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Geometry

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The word *geometry* means to “measure the world,” and humans have evolved sensitivities to some of the world’s geometries, including its small-scale, manipulable objects and its large-scale, navigable places. Humans, in turn, have populated their world with geometry; across cultures and historical time, human art has been full of abstract geometric designs. From at least the time Euclid organized all the definitions and postulates of his *Elements*, geometry has also meant the study of such abstractions, including infinitesimal points, lines, and surfaces, which go beyond what can be directly experienced. Both intuitive geometric abilities and abstract formalizations have supported many of humanity’s greatest cultural achievements, from art and architecture to science and technology. For the cognitive sciences, the task is to understand the origins of these geometries within the human mind, including what they measure in the world and how.

History

Plato made geometry the gateway to his Academy; according to legend, the warning “Let no one ignorant of geometry enter” was etched above its portal. Geometry was seen as the model of abstract thought—indeed, of intelligence itself as measured by whether someone could mentally traverse the *pons asinorum*, “the bridge of asses,” which was the name given to the isosceles triangle theorem. Just as Plato extolled geometry’s virtues, he also sought its origins, famously eliciting the doubling of a square’s area from an unschooled boy in the *Meno* to support his theory of innate ideas.

After Plato, philosophical debates over the origins of geometry continued, with a long history of compelling—and often contradictory—accounts by the likes of René [Descartes \(1637/2006\)](#), Immanuel [Kant \(1781/1998\)](#), and Edmund [Husserl \(1939/1970\)](#). These accounts relied on different understandings of the human mind, and contemporary work in the cognitive sciences intervenes with empirical investigations that examine whether and how formal and informal, abstract and intuitive geometry might originate and grow in such a mind. These accounts also relied on different understandings of the world, in particular, especially since the 19th century, whether that world conforms to the principles of Euclidean, plane geometry.

With a continued emphasis on age-old questions of geometry’s innateness, universality, and origins, whether in the world or in the mind, geometry has regained some of its status as the paradigmatic model of abstract thought in the contemporary cognitive sciences.

Core concepts

The human mind contains different geometries, from unconscious intuitions about shape and space to verbal and visual proofs learned in school. The goal of a cognitive science of geometry is to elucidate the scopes and limits of each geometric ability and then to ask whether and how they are related.

Geometric cognition includes three areas: *everyday geometry*, *symbolic geometry*, and *abstract geometry*.

Everyday geometry

Everyday geometry comprises intuitive sensitivities to geometric information like lengths, distances, and directions that are used to recognize objects by their shapes or navigate from one place to another.

Before infants can reach, crawl, or talk, they are sensitive to the basic geometry of shapes ([Schwartz & Day, 1979](#)). They are more sensitive to changes in a shape's side lengths than its angles ([Dillon et al., 2020](#)) or the direction it is facing ([Lourenco & Huttenlocher, 2008](#)), perhaps reflecting a use of *shape skeletons*—abstract, hierarchical structures common across the forms of living things ([Ayzenberg & Lourenco, 2022](#)). Adults across cultures ([Dehaene et al., 2006](#)) as well as nonhuman animals ([Spelke & Lee, 2012](#)) show these same shape sensitivities, so early shape sensitivities may have evolutionary origins ([Spelke, 2022](#)).

Consistent with the reorientation behavior of nonhuman animals ([Spelke & Lee, 2012](#)), young toddlers reorient themselves after being disoriented in simple, navigable environments using the distance and directional relations of the surfaces in the extended layout ([Lee et al., 2012](#)) [see [Spatial Cognition](#)].

Symbolic geometry

Symbolic geometry is how geometric information is made explicit in symbols, whether words or images. Symbols that refer to the everyday geometry of objects and places tend to make shape information about objects explicit, but they tend not to make location information about places explicit.

Languages convey distinctive information about an object's shape but do not specify location information without a specialized measurement vocabulary. Even spatial prepositions convey only schematic information about locations in space ([Landau & Jackendoff, 1993](#)).

Young children's drawings often include objects but omit the extended surfaces that define the geometry of a place, and the first extant depictions of objects in the art historical record are tens of thousands of years earlier than the first extant depiction of a place's extended surfaces ([Dillon, 2021](#)). Despite this emphasis on objects in drawing production, young children can just as easily use depicted place information as they can object information when interpreting a symbolic map or picture ([Dillon & Spelke, 2017](#)).

Abstract geometry

Abstract geometry goes beyond the perceived world to conceptions of dimensionless points, widthless lines, infinite planes, and other ideal objects that populate formal geometries.

Adult humans develop concepts conformal with Euclidean abstractions regardless of formal schooling and even when their language does not include formal geometric vocabulary ([Izard et al., 2011](#)). Across cultures, geometric proofs often rely on pictures and language to elicit such abstractions, as in the Indian mathematician Bhāskara II's seeing-is-knowing “behold” proof of the Pythagorean theorem or in the “broken bamboo” problem for the same theorem in the Chinese *Nine Chapters on the Mathematical Arts*.

In professional mathematicians, the same brain regions are active during reasoning about geometric abstractions as those that are active in nonmathematicians during basic judgments about number and space ([Amalric & Dehaene, 2016](#)), suggesting that abstract geometric intuitions might be grounded in everyday ones.

Questions, controversies, and new developments

Four main dichotomies frame the current debate about geometry's cognitive origins. The first is whether geometry is uniquely human ([Sablé-Meyer et al., 2021](#)) or is founded on geometric sensitivities shared by humans with other animals ([Spelke & Lee, 2012](#)) [see [Animal Cognition](#)]. The second is whether geometric reasoning is abstract and symbolic ([Sablé-Meyer et al., 2022](#)) or must be supported by mental simulations of physical information, like simulated navigation ([Hart et al., 2018](#)) [see [Mental Representations](#)]. The third is whether human geometry is Euclidean ([Izard et al., 2011](#)) or merely approximates Euclidean geometry ([Hart et al., 2022](#)). The fourth is whether human geometry emerges from a specific, modular language of thought ([Dehaene et al., 2022](#)) or from humans' domain-general natural language faculty ([Lin & Dillon, 2024](#)) [see [The Language of Thought Hypothesis](#)].

In striking ways, these debates return to Plato, in whose footsteps contemporary cognitive scientists continue when looking to the child—or even infant—to elicit the mind's innate and learned geometries [see [Cognitive Development](#)]. Like so much of cognitive science, the study of geometry also often seems Kantian, seeking the concept-generating work of synthesis in cognition ([Dehaene & Brannon, 2010](#)).

Broader connections

Understanding how humans come to know the abstractions of formal geometry from its cognitive origins may be the gateway to improving formal mathematics education around the world ([Dillon et al., 2017](#)). The boy in Plato's *Meno* was enslaved; perhaps this was his only encounter with formal geometry or any mathematical instruction. What insights on the world he may have discovered had the lessons continued ([Goldin et al., 2011](#))!

Researchers in machine learning and artificial intelligence have recently turned to geometry as a test case for understanding abstract reasoning ([Trinh et al., 2024](#)). By testing whether geometry can be achieved by purely learning-driven approaches ([McClelland, 2022](#)) or instead requires some innate inductive biases, these investigations may ultimately inform nativist/empiricist debates about the origins of knowledge more generally [see [Bayesian Models of Cognition](#)].

Geometry is an interdisciplinary subject par excellence, and striking findings from the past few decades have shown that the cognitive sciences give unique insight into its origins and use ([Reilly, 2019](#)). The rich history and future of the cognitive study of geometry suggests Plato was onto something when he privileged geometry among the sciences.

Acknowledgments

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