

SCIENTIFIC THINKING IN EVERYDAY LIFE:

Banana Chips: A Dining Table Conversation

1 A Controversy at the Breakfast Table

[One rainy morning after breakfast, a 9-year old child (Mali), her mother (Tara), and father (KP) decide to taste some sugar-coated banana chips from a newly opened fancy package.]

- KP: (bites into a chip) Hey, these chips are great, they're really crisp!
- T: (bites into a chip) M-kmm, they're just hard, not crisp.
- M: (bites into a chip) Hard!
- KP: That's strange. Are we making assertions about chips from the same packet?
- T: Well, may be we have different meanings for the word 'crisp'.
- M: What do you mean, different meanings? We're all speaking English, aren't we?
- T: Let's see. *(looks at Mali for a few seconds.)* Try this. *(holds up her right hand)* How many fingers do I have on this hand?
- M: Five, of course, silly!
- T: *(moves her thumb)* Is this a finger?
- M: Of course, it is.
- T: You know, Amz, the word 'finger' has two meanings. One is your meaning: a digit on the hand. It includes the thumb. The other meaning is, a digit on the hand, other than the thumb. So the thumb is not a finger. Look it up in the dictionary if you want. So if my meaning of the word 'finger' excludes the thumb, and I say I have four fingers on this hand, not five, is that true or false?
- M: Oh! Oh, I see. Yeah, that would be true.

Incommensurability

KP: Ah, this is a good example of what Kuhn called incommensurability of observational statements.

Thomas Kuhn was an American historian and philosopher of science.

M: What is incomm...blblbl?

KP: Imagine this. Suppose you say there is no democracy in India; I say there is. Do we have a *real* difference of opinion? To find out, let's see what we mean by "democracy". For you, a system is democratic if its people have the power to influence decisions that affect their lives. Let us call it DEM-1. For me, a



system is democratic if its people have the power to elect their leaders. We'll call it DEM-2.

Suppose there is a monarch who listens to her subjects express their opinions, interests, and demands. Her decisions and policies are shaped by the voice of the people. Is she democratic under DEM-1?

M: Of course. She would be a democratic monarch!!!

KP: But this system is not democratic under DEM2, right? Now take an elected government that ignores the interests of the majority of people. Its decisions favor a powerful minority of Multi-National Corporations, business heads, and the mafia. This system is democratic under DEM-2, but not under DEM-1. These two meanings of democracy are incommensurable. Just like the two meanings of 'finger' are incommensurable. Now if we use the terms DEM-1 and DEM-2 to discuss this further, I'm sure you and I will agree about whether there is DEM-1 and DEM-2 in India, right?

M: Right!

KP: You know, many debates, even among academics, arise from the incommensurability of the same word interpreted in two different ways.

Objective Reality vs. Sensory Experience

T: Listen, there may be another explanation for our different judgments. May be our sensory experience of the chips was different. Perhaps because you have stronger teeth...

KP: Yes! Differences in what the Greek philosophers called *qualia*.

M: Hey, you shouldn't use such big words that I don't know.

KP: Sorry-oh! Okay, remember the chutney we had yesterday? You thought it was exploding hot, and I thought it was bland. It was the same chutney, but our *experiences* were different. Such subjective experiences are *qualia*.

Take another example. Imagine Jay and Viru in the same room. Jay finds the room cold, but Viru finds it warm. The *objective reality* of the temperature in the room is the same, right? But their *experiences* are different. The difference would make perfect sense if Jay has a high fever and Viru doesn't.

[The story didn't end here, because this family found it hard to settle for either explanation. The experimentalists among them, T and M, tried a few more chips.]

M: Hey, I just got a crisp one, they're not all hard.

T: I too got some crisp ones, though some were hard.

M: (opens the packet towards KP) You try some more too.

T: (while KP eats a few more) Ha! So based on one chip each, you concluded that they were all crisp, and we concluded that they were all hard... Extremely defective sampling!

KP: Amz, this is what we call anecdotal evidence. This is exactly like meeting a six-foot tall Australian and a five-foot tall German and concluding that Australians are taller than Germans. We make such hasty conclusions all the time, in ordinary life and in academic research.

2 Looking for an Explanation

[Human beings have a compulsive need for making sense of their experience. The Mohanan family's curiosity was aroused. Why were some chips crisp and others hard? Was the difference systematic? Or was it random? Was there a pattern in the difference?]

T: Look, the sugar-coating on the chips is not even. Looks like the ones with more sugar-coating on them are the hard ones, and those with less sugar are crisp.

KP: That makes intuitive sense. So we now have some data. The packet has both crisp and hard chips. And we have an *intuitive explanation* for the data: the difference in hardness vs. crispness depends on the amount of sugar-coating.

M: But how do we know how much sugar-coating there is? We can't judge the amount by just looking. How do we measure it?

T: You're right, Amz, we have no way of observing, let alone measuring the amount of sugar on the chips.

KP: Right. That makes the claim *untestable*. Every time we find a hard chip, we can claim that it has a lot of sugar-coating, and every time we find a crisp chip, we can claim that it had less sugar-coating. So our claim is unfalsifiable, unless we can find an independent test.

M: What does that mean?

T: May be you should ask him later, otherwise you're in for a lecture on falsifiability. Or may be not. We'll come back to the chips after the lecture!

Falsifiability

KP: 'Untestable' means there is no way to find out if it is true or false. Suppose I tell you that a headache is caused by headache demons. Whenever anyone has a headache, I say, "Ah, a headache demon has possessed him!" And when headache is gone, I say, "Oh, the headache demon has left him."

M: But what if the headache goes because of taking aspirin?

KP: I would say that some headache demons don't like the taste of aspirin, so they go away. But there are other headache demons that don't mind aspirin, so even if you take it, they'll still be inside your head.

M: But that's a silly theory!

KP: Yes, I know. It's silly because it is unfalsifiable. There is no way to even imagine what kind of a situation would prove the theory to be wrong. We don't know what kind of evidence would tell us whether the theory is false. Such a theory is unfalsifiable.

3 Developing an Intuition into