Why Don’t Spinning Tops Fall?

Conversations With Curious Caroline

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About the Author

Charles DeLisi is an American Biomedical Scientist and Dean *emeritus* of the College of Engineering at Boston University. From 1999 until his retirement in 2024 he was the Metcalf Professor of Science and Engineering. He is currently Distinguished Visiting Professor at Boston University's Center for Data Sciences and Research Professor in the College of Engineering. In addition to authoring or co-editing ten books, he, his students and collaborators have published more than 300 research articles in biophysics, cancer genetics, immunology and computational science. In 2001 he was awarded the Presidential Citizen's Medal for seminal contributions to the initiation of the Human Genome Project. In conferring the honor President Clinton said: "Just as Lewis and Clark set forth to explore a continent shrouded in mysterious possibility, Charles DeLisi pioneered the exploration of a modern-day frontier, the human genome… [his] imagination and determination helped to ignite the revolution in sequencing that would ultimately unravel the code of human life itself."

Dedication

To the genius of free higher education and to The City College of New York in particular.
To Sidney Moskowitz, BSEE, CCNY, 1939

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Preface

“Mommy, why is grass green?”

Mother: “That’s a good question; ask your father.”

“Daddy, what holds up the moon? And my spinning top — just because it spins it doesn't fall?”

Father: “Yes, it does seem strange now that you ask. Tops seem to defy gravity— maybe your mother has an explanation.”

“Mommy, Daddy, do you mind that I’m asking all these questions”

Parents: “…of course not Caroline; how else are you going to learn?”

For many adults, curiosity about the world fades over time. The mysteries surrounding us become so embedded in daily life that they no longer register as mysteries — until someone asks a question. Such questions, often posed by children, are jarring and almost embarrassingly difficult to answer. Not surprisingly, they frequently go unanswered and eventually they cease altogether.

This book seeks to rekindle that sense of curiosity, addressing questions that might otherwise remain unexplored. While the idea of tackling everyday scientific and technological mysteries is not new, my approach here is different. Rather than presenting a list of questions with concise answers, I’ve chosen to frame these explorations within a narrative structure.

Initially, I intended to write a straightforward question-and-answer book, offering succinct explanations for common phenomena. However, as I began writing, I found myself drawn to the idea of conversations. These dialogues involve not just questions and answers but also the interplay of perspectives among family members and friends. They mimic the organic flow of real-life discussions, where one question sparks another, and understanding deepens through shared exploration. Consequently, the book unfolds as a series of narratives that reflect the natural curiosity of its central character, Caroline, as she matures from a 13 year-old high school freshman to a 17 year-old senior. Her enthusiasm drives free associations, connecting seemingly disparate ideas with remarkable agility. The discussions often diverge into unexpected territory, from ethical debates to poetry, literature, and music, while always returning to the central theme of science. This approach mirrors the interconnectedness of knowledge and the unpredictable nature of unstructured conversation.

It’s important to emphasize that this book is not a textbook. Unlike a traditional text, its chapters do not form an interdependent sequence, nor do they confine themselves to a single discipline. Each chapter is a self-contained exploration, guided by Caroline’s curiosity. This unstructured approach allows for spontaneity but also requires readers to engage actively, connecting the dots as they progress.

Writing Caroline posed two major challenges. The first was recalling the questions that once seemed so pressing. With time and familiarity, even the most intriguing mysteries can lose their luster. The second was grappling with the limits of human understanding. How much of what we "think" we know is truly understood? While this is a profound question, beyond the scope of this book, I touch on it briefly to establish a standard for what constitutes a satisfactory explanation, and to address the question of when to stop asking why in response to an answer.

The answers presented here often reflect well-established knowledge, particularly in engineering and technology. However, simplifying complex concepts for an audience ranging from late grade school to early college inevitably leads to some level of superficiality. To address this, I've included references after each section to encourage deeper exploration. My hope is that readers will pursue these topics further, embracing the layered complexities that make even simple phenomena fascinating.

Although I've aimed to make the science accessible to a thoughtful high school student, the narrative itself often operates at a level more suited to an intelligent adult. This choice reflects my belief that people learn best when they actively engage with material, seeking out unfamiliar words or concepts to enhance their understanding. Consequently, some sections may require a dictionary, Google, or a chatbot for full comprehension.

Finally, I've chosen to focus on a limited number of topics, presented as 69 declarative statements across nine chapters. While I could have included twice as many, this seemed a reasonable scope for an experimental book. Caroline, after all, is well on her way to a distinguished career and is fully capable of conducting her own research.

It is my hope that this book will inspire teenagers—and especially young women, who remain seriously underrepresented in the hard sciences—to explore the mysteries of the commonplace through science, technology, engineering, and mathematics (STEM). More broadly, I hope that *Caroline* will encourage readers to rediscover the joy of seeing the world through the fresh eyes of an adolescent with a childlike curiosity who can't stop asking, "Why?"

