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Mo'Math Mo'Fun!

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Synopsis

A youth named Kartik encounters the National Museum of Mathematics in NYC.

In 2006, the only mathematics museum in The United States at the time, The Goudreau Museum, shut its doors. Shortly after, a team began planning to create a Museum of Mathematics with a much larger scope. Led by Glen Whitney, a hedge fund quantitative analyst at Renaissance Technologies, a group of innovators got to work dreaming up the museum. Prior to opening, the museum raised over 22 million dollars; this enabled the idea to morph into an incredible reality.

Figure 1: National Museum of Mathematics. Image by *Beyond My Ken* [CC BY-SA], from https://en.wikipedia.org/wiki/Museum_of_Mathematics via Wikimedia Commons.

The National Museum of Mathematics, or MoMath, opened its doors on December 12, 2012 at 11 East 26th Street between Fifth and Madison Avenues in Manhattan, New York City. The two-floor, 19,000 square foot space contains interactive exhibits that present mathematics in an exciting and innovative way. The museum aims to illuminate patterns that abound in our world and to enhance public understanding and perception of mathematics, as well as to combat the current complacency surrounding innumeracy in the United States. During my summer internship at the museum, I witnessed the incredible impact that the museum had on many of its visitors. This piece attempts to capture the experience of a young child, Kartik, truly experiencing mathematics for the first time at MoMath.

As Kartik strolled through Madison Square Park, a distant pi-shaped doorknob piqued his attention. His feet quickly followed his wandering eyes into The Manhattan Museum of Mathematics. Once inside, he was utterly confused. Instead of being surrounded by numbers and equations, Kartik found himself in the company of a Hyper Hyperboloid, a three-dimensional printer, and two Square-Wheeled Tricycles.

Kartik wondered: "How can these exhibits contain any mathematics? How can they possibly be related to the math I see at school?" The exhibits seemed completely unrelated to the monotonous calculation and memorization that he was familiar with.

Kartik's confusion reflects an unfortunate side effect of current mathematical pedagogy practice: the misrepresentation of mathematics. Their experiences with school mathematics often lead students into believing that mathematics is just the study of numbers and computation. This is, in actuality, only a partial truth. Mathematics is also the study of patterns and their varied representations.

The Museum of Mathematics offers visitors unique mathematical encounters, urging them to interact physically with mathematics. This enables them to experience the omnipresence, beauty, and diversity of mathematics concretely, in contrast to the pencil-and-paper conventions of school mathematics which students are most accustomed to. Like many other museum visitors, Kartik's time in the museum would permanently alter his perception of mathematics.

Kartik first went over to the "Coaster Rollers" exhibit, wondering what type of mathematics lay hidden within it. The exhibit featured a movable platform in the shape of a Reuleaux Triangle[1] which rested upon a layer of objects, each of constant width and acorn-like in shape.

Figure 2: Coaster Rollers at MoMath. Left image by Stephanie Ogozalek (available at http://mommypoppins.com/content/the-new-museum-of-mathematics-adds-up-to-educational-fun-for-nyc-kids), right image by MoMath (available at http://momath.org/gallery/), used with their permission.

As Kartik examined the exhibit, a MoMath staff member asked him if he wanted to go for a ride. Naturally, he obliged. As he climbed onto the platform, the staff member asked him if he expected to experience a smooth or bumpy ride as he and the platform moved across the various objects below. Kartik responded: " Well, probably bumpy! I mean … The objects aren't spherical? Not like bowling balls or anything."

To his great surprise, Kartik experienced a smooth ride as he pulled himself and the platform across! Perplexed, he inquired after the workings of this apparent magic and learned about shapes with constant width. Kartik was astonished to learn that there were shapes other than spheres that had a constant height regardless of what point was touching the ground. Indeed he learned of a plethora of three-dimensional shapes, all with constant width.

[1] The Reuleaux Triangle, which can be formed from three identical circular arcs, is a shape of constant width; in fact it has "the smallest area for a given width of any curve of constant width," see http://mathworld.wolfram.com/ReuleauxTriangle.html.

