How Our Emotions and Bodies are Vital for Abstract Thought: Perfect Mathematics for Imperfect Minds

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Synopsis from chapter abstracts

Mathematics is uniquely, beautifully, incredibly precise. The human brains that we use for math, on the other hand, are anything but perfect. How could this be true? Is mathematics really eternal, universal truths we discover? Or could it simply be a human invention? Introducing a neuroscience-inspired approach to this puzzle, this chapter addresses formal logical thinking, the phenomenon to which, people like to believe, math owes its special status. Formal logic is not perfect, and it cannot be the only tool of math or any other genuine intellectual creativity. Philosophy, psychology, linguistics, epistemology and the history of science all seem to support that idea; most importantly, strict mathematical logic itself agrees, as Gödel's incompleteness theorem tells us. Real breakthroughs in science demand both conscious logical thinking and subconscious, emotional, intuitive processes (for example, the Eureka moment). What's more, emotion precedes cognition and paves the way for formal logical thought. Chapter 1 introduces these ideas and refers to George Lakoff's theory about the nature of human thought. According to Lakoff, people divide things into categories, and think about them not in a logical, but rather an analogical way, in accordance with superficial similarities. This categorization is the foundation of all our thinking, from the perception of concrete objects up to the very highest mathematical concepts; clearly, however, it does not have much to do with pure reason.

The human cortex is considered to be the seat of abstract thought, so how it creates abstractions is central to this discussion. Chapter 2 demonstrates that this process is never precise, for two reasons: first, because of the way the cortex integrates external stimuli have in common, and second, because of the way in which the cortical columns function. These microscopic neuronal formations group things together, by unconsciously dividing concrete objects into categories by analogy, according to apparent similarities between them. These are the deceptive categories Lakoff describes. From the start, they compromise the validity of increasingly abstract neural representations. Because neuronal resources are limited, phenomena that we poorly understand are often placed in inappropriate categories, or remain uncategorized and are therefore excluded from the cognitive process altogether. Categorization is the original sin of abstract thought: it is unconscious, it is biased toward external features, it precedes logic, and therefore it cannot be logical. Yet logical thought fully relies on categorization. This chapter also discusses numerical cognition, and concludes that neither the concept of a number, nor any numerical operation, can be absolutely error-free.

Chapter 3 turns to Working Memory, which is a person's ability to hold information in his mind and manipulate it. No logical sequence can be built without it. In terms of physiology, Working Memory is the simultaneous retaining of several neural networks that encode units of information. Any information in Working Memory can be combined in various configurations in pursuit of the optimal solution to a problem. This is how our conscious logical processing functions. But Working Memory has two serious constraints. First, it is highly tuned to the environment and biased towards the superficially apparent features of things, while it pays the internal world — the body — little attention. Second, it has a very limited capacity. To be useful, every neural network entering into it must encode a large quantity of information in compact, abbreviated form. These shortened networks inevitably dismiss and distort some relevant data. Therefore, a portion of potentially valuable information never penetrates into Working Memory and thus cannot be taken into consideration logically. This is one more reason the cortex, which is responsible for formal logic, cannot create precise abstractions. But mathematics does in fact do this, so there must be additional players at work.

As Chapter 1 shows, intuition is the engine of formal logic. But intuition is an emotional phenomenon: it does not prove a solution itself, but rather gives us a strong feeling of confidence in it. So Chapter 4 takes a look at the neurophysiology of emotions, specifically the emotional brain, located in the limbic system. That system is also a central regulator of how the body functions as a whole. The emotional brain is the central hub where the neural networks representing our bodily life are most closely in touch with cortical networks representing the external world and our thoughts. In other words, this is the central interchange where body and mind meet. The chapter explains why cortical activity, and specifically cognitive activity, are impossible without functioning emotions, addressing these issues from several points of view: evolutional, neuroananatomical, neurophysiological, behavioral, and psychological, using examples from clinical practice, literature, history, and the biographies of great mathematicians. Surprisingly enough, emotions not only necessary but especially important in solving complex abstract problems that we usually think of as purely logical.

Finding the correct solution to any problem ultimately means recognizing it as the correct solution. Chapter 5 examines the mechanisms of recognition. Clinical studies have shown it has two components: cognitive, concerning factual information about the object, and emotional, the feeling of familiarity. The emotional brain generates the feeling of familiarity only when cortical networks representing the external features of an object and factual information about it correspond with their internal, bodily equivalents. For recognition to be genuine and complete, both its cognitive and emotional components must arrive in Working Memory. In this case we usually do not attach importance to the role of emotion and wholly attribute solutions we find to our conscious logical processes. But we are not always aware of enough relevant information. The sense of familiarity may penetrate into Working Memory alone, without its cognitive counterpart. In that case, we feel that solution is correct, but we cannot yet prove it. Sometimes this results in what everyone knows as a "Eureka moment."

Chapter 6 addresses what might constitute a correspondence between bodily and cortical neural networks. Both types of neural networks are traces remaining of our previous experiences (personal or evolutional). These schemes may break down into fragments over time, so remembering, recognizing, and problem-solving requires putting the fragments of cognitive and bodily networks back together again. If they match, we can experience the feeling of familiarity. But making a scientific discovery means finding something for the first time, precluding previous experience by definition. In that case, the correspondence between schemes needs to be sought at a deeper level, in terms of the biological and physical characteristics of their material carriers. The bodily tissues of the human brain have at their disposal the immense repertoire of biological and physical processes and interactions that take place in nature, and thus it has immense capabilities for finding correspondences between them. This is how the body might provide logic with vital information and significantly improve its performance.

The outwardly apparent features of objects inevitably mislead our formal logic, yet our understanding of mathematics is nevertheless extremely precise. Why? In math, the cortex cannot rely on appearances, because unlike all the other sciences, math is about every object and phenomenon. In this case the cortex cannot categorize things, so it cannot misinform the body about them. Here the body first suggests to the cortex what they might have in common. The book proposes that those commonalities might be the characteristics of physical motion, which is inherent to every living matter and reflect the most fundamental features of nature: space and time. In the brain, space, time and numbers are inseparably linked even at the level of a single number neuron. Physical movement, and the space-time relationships that movement reflects, are what we perceive first, and they also serve as the foundation for how those objects and quantities are later conceptualized. Space-time relationships between signals from the outside are the ultimate common denominator that allows us to classify information, develop new neural networks and transform concepts one into another. Chapter 7 and the book, then, conclude that we cannot do math, or think at all, by reason alone. Abstract thought requires the physicality of our nature; it is literally incarnate in our bodies and our emotions. Indeed, mathematics, which we often think of as the pinnacle of our powers of logic, succeeds thanks to the fact that in math, uniquely, our logical intellect does not lord it over the feelings and the body, but instead heeds them very carefully. This is why in mathematics we have succeeded so well at mitigating the fallacies of cognition and creating uncannily precise and universal scientific models.

Orthodox mathematical Platonism, though it may seem to be the quintessence of pure reason, has not so much intellectual as aesthetic, or emotional, roots. Math is first and foremost a sense of absolute beauty, complete internal harmony. Only secondarily is it an attempt, even if a very successful one, to express this divine feeling in impoverished human language and share it with the world. Whether we like it or not, our algorithmic logic still needs to rely on intuition: on the feelings that overwhelm us, on the body that is indivisibly linked to them, and on our physical nature, which reveals itself to us in the language of mathematics. We people did not invent this nature — rather, it invented us; and in just the same way, we did not invent its language. We only found a way to understand it.