Conversation 1

Blood, Straws and Pressure

Caroline Angstrom asks simple questions about blood pressure and the stock market, but her parents, Mary and Don, answer with an extended discussion about pressure while placing on hold a conversation about the unrelated field of financial markets. She is stunned when she's told that air has weight, and surprised even more when she learns about gravity defying fluids. Finally, Caroline receives the answer to the question she asked weeks earlier, when her Aunt Zoe explains blood pressure and those strange numbers.

Newton's Law of Gravity Applies Everywhere in the Known Universe

It's six p.m. and Mary Angstrom has just arrived home from Packard Analytics, a Wall Street firm that provides investment advice. She looks more frazzled than usual, and her husband Don is concerned, as is her daughter, Caroline.

"I've had a difficult day," she says, responding to Don's disquiet as she finds her way to the sofa. "The stock market dropped another half a percent — it was the tenth drop in prices in the last thirty days and it comes in a year when the market has been both volatile and bearish."

Caroline: "What does bearish mean?"

"I thought Packard Analytics was doing reasonably well," Don says with surprise, being too focused on his wife for Caroline's question to penetrate.

Mary: "It's doing better than most funds, but that's not saying much. Sometimes I feel like I'm ready to retire."

Don: "Well, retiring at the age of thirty-five is great if you can do it."

Mary: "Yes, nice work if you can get it, as the song goes. Even my blood pressure's up." Mary turns to her husband and after a pause says with a hint of good-humored and loving sarcasm—"I just took it before I left my office with that romantic sphygmomanometer you gave me for my birthday."

"What was your blood pressure?" Don asks with concern.

"One-forty over ninety—the systolic and diastolic pressures are both high."

Caroline, whose curiosity caused her to lose sight of Mary's condition, impatiently interjects, telling her mother that she doesn't understand a word they're saying. "I mean, I know Packard Analytics is the company you work for, but what's a stock market—and what's a sfigo…"

Don immediately intervenes: "Sphyg mo man ometer—a device that measures blood pressure."

Caroline (now with perfect diction): "Sphygmomanometer—but what's blood pressure? And what do those numbers mean, one-forty over ninety? And you still haven't told me what a stock market is."

Don, who heard all of Caroline's questions: "OK, let's take one thing at a time. I'm sure you know what a market is."

Caroline: "Yes, it's a place where you buy stuff."

Don: "Yes, a market is a place where people buy and sell commodities, trade goods and services—and a stock market gives people a way to trade, to buy and sell, parts of companies. Someday when the weather's unpleasant, we can set aside time to discuss buying, selling and trading, but for now let's focus on blood pressure."

Mary, who is now starting to feel a bit better, turns to her husband and asks if he wants to take a first shot at trying to explain blood pressure.

Don: "Why don't we do it together on Saturday when we'll have more time—you know our daughter, she can be exhausting, and besides we still haven't had dinner, and I'm also a bit tired."

It's Saturday morning just after breakfast, and Mary, Don and Caroline move to Mary's study where she begins to explain those mysterious blood pressure numbers.

Mary: "In order to understand what those numbers mean, you need to know the meaning of pressure, and to understand pressure you need to understand force, and to understand force you need to know the difference between mass and weight.

"*Mass is the amount of material in an object, for example, the number and types of molecules. Weight is the force of attraction between two masses*, e.g. your weight is the gravitational force of attraction between the mass of your body and the mass of the Earth. Have you heard of Newton's law of gravitation?"

Caroline: "I've heard it mentioned but I don't know anything about it."

Mary: "I'm sure you'll learn about it next year when you enter high school. *Newton's law of universal gravitation says that the force between any two objects is proportional to the product of their masses and inversely proportional to the square of the distance between them*.

The remarkable thing about it is its universality: it applies to any two masses in the Universe—not just between you and the Earth, but also between the Earth and the Moon, the Moon and the Sun—literally between anything, even between you and your glass of milk, but that force is so small compared to the gravitational attraction of the Earth that you don't notice it."

"Yes, Mom, it doesn't take much for me to resist the pull of a glass of milk," Caroline quips with a winning smile.

Mary continues, ignoring her daughter's suggestion that she doesn't care for milk. "There are many other kinds of force—I'm sure you're familiar with magnetism, which you can feel when you bring two magnets close together."

Caroline: "What about when I push against this table? Am I exerting a force on it?"

Mary: "Yes, that's an example of a mechanical force."

Caroline: "Even if the table doesn't move?"

Mary: "Yes, even if it doesn't move. That's not so strange. When you remain perfectly still, the Earth is still exerting a force on you, right?"

Caroline: "I guess."

Don interjects: "You're touching on the difference between force and work, and I'd like to avoid digressing too much. Can we save that discussion for another day?"

Caroline: "OK."

Don continues: "Pressure is closely related to force. Scientists talk about pressure—force divided by the area on which it acts. For example, the pressure that your history book exerts on the table is the weight of the book divided by the area in contact with the table. If a book that weighs five pounds and has an area of ninety-six square inches (sq. in.) is placed flat on the table, how much pressure does it exert?"

Caroline: "Five divided by ninety-six?"

