Math stimulation from birth

Cognitive neuroscience has revealed we can discriminate between two groups of dots according to their quantity as early as just 48 hours after birth. What are the implications of such early skills for how mathematical development should be supported during infancy?

Author/s:

Alejandro Maiche

Professor of Cognitive Psychology, University of the Republic, Uruguay

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"And the first step…is always what matters most, particularly when we are dealing with the young and tender. This is the time when they are taking shape and when any impression we choose to make leaves a permanent mark."
(Plato, 428-348 BC; cited in Clarke and Clarke, 2000, p. 11)[1]

Executive summary

This article presents arguments in favor of the idea that children come to the world with some innate pieces of knowledge, particularly the knowledge about quantities that seems to arise from perceptive abilities. Specifically, the *approximate number system* (ANS)—which allows estimation of the magnitude of a group—is presented as the core knowledge system upon which the symbolic numerical skills will develop. My claim here is that an accurate ANS will allow a more refined mapping process between numerical symbols ("1," "2," "3," etc.) and approximate sets (i.e., the quantity of a set of objects).

Following this analysis, we conclude that early experience of number matters. Thus, stimulation about objects and numbers from the beginning of life seems to be a key factor for the future of learning math. The general idea is to support stimulation of the ANS in training programs that are designed to reinforce the transition to symbolic numbers. In order to do this, it is suggested that caregivers, teachers, and schools should develop different activities that could refine the mapping process between approximate numbers of objects and the exact symbols that represent quantity. In order to contribute to this process, we must transform our cognitive interventions into pedagogical strategies that teachers can implement by themselves in their classrooms.

Introduction

Let us begin at the beginning. Imagine that you have just been born. It may happen that you still have not opened your eyes, though you have surely noticed already that you have more space to move around than just a few hours ago. You can now stretch your arms and, at the same time, you start to discover that sounds are different from those you have heard from "the inside." The world begins to abruptly unfold through your senses and the stimuli from this world are going to influence your behavior for the rest of your life. Interestingly, this storm of stimuli does not seem to prevent you from pursuing two important goals at this time: eating and sleeping. Thus, an important question arises: How do we do it? How do we manage to survive in the middle of this storm of stimuli that continually threatens to distract us from what we need the most?

Biology. This might be the first answer. We could assume that biology protects us from losing our survival goals. However, a deeper answer to this essential question would require understanding a few principles of the human mind. It directly leads us to reflect upon a long-debated issue in the context of human sciences, since it addresses the tension between what is determined by our experiences and what we bring with us from birth: the so-called *nature versus nurture*[2] debate.

The idea that biology was destiny prevailed within the framework of the nineteenth-century dominant doctrine, when most scientists assumed that basically we were our genes. However, the idea that genes could explain what we are or what we do has not further proliferated through time. As a matter of fact, modern biology has smashed this idea by discovering that a given set of genes can have different effects depending on the environment that develops or, in scientific language, genes express themselves in response to environmental signals.

The twentieth century was dominated by another big idea: the idea that the mind is a blank slate (*Empiricism*). Empiricists assume that we arrive into the world as empty containers that will be filled by experiences. This doctrine was a keystone of *psychological behaviorism* (that argues all human behaviors are learnt) and it has extended to *social constructivism* (that holds all knowledge is constructed through interaction with others), as well as to different aspects of politics. This uptake is probably because the idea that our differences result from our life experiences seems more acceptable than the idea that our differences come from our genes. However, this does not seem to be the case.

In the last decades, developmental psychology has shown that all humans are born with basic cognitive skills that are a foundation for our efforts to understand the world. Moreover, these basic skills with which we come to the world are not an exclusive property of human beings but are a primitive knowledge that we share with other species. This core knowledge[3] underlies everything we learn throughout our lives. Research on human infants, animals, and children and adults in different cultures and with different experiences has shown that there are some basic systems of knowledge that operate in the young human mind for learning but also continue to play a central role in the adult mind. Therefore, we could assume today that either our genes can explain what we are or that the mind is a just blank slate that has to be filled.