Upon further reflection, the oddity began to make more sense to Kartik. If the height of the platform stayed constant and was only resting upon the objects below, one could deduce that the height of the objects below must stay constant as they roll with the platform. The mathematician explained that all the 'acorn-like' shapes beneath the platform actually have less volume than spheres of the same constant width. This makes these shapes more efficient than spherical objects in situations where material is a costly input. Kartik was slowly becoming persuaded that MoMath might be filled with mathematics after all. Eager for more, Kartik proceeded to the square-wheeled tricycle, the museum's famed exhibit.

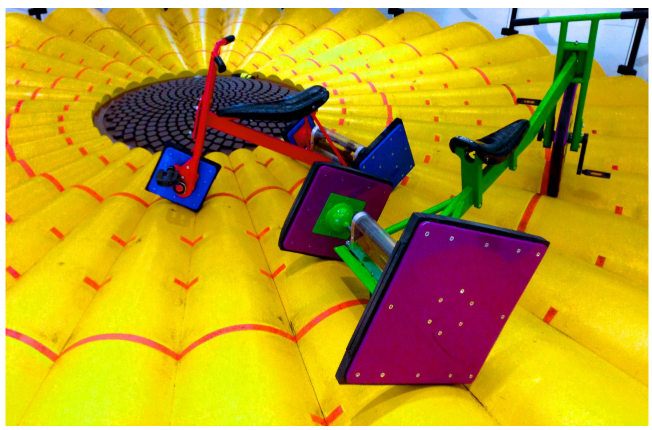

Figure 3: The square wheeled tricycle at MoMath, reflecting Glen Whitney's comment that there exists a road for every wheel. Photo by Lola Thompson, available at http://math.uga.edu/~rscott/teaching/4250_Sp2013/, used with her permission.

Kartik hopped on the tricycle and embarked on a bizarre ride. He was yet again surprised by the smoothness of his ride: "How can a square wheeled tricycle ride smoothly?!" Soon he noticed that the corner, or the vertex, of the wheel always landed in the divots of the curved track. He thought he had discovered all the mathematics that the exhibit had to offer and explained this to the docent working the exhibit.

To Kartik's surprise, the woman had more mathematical information to offer. She explained that the track was not composed of a randomly curved surface but rather by a catenary curve. She informed him that there was a specific equation to represent a catenary curve, $y = a\cosh(x/a)$. She was confident that Kartik had seen many catenaries in his life; the famous Gateway Arch in Missouri and natural hanging chains are examples of catenaries.

Kartik also learned that if the corner of the wheel always lands in the divot, one could deduce that the arc length of the catenary must equal the length of the side of the wheel. The docent also told him that the tricycle track is intentionally in the shape of a sunflower.[2] Kartik was thrilled! He was realizing that he lived in a world built upon mathematical foundations.

Kartik then walked over to the Hyper Hyperboloid exhibit. Another amicable docent told Kartik that a hyperboloid is a type of three-dimensional surface described by the equation $\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{z^2}{c^2} = 1$.[3] Kartik stepped inside of the hyperboloid and sat upon the inner swivel chair. As he spun, the two hyperboloids transformed before his eyes into lined vertical cylinders. Kartik was amazed that a curved surface such as a hyperboloid could be composed of straight lines.

Figure 4: The Hyper Hyperboloid exhibit at MoMath. Photo by Marissa Fessenden, from http://blogs.scientificamerican.com/observations/please-play-with-your-math-new-museum-opens-in-new-york-city/, used with her permission.

[2] The numbers of clockwise and counter-clockwise spirals in the middle of sunflowers are typically two consecutive Fibonacci numbers, see http://momath.org/home/fibonacci-numbers-of-sunflower-seed-spirals/ for more.

[3] For an easy introduction to the hyperboloid and other quadric surfaces see http://tutorial.math.lamar.edu/Classes/CalcIII/QuadricSurfaces.aspx.

While Kartik found the result surprising, he could not see the importance or application of such a finding. The docent explained that it is often difficult to bend certain construction materials and that this information could be used to create curved structures by using otherwise straight materials. Many materials lose their strength when they are bent, therefore using straight materials allows for the creation of stronger curved structures.