Don: "Which is?"

Caroline: "Can I use my calculator?"

Don: "No. Suppose the contact area was one hundred square inches (sq. in. or in^2), what would the pressure be?"

Caroline: "Five divided by one hundred, or one-twentieth of a pound per square inch. So it's a little more than zero point zero five pounds per square inch? Now I see how to make the estimate. If the book has an area of ninety-six square inches, the pressure would be closer to one-nineteenth of a pound per square inch (five divided by ninety-five)."

Don: "Yes, you've got the idea."

Mary: "By the way, and this is important, the word pound as defined by *the British System of scientific standards refers to mass, not force. The unit of force (weight) is the pound-force (lbf). However, lb (pound) and lbf tend to be used interchangeably*."

Caroline: "That really *is* confusing."

Caroline then retrieved a notebook that she had recently bought to keep a record of discussions that confused her. The notes proved to be very helpful and she would invariably return to them and augment them as her understanding slowly developed.

Mary continues: "It can be, but it usually isn't because context can clarify. The possibilities for confusion, however, go beyond ambiguity. The USA and the United Kingdom are among the few countries in the world that use the so-called Imperial system of units—most of the rest of the world uses the metric system, which I was planning to talk to you about later. For now, just keep in mind that if you weigh yourself in France or Italy, or any number of other countries, the scale will display kilograms, which is a unit of mass."

Caroline: "And in Britain and the U.S. does the scale show your weight or your mass?"

Don: "All scales measure the gravitational force exerted by your body, which is your weight. However, they are calibrated to display your mass. For instance, in Europe, scales measure your weight in newtons but are calibrated by dividing the gravitational field intensity which is 9.8 meters/second^2 (m/s^2) to display your mass in kilograms. On the other hand, in the U.S. and Britain, the scale divides by thirty-two feet per second squared."

Don continued by noting that as long as everyone agrees on the meaning, the label—pounds, kilograms, or anything else—doesn't really matter. Then he added with an impish grin, "A pound by any other name would weigh the same."

Mary (rolling her eyes): "Really, Don?"

Caroline, to her mother: "What's Dad talking about?"

Mary: "Your father is alluding to a famous line from one of Shakespeare's most popular romantic tragedies, Romeo and Juliet, in which Juliet laments her family's opposition to her involvement with Romeo because of a long-standing feud between her family and his, and not because of substance. It's been a long time since I read the play, but who can forget the famous couplet:

What's in any name? That which we call a rose.

By any other name would smell as sweet."

Don: "I thought I was being clever as well as humorous—there is a connection."

Mary: "Please ... I think you owe Shakespeare an apology."

Don: "I was of course only trying to add some levity—Juliet's words capture so precisely and presciently the tragedy that's about to unfold as the result of conflating descriptors and substance. Shakespeare, as we both know, was no ordinary genius, and the play has a profound message, whereas my discourse on units is not, to say the least, nearly as deep."

Caroline: "The play sounds fascinating and I can't wait to read it, but I have to say that sometimes the two of you are more childlike than I am. Anyway, I'd like to return to the discussion of weight and mass so I can be sure I understood correctly: whether I weigh myself in Europe or the United States I'm finding my mass, but the units are different, so the numbers are different."

Don: "Yes, you've got it—but enough, let's move on."

Caroline was so caught up in the distinctions that she didn't fully assimilate what her father just said about moving on, and asked what she would weigh on the Moon.

Mary: "You know that the gravitational force between two objects, such as between you and the Earth or you and the Moon, depends on the product of your masses. That means your weight on the Earth, or the force between you and the Earth, would be proportional to your mass times the Earth's mass, and your weight on the Moon would be proportional to your mass times the Moon's mass—so of course you would weigh a lot less on the Moon."

Caroline: "I know all that, but what would I weigh?"

Mary: "If you were using a scale properly calibrated to the Moon's gravity, your scale would display the same number that it does on Earth because your mass is independent of whether you're on the Earth or on the Moon or anywhere else in the Universe. However, your weight would be different, but that's not what scales display."

Caroline: "OK, I think I understand, but I still want to know what my weight would be on the Moon."

Don: "Don't you think that you should be able to figure that out for yourself?"

Caroline: "No, because I don't know what the distance would be between me and the Moon, I mean I'd be standing on the Moon's surface, but the distance can't be zero."

Don: "That's an important point. I'll tell you what to use but the explanation will probably have to wait until you study mechanics in college."

Caroline: "Try me; I'd like something to think about."

Don: "It has a simple answer that's difficult to understand—you can think of the mass of the Earth as being entirely at its center, so since the Earth is essentially spherical and you're standing on its surface, the distance you need is the radius of the Earth."

Caroline: "You were right, I don't understand why you can consider the entire mass of a spherical object to be at its center."

Don: "That's OK, even Newton took a while to prove it, so do give it some thought—but for now let's continue with our more pedestrian discussion of atmospheric pressure."

Caroline: "OK, I've taken a bunch of notes and I'll get back to you when I think I have an answer."