The more accepted idea among scientists today is that we do come to the world with a bunch of "programs" that enable survival, but the process of surviving may be mediated by learning (because this is the only way to keep you alive in a dynamic environment—i.e., one that is changing). Learning is not a set of rigid instructions for behavior, but rather programs addressed to take information from the senses that enable new actions and new thoughts. Thus, the baby will probably need primarily to eat and sleep, but he or she will also need to deal with key elements of the world, such as faces, others' intentions, or even quantities in order to guarantee their survival in the future.

Cognitive science has shown that there must be some innate mechanisms that make it possible for newborns not to deviate from their goals (sleeping and eating in our former example) while stimuli and experiences prepare them to understand new things. In the words of Pinker, we could say "The development of organisms must use complex feedback loops rather than pre-specified blueprints. Random events can divert the trajectories of growth, but the trajectories are confined within an envelope of functioning designs for the species"[2].

Dewey already expressed a similar idea in the context of school. He believed children did not arrive at school as blank slates upon which teachers might write the lessons of civilization. By the time the child entered the classroom, "he was already intensely active, and the question of education is the question of taking hold of his activities, of giving them direction"[4]. This is exactly the case for math. In the last decades, research has shown that children (even babies) come into the world with a rudimentary understanding of numbers referred to usually as a primitive number sense. In the rest of this article, we try to argue that the teaching of math at school should take into account that children already have some primitive (and approximate) knowledge about numbers.

Numbers from birth—really?

A long time before entering school, children have an intuitive, nonsymbolic, approximate sense of number[3]. This intuitive sense of number is something that we, as adults, continue to use throughout our life. It is what helps us estimate the number of people on the bus, birds in the sky, or cookies in the package. We use it every time we think of math (both in school and in our everyday lives), and we have discovered in recent years that some specific brain areas activate every time we perform these kinds of tasks[5]. These brain regions support what has been called the approximate number system (ANS), a system that is functional in newborn infants from when they are 2 days old[6].

Cognitive neuroscience has shown that newborns as young as 48 hours old can discriminate between two groups of dots according to their quantity. In this experiment[6], behavioral data show that babies (2 days old) can discriminate between sets of 4 versus 12 dots and also between 6 versus 18 dots, but they fail to discriminate between sets of 4 versus 8 dots. This piece of evidence supports the idea that the ANS is part of the knowledge that enables us to understand the world from birth. Nevertheless, taking this result together with the results of some other experiments, we must assume that the precision of the ANS emerges with cognitive development, which also suggests some flexibility in this capacity[7]. For example, 6-month-old babies can discriminate numerosity in a 1:2 ratio (8 versus 16) and 10-month-old babies are expected to discriminate quantities that differ in a proportion of 1:3.

Recently, an interesting discussion has arisen about how and why this refinement process occurs. Data seem to show that age and education primarily increase the ability to focus on number information and avoid interference from irrelevant, but often co-varying, dimensions such as area or density[7]. In addition, there is a positive correlation between ANS acuity and symbolic math performance throughout development, suggesting that the ANS may be a foundation for the acquisition of uniquely human symbolic numerical capabilities[7]. Indeed, some studies suggest that children's early number sense is an important predictor of later math performance[9]. Inspired by those studies, some recent work has suggested that training ANS precision may transfer to improvements in symbolic mathematics. Specifically, it seems that training with nonsymbolic addition and subtraction has an enhancing effect on math performance[10].

However, increasing ANS precision alone is likely to be insufficient for improving math performance at school. The idea that the ANS would be a foundational skill for number understanding assumes that children must connect information that the ANS provides with the symbolic and exact world of math. Thus, in respect of our claim that teachers should consider the knowledge of quantity that children acquire before starting school, we can say acquiring a precise ANS is like possessing "good terrain" for math readiness. It is very likely that a precise ANS will better support the mapping process between concrete elements (e.g., the number of objects that a child observes) and exact symbols.

Conversely, if attempts to acquire symbolic math occur against a background of low ANS precision, the mapping process between approximate sets and numbers will probably be noisier. In those conditions, it is very likely that mathematical concepts could be acquired only as formal procedures with scarce connection to the manipulation of real objects. That may result in poor understanding of the meaning of the formal procedures that the symbols represent. In such circumstances, children will acquire formal math competences, but their possibilities for expanding mathematical knowledge will be limited because they cannot use the power and flexibility that abstract concepts usually permit. So, the acquisition and subsequent handling of the math symbols will be weak if the mapping process is established alongside a blurry and noisy ANS that cannot sharply discriminate between different quantities.