Moving over to the next exhibit, Kartik faced the Tracks of Galileo. This exhibit contained an alterable roller coaster track along with a small car.

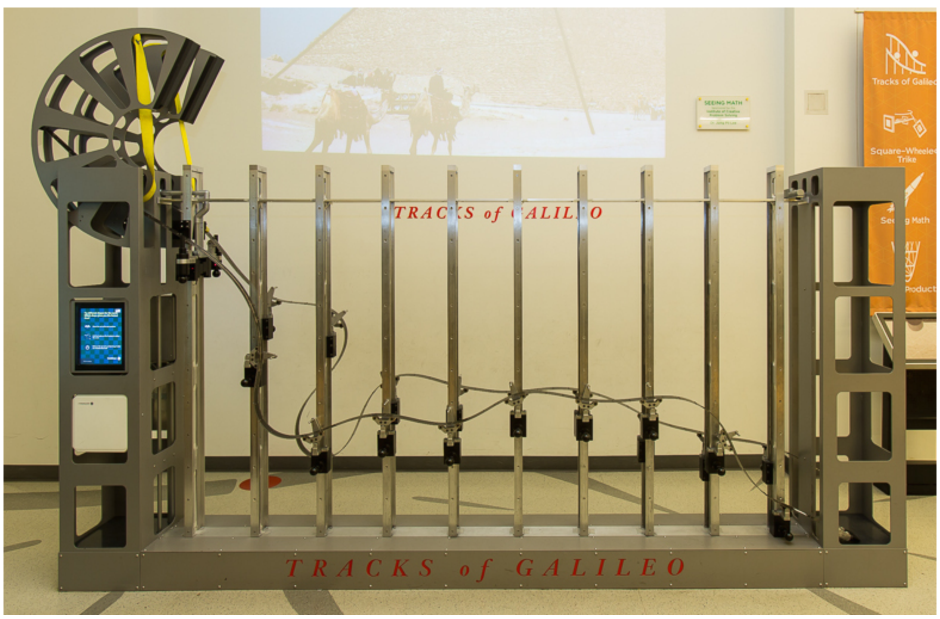

Figure 5: Tracks of Galileo at MoMath. Once the brake has been released, the car achieves motion via gravitational force. The height of the track is adjustable at any given point allowing visitors to create any roller coaster track that they desire. Photo from http://www.maltbie.com/our-work/projects/visitors-centers/momoth-museum-mathematics/, ©Kubik Maltbie, Inc. 2013, used with permission.

The docent at Tracks of Galileo challenged Kartik to create the fastest track possible to transport the car from the start to finish. Kartik instinctively made the track a straight line, recalling that this was the shortest possible path between two points. Confident in his answer, he read the exhibit text and instead discovered that the fastest curve is called a Brachistochrone Curve, a portion of an inverted cycloid curve. To even begin dissecting this statement, he had to first learn that a cycloid was defined as "a curve (resembling a series of arches) traced by a point on a circle being rolled along a straight line."[4] To make the solution even more daunting, the reading brought in the dreaded "c" word: "calculus". The Brachistochrone Curve was explained to be derived from the "calculus of variations". The exhibit's lesson depicted that the shortest path was not the fastest path due to the effects of acceleration.

While Kartik had learned so much during his experience, he departed the museum still unsure of the workings of one exhibit: "Monkey Around". That exhibit was located in the basement of the museum, appropriately labeled floor (-1). As Figure 6 below displays, the exhibit contains a lever that rotates the middle ring of a circular display with three concentric pieces. The numbers of red and blue monkeys both magically change by one when the lever is pushed. Kartik did not understand how this could be possible. He got as far as realizing that there must be conservation of monkey mass because no monkey truly disappears.

Figure 6: Monkey Around at MoMath. Screenshots from video (available at https://www.youtube.com/watch?v=0NH5q45vDcw) by Cindy Lawrence. Included with her permission.

What do you think?
How does a monkey magically disappear and reappear?

[4] http://www.oxforddictionaries.com/definition/english/cycloid, accessed on July 17, 2015.