Decoding the Geometry of the Mind: An Exploration of Universal Geometric Cognition

JULY 18, 2023

In the growing field of geometric cognition, one name stands out due to her significant contributions: Elizabeth Spelke. A Professor of Psychology at Harvard University, Spelke is known for her pioneering work on the cognitive development of infants and children. Her research has provided fundamental insights into how young minds perceive and understand the world around them.

One of Spelke's most influential research areas involves understanding how human beings, from infancy, comprehend the geometric properties of the world (https://geometrymatters.com/beyond-core-knowledge-natural-geometry/). This work has been instrumental in shaping the field of geometric cognition, a branch of cognitive science that studies how people understand, perceive, and reason about geometry and space.

Spelke and her collaborators have proposed a fascinating theory: that humans possess innate geometric abilities that emerge early in infancy and form the foundation of our understanding of the physical world. This suggests that geometry is not merely a mathematical concept taught in school but a universal mental construction inherent to the human brain.

In the "Geometry as a Universal Mental Construction," chapter (from "Stanislas Dehaene & Elizabeth Brannon, *Space, Time and Number in the Brain*) co-authored with Véronique Izard, Pierre Pica, Stanislas Dehaene, and Danielle Hinchey, Spelke delves deeper into this theory. They present compelling evidence supporting their idea, drawn from studies conducted across different cultures and age groups.

The team begins their exploration by discussing the broad concept of geometry and its universal presence. They state, "The study of geometry concerns the properties of space, as revealed through the shapes and relative positions of objects". This statement indicates that geometry is not limited to academic contexts but is deeply interwoven with our day-to-day perception of the world.

The researchers argue that humans and many animal species share an intuitive understanding of basic geometric principles. This understanding guides their interactions with the environment and aids in navigation. Furthermore, this geometric intuition seems to be innate, surfacing in infancy long before formal education begins.

The authors make a compelling case by citing a variety of studies. For instance, they reference research showing that babies as young as six months old can recognize simple geometric shapes and patterns. Other studies demonstrate that preliterate cultures, devoid of formal geometric instruction, still exhibit a robust understanding of spatial relationships and geometric properties. Spelke's team also delves into the universality of geometric cognition. They write:

> "Geometry is not a cultural invention, but a universal mental construction", underscoring the inherent nature of geometric understanding, and reinforcing the idea that it transcends cultural and educational boundaries.

While the universality of geometric cognition may be compelling, one might wonder how this inherent understanding develops and evolves over time. Spelke and her team address this question by exploring the cognitive mechanisms that underpin our geometric abilities. They propose that our brains are wired to process geometric information and that this ability becomes more refined and complex as we grow and learn.

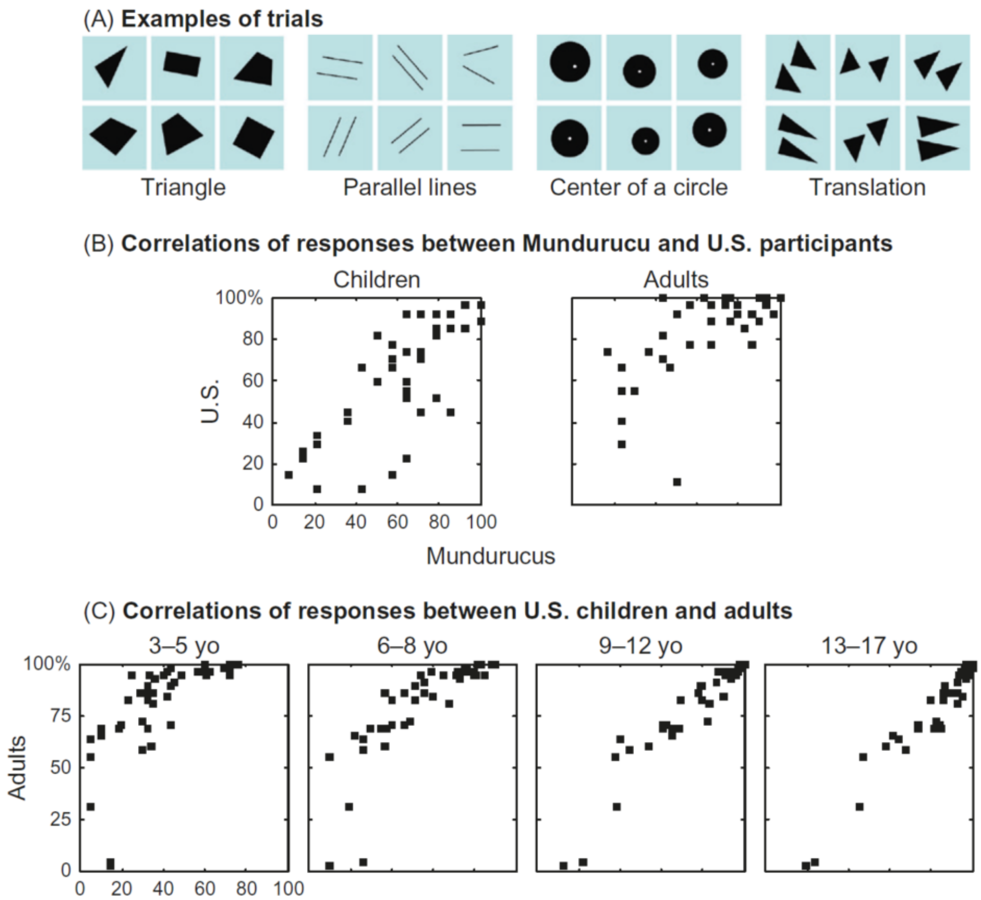

FIGURE 19.1 Generic test of geometric intuitions. Participants were presented with a series of 45 slides such as those in (A), each illustrating a distinct geometric property. In each slide, five of the images share a geometric property which the last image lacks. The participants were asked to pick the image that was "different", or "weird and ugly". The test was first administered to 14 children and 30 adults from the Mundurucu population, as well as control groups of 26 children and 28 adults in the US. The responses across trials were highly correlated between these two populations, in each age group (B). Later, the test was also administered to 448 participants from the US aged three to 51 years, and revealed the same correlation across age groups (C). A and B adapted from [2]; C adapted from [3].