These conclusions are based on data that support the idea that the ANS is a prerequisite for learning mathematics, at least in the initial stages of development[11]. However, it is true that cognitive science has still to fully understand the finer mechanisms that permit a connection between the ANS and formal math. This future understanding will help disentangle the multiple sources of information that play a role in this mapping process from the first time that newborns start sensing the world.

From perception to numbers: An evolved capacity for math

It is clear to every parent or teacher that a child begins with an imprecise representation of quantities and numbers. This imprecision increases with the cardinal value to be represented[12]. It has been shown that newborns use the ANS to discriminate between different dot clouds[5]. This ability to discriminate dot clouds increases from childhood to adulthood[13] and reinforces the idea that the ANS could be understood as a key building block that supports acquisition of formal mathematical skills. Several studies have shown a high correlation between this perceptual discriminative ability guided by the ANS and the different formal mathematical abilities of individuals, measured by different standardized tests[14]. Furthermore, the relationship between ANS acuity and math ability remains even when controlling for nonnumerical cognitive abilities such as general intelligence, visuospatial ability, and working memory. In fact, there are studies that suggest that a preschool child's accuracy on the ANS is a good predictor of his future mathematical performance[10].

From this perspective, we assume that the approximate computation of numbers is grounded on our most primitive abilities and resembles the way we estimate other perceptive dimensions such as color, speed, brightness, or even duration[15]. Thus, from this viewpoint, it is reasonable to think that the core principles of perceptive organization[16] and low-level perceptual mechanisms, such as adaptation[17], provide a basis for the appearance of mathematical abilities in children. The main idea these studies support is that our perception of objects constitutes the first level in processing information, which will constitute the basis to develop more abstract abilities such as the handling of numbers, sequencing, and even the possibility of performing symbolic operations. Therefore, we may say that it is the perceptual processing of objects that prepares the human mind to handle symbols and algorithms.

Arithmetic could be understood as a symbolic game with more or less complicated rules[19]. This is the main reason why math teaching should take into account the cognitive foundations that support the emergence of symbolization in humans and how their ontogenetic development is understood. Symbolization is a developing capacity of the human mind, and it is also what makes mathematical thinking a powerful tool to solve problems. It is used to evoke a procedure but also to calculate a result that can be used again as a part of another procedure, so supporting a higher level of mental manipulation. This iterative process implies that compact symbolism can be used to represent a complex concept[20]. In this sense, we claim that mathematical skills can be a direct consequence of the cognitive abilities that underpin them and, for that reason, the stimulation of these underpinning cognitive abilities from birth should be a key factor for teachers to consider.

Implications for caregivers and teachers

Children start becoming prepared for math a long time before we, as caregivers or even teachers, usually notice. For that reason, it is important to be ready to play with them in ways that involve numbers and quantities as much as we can. Also, it can be useful to have "number talks" in every situation that allows these. Caregivers and teachers have to keep in mind that children are always trying to understand the world around them and information about quantities is something they naturally seek to understand better. They are aware that those "strange words" like "two" or "five" that they hear a lot are an important part of the world they have just arrived in. Thus, they will always be eager to capture information about numbers to more fully understand the relationship between objects and these words, which represents some emerging quality about sets of objects (i.e., quantity).

It may be very important that caregivers and teachers keep these ideas in mind when interacting with children. In this way, they can naturally guide their interactions with the intention of refining the mapping process between sets of objects and symbols as numbers or number-words.

Implications for policy makers

The ideas discussed above aim to provide evidence for the importance of design activities or games that are addressed specifically to facilitate the connection between the approximate number system and the exact symbols that are used in formal math. From this viewpoint, a game-based preschool curriculum—particularly for stimulating the ANS—would be a clear advantage for preschool education.

Moreover, data of academic trajectories show that investment in preschool can boost primary school achievement. Thus, investment in preschool activities, games, and pedagogical resources is clearly the best investment for better education. However, a focus on parenting could also be part of an economic policy aimed at supporting math competence in early childhood, although it is important to remember that such aspects of educational policy focused on parenting should form part of a general policy that is directed and promoted by the school.

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