad, encompassing not only informal knowledge of numbers but also formal math areas such as arithmetic or geometry^[3]. Different studies analyzing data from different countries have shown that early mathematical competence was the most powerful predictor of overall academic achievement throughout the elementary school years^[25].

The contribution of SES to educational outcomes seems not to be equally distributed among different competences. Data from different standardized tests (PISA, PIRLS, etc.) show that SES differences in math are greater than SES differences in language or science. So, we could say that—in most countries—the social gap for math performance in school is bigger than the gap for other areas of knowledge. This kind of analysis comes from data of standardized tests that are usually not taken at the beginning of school. For this reason, the biggest gap for math could also be a consequence of how different areas address the social gap. The increasing gap observed in math might arise from the fact that thinking mathematically is an accumulative process requiring construction on a solid basis in order for abstract operations to be acquired. Accordingly, a common belief is that math teaching and early math learning are some of the greatest cognitive challenges for human beings.

SES-related differences, which have been identified from arrival at elementary school, would not be a big problem if schooling could reduce them. But, socioeconomic gaps in school learning emerge early in life and lead to gaps in long-term achievement^[26]. Research in cognitive neuroscience reveals that poverty affects brain development in ways that can compromise future learning, which can then increase the differences between groups with different SES. Hence, in most occidental countries, the SES-related differences persist and become more pronounced with time^[4]. For example, this means that the differences detected at elementary school continue along the academic trajectory of students, provoking rates of dropout in high school that are usually three or four times higher for low-income adolescents than their middle-class peers,

globally speaking. Figures in the USA are even worse—data from 2009 showed that low-income (bottom 20 percent of all family incomes) students were five times more likely to drop out of high school than high-income (top 20 percent of all family incomes) students^[5].

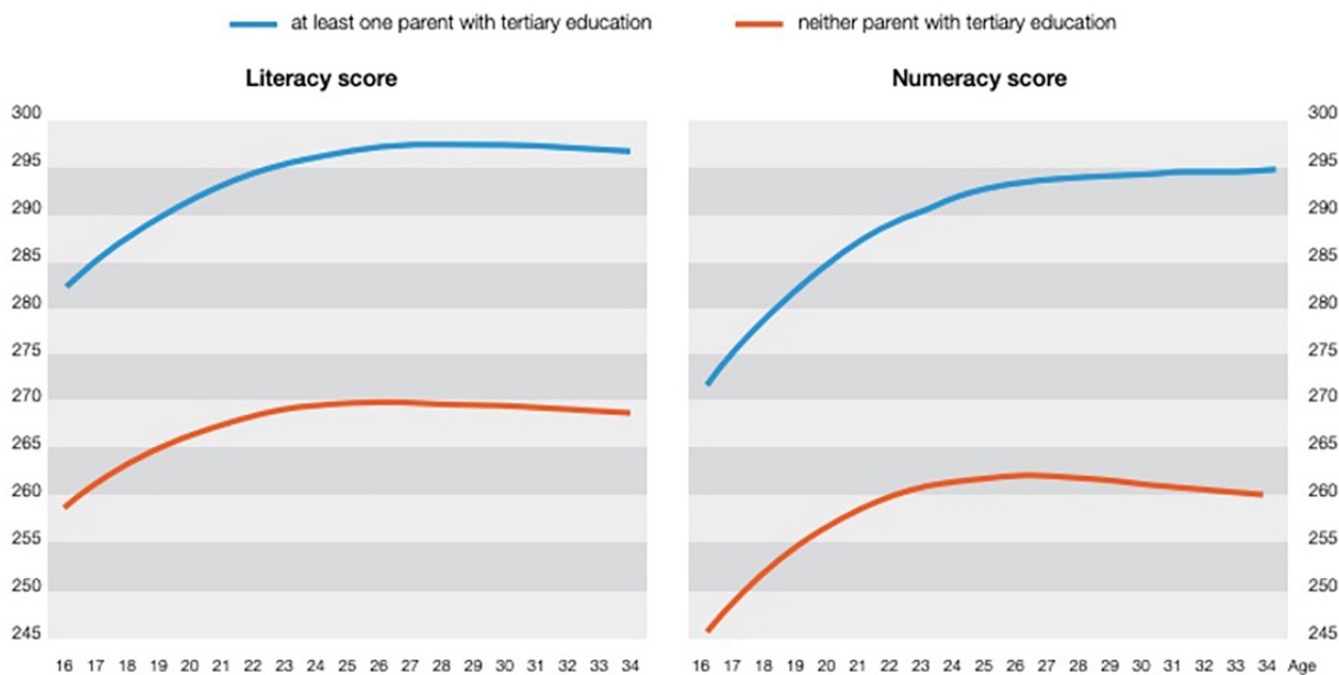
However, there is still some debate about where such early differences come from^[6], although researchers agree that they take root well before children begin school. The reasons for these differences probably include perinatal factors as well as differences in early cognitive stimulation. Most researchers agree that a key factor in explaining these differences may be the quality of the information and social interactions to which the children are exposed in their first years of life. We all know now that children do not arrive at school as blank slates upon which teachers might write the lessons of civilization. Thus, although early schooling might show no systematic differences in elementary numerical abilities, there may already be cognitive differences present that undermine mathematical learning. Low-income children often start to experience difficulties in mathematics at the beginning of the school which predict an increased risk of school failure. Economically disadvantaged children receive less support for mathematical development both at home and in preschool. Additionally, it is also true that parents' mathematics beliefs and practices vary with socioeconomic status. Middle-SES parents tend to believe the home environment plays a role as great or greater than preschool in preparing young children for school mathematics, whereas lower-SES parents believe the preschool environment plays the greater role^[7].