The researchers highlight the role of two core systems in the development of geometric cognition. The first system, referred to as the "object core system," allows us to perceive and understand the geometry of small-scale, navigable space around us. This system helps us recognize shapes, understand their properties, and comprehend their position in relation to other objects.

The second system, known as the "geometric module," is responsible for understanding large-scale environmental geometry, enabling spatial navigation over large distances. This system helps us form mental maps of our surroundings and navigate complex environments, using geometric cues such as distance and direction.

These core systems, according to Spelke and her team, are not unique to humans but are shared with other animal species. This shared geometric intuition, they argue, points to the evolutionary importance of geometric cognition, reinforcing the idea that the ability to understand and navigate space is critical for survival.

Spelke's team goes on to discuss how these core geometric systems interact with other cognitive processes. They suggest that language plays a crucial role in shaping and refining our geometric understanding. For example, the words and phrases we use to describe space and location can influence how we perceive and navigate our environment.

The researchers also touch upon the role of cultural and environmental factors in shaping geometric cognition. They argue that while the basic framework of geometric understanding is universal, the specifics can be influenced by one's cultural background and experiences.

This exploration of geometric cognition has profound implications for education. By understanding how children naturally perceive and understand geometry, educators can better tailor teaching strategies to harness these innate abilities. This approach could potentially make the learning of complex geometric concepts more intuitive and enjoyable for students.

Spelke and her team also point out the potential for further research in this field. They suggest that understanding the cognitive processes behind geometric cognition could shed light on broader questions about human cognition and brain function.

The researchers illuminate the fascinating interplay between geometry, cognition, and language. They propose that our geometric understanding shapes our language, which in turn influences our perception and navigation of space. This cycle, they suggest, drives the development of geometric cognition throughout our lives. This perspective opens up new avenues for exploring the relationship between language and cognition. By studying how different languages describe and categorize space, researchers can gain insights into how language shapes our thought processes and perceptions.

Spelke's team concludes their chapter with a call to action for researchers. They encourage further exploration of geometric cognition, suggesting it could be a fertile ground for uncovering fundamental truths about human cognition and brain function.

This research brings to light the profound and pervasive influence of geometry on our daily lives. From the way we perceive objects and navigate our surroundings, to the way we conceptualize and communicate about space, geometric cognition underpins many of our interactions with the world. But perhaps one of the most exciting aspects of Spelke's work is the potential it holds for future research and applications. As we deepen our understanding of geometric cognition, we may find new ways to enhance learning, navigate our environment, and even interact with technology.

By combining insights from psychology, neuroscience, linguistics, and education, we can build a more comprehensive understanding of how humans perceive, understand, and interact with the geometric world.

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Chapter Glossary

Universal
Present in all normally developing human beings, irrespective of their environment, level of education, etc. Some properties may even be universal beyond the human species, but in the present article we will only consider claims pertaining to humans.
Innate
Determined by genetic or epigenetic mechanisms, rather than learned from the environment. Some innate features may not be present at birth, as for example the beard

in human males. Claims of innateness are hardly accessible to experimentation, contrary to claims of universality.

Intuition

A form of knowledge that is accessible to explicit report, although its justification is not. In the present experiments, participants were often able to pick the correct response without being able to explain why they took such choice.

Sense

The geometric property that distinguishes two figures that are mirror images of each other. More generally, given a trajectory in a geometric space, a value of sense can be attributed to this trajectory depending on whether it bears more often to the left or to the right.

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Chapter Summary

Geometry, etymologically the "science of measuring the Earth", is a mathematical formalization of space. Just as formal concepts of number may be rooted in an evolutionary ancient system for perceiving numerical quantity, the fathers of geometry may have been inspired by their perception of space. Is the spatial content of formal Euclidean geometry universally present in the way humans perceive space, or is Euclidean geometry a mental construction, specific to those who have received appropriate instruction? The spatial content of the formal theories of geometry may depart from spatial perception for two reasons: first, because in geometry, only some of the features of spatial figures are theoretically relevant; and second, because some geometric concepts go beyond any possible perceptual experience. Focusing in turn on these two aspects of geometry, we will present several lines of research on US adults and children from the age of three years, and participants from an Amazonian culture, the Mundurucu. Almost all the aspects of geometry tested proved to be shared between these two cultures. Nevertheless, some aspects involve a process of mental construction where explicit instruction seem to play a role in the US, but that can still take place in the absence of instruction in geometry.

Geometry as a Mental Universal Construction, Véronique Izard, Pierre Pica, Stanislas Dehaene, Danièlle Hinchey, Elizabeth Spelke in
Space, Time and Number in the Brain, Elsevier, pp.319-332, 2011

VIA: GEOMETRY AS A UNIVERSAL MENTAL CONSTRUCTION (HTTPS://PHILPAPERS.ORG/ARCHIVE/IZAGAA.PDF)

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