However, the important point here is not to determine if these differences are more related with nature or nurture, but to highlight that our school system is not achieving greater success in reducing such differences. We all know that children from some groups come to school with fewer experiences than others. For too many, these dissimilarities do not disappear at school but rather they increase. The obvious consequence is that those who lag behind their peers in specific domains learn more poorly than those who are already in possession of relevant knowledge, and this is like *a snake biting its own tail* because the "achievement gap" does not close—it widens.

Math education and democracy

Democracy is supported by the general idea that all citizens have the same rights and obligations (everyone is equal in the eyes of the law). For that reason, the election procedure must implement the principle of the same value per vote. However, we know that everyone is not equal in terms of knowledge, and less equal we are in terms of mathematical knowledge. This could be a problem for our democracies since, to understand most of the issues that are part of the political debate, citizens need a good level in mathematical skills. The normal discussions about economics, education, or even about the environment require having some mathematical knowledge in the form of percentages, probabilities, or simply understanding the information provided by a graph.

However, results of international tests on adult cognitive skills (Programme for the International Assessment of Adult Competencies of the OECD, known as PIAAC) reveal this is not the case. It seems clear that in many countries a large number of the adults do not have the basic tools that allow them to fully understand many of the topics that are usually discussed in political campaigns (to have a clearer view about the results of PIAAC, see the 2nd edition of the Technical Report of the Survey of Adults Skills^[8]). So, there might be a significant portion of adults who would have serious difficulties in analyzing the information to which they are exposed. That means they are more vulnerable to political campaigns based on false or misleading information (or, the so-called "fake news").



Note: International country average.

Source: OECD Survey of Adult Skills (2012, 2015), www.oecd.org/skills/piaac/publicdataandanalysis.

Figure 1. Differences between those who come from homes of parents with and without tertiary education in language and math skills throughout life (in the period 16–34 years).

Results about mathematical skills of adults reported are especially interesting. The OECD's international studies on adult skills (PIAAC) conducted in 2012 and 2015 show that the social gap in language and mathematical skills has different trajectories throughout adult life. As can be seen in the graph, the difference in language skills between those who come from homes of parents with and without tertiary education remains relatively stable throughout life (in the period 16–34 years). However, this difference increases for mathematical competences throughout life: The gap starts at 16 years old on 25 points and ends at 34 years old with 35 points of difference. This clearly shows that the weakest aspect of adults that come from homes without tertiary education is mathematical competence, which makes them especially vulnerable when it comes to processing information about numbers that, as we know, is a key aspect for a successful adult life. Recently, it has been shown that being better at math at the age of seven is linked with a rise through the social ranks: a better job, better housing, and higher income as an adult^[9]. However, as the authors of the report also suggest, it remains possible that childhood mathematics ability is an indicator of other variables that were not included in their model.

In short, mathematics is a way of thinking in which reason and appropriate arguments take the leading role. For that reason, mathematical education is a key factor for the strengthening of democracy. Equity in math learning is a cornerstone of a free society. It dissuades those who want to dominate people and for that reason democracy must address poor math as a fundamental problem, an attack on the basis for real democracies. In this way, promoting mathematics education in the early stages of life not only contributes to equity but also helps create empowered citizens able to participate in the big discussions our societies have today.

Could math be a driver for equity?

In the last decades, research in numerical cognition has shown that children (even babies) come into the world with a rudimentary understanding of numbers, generally referred to as a primitive number sense. Therefore, children have an intuitive, nonsymbolic, approximate sense of number^[10] that remains active across their whole lives^[11]. This sense of number supports the estimation of groups of objects and helps us to estimate different quantities in our daily life (that is, the number of people on the bus or how many cookies are still in the packet). This ability^[12] is derived mainly from a type of perception and we have identified the brain regions that support it. The brain system involved has been called the *approximate number system* (ANS) and it is a system that seems ready to be activated from birth. Recent research has shown that this system is functional in newborn infants at two days old^[13]. Therefore, we can say that the approximate number sense (ANS), which is the primary source for mathematical knowledge, is present at birth and seems to have similar properties for all of us. So, we could

say that the underpinnings of our math knowledge begin at similar starting points. In addition, research has shown that the acuity of the ANS measured during the first years of school predicts math performance later in high school^[13]. Therefore, stimulating the ANS could be useful to reduce future SES differences in formal math.

The second reason why we suggest the idea that math could be a driver to promote equity in our societies is the well-known link that exists today between math achievement and academic success. This must be an important factor, as knowledge of mathematics even in preschool predicts later general school success. Specific quantitative and numerical knowledge is more predictive of later achievement than tests of intelligence or memory abilities^[14]. Also, we know that school mathematics ability is an important factor to explain differences in later job attainment, salary, and personal debt^[15]. There is a clear narrative in our occidental societies today that connects progress, economic superiority, and mathematical competence. In a recent study^[16], researchers that had previously identified a large sample of 13-year-old adolescents who were exceptionally talented in math (measured by their SATS scores), reported data about their actual life trajectory (40 years later) and showed that most of them had accomplished even more than expected. After the analysis of their answers from a survey about their careers, accomplishments, psychological well-being, families, life preferences, and priorities, researchers affirmed that “mathematical precocity early in life seems to predict later creative contributions and leadership in critical occupational roles”^[16]. For this reason, improving math ability from the beginning (when it is easier to do) should be considered a policy for equity in the future, because math knowledge will be a determining factor for future life. So, from this perspective, policies focused on low-SES learners should be considered a particularly important part of such a social equity policy.

The previous data confirm that we must do better in understanding the sources of individual variability in mathematics comprehension and performance if we want to change the extent to which learning is determined by SES. Self-confidence is another factor that seems to be very generally important for learning. Some studies have shown that students' self-confidence in learning math influences their mathematical learning achievement. However, while there is increasing acceptance within mathematics education that confidence plays a crucial role for achievement, not much is known about the nature of this relationship and how we can stimulate self-confidence in math. It is very likely that self-confidence in math arises easily when someone obtains good results on math tests, while obtaining confidence without success appears unlikely. Two different recent studies^[17,18] have shown that training students in ANS tests for a brief period (minutes) improves performance on a subsequent formal math test. This short period of training is unlikely to directly improve math ability, so it would appear that it is simply boosting children's confidence (almost at the perceptual level) that improves their formal math performance. These studies provide preliminary evidence that interventions targeting the ANS may help children feel more confident with math content and, for that reason, better prepared for the mathematical operations they will learn to perform symbolically at school.

What account for social differences in math learning?

Differences in the elementary numerical abilities that appear at an early age in relation to SES are a too frequent reality. In order to design policies that counteract this process, we must better understand which factors determine these differences. One important issue is to clarify where and from when these differences start. Previous work by our team has found that children from low-SES schools have a less precise ANS representation than children from high-SES schools^[19]. These data show that differences arise not just for symbolic math (as standardized tests usually show) but also for estimation tasks that are based in perception. Also, it seems that those differences in the accuracy of ANS arise from a very early age (before 6 years old). It is possible that there are already perceptual differences from the first years of life, which further undermine mathematical learning.

The origin of these early differences is not clear and probably will always be debated. However, differences in parental beliefs, differences in self-confidence about how competent children are, or even differences in the type of activities and games that parents play with their kids are factors that are involved. In addition, there are differences in the use of language (vocabulary but also the type of grammatical structures that children are exposed to) that also seem to play an important role for math learning. The conceptualization of number and the formal learning of mathematics depend on children's mastery of the generative rules of their language. Therefore, the quality of stimuli but also the quality of the interaction they can have with adults help generate the differences that arise. Generally speaking, children from low-income families receive less support for math development in their home. This includes being exposed to a narrower range of mathematical concepts, compared with their middle-class peers who are usually exposed to more sophisticated counting strategies, comparison of numbers and sequencing activities as part of their daily life. So, many environmental factors may play a role in producing differences, but the quality of the interactions is the most important aspect that may counteract other environmental adverse conditions.

Implications for policy makers

Many children around the world underperform in school, especially those living in poverty. The terms “poverty” and “low SES” have been used broadly to refer to scarceness of resources and are generally associated with risks to cognitive development. However, to design evidence-based policies and interventions, it is imperative to determine what components of low SES present the major risks for cognitive development and how they interact with other factors.

For example, it has been shown that poverty influences the development of the brain in ways that may affect the basic abilities needed to benefit from traditional education programs^[20]. This in turn leads to a kind of “Matthew effect” (to he who has shall more be given). So, it is imperative that researchers and decision makers in public policy make efforts to find effective training programs that can enhance low-SES children’s abilities. This is one of the main objectives of the nascent field of educational neuroscience^[21], which is a discipline that should be more involved in the design of public policies in education. One of the crucial prerequisites for any intervention is determining the cognitive faculties that are most remediable and significant, in the sense of being easier to modify and most likely to have an effect. The hope of such an approach is that it can lead to cost-effective interventions that can be applied on a massive scale.

Parenting, as part of public policy, is a good example of this. Family support for education is a key resource for low-SES communities that needs to be explored in relation to its influence on mathematical performance. Most parents declare not to be prepared to educate their children. However, specific programs to help low-SES parents orientate their interactions in the early stages of childhood could make a big difference to the readiness of those children for school. Researchers^[22] have demonstrated a range of interventions, based on the principles that we describe above, able to promote math learning from a very early age. It is time for states to implement these as part of public policy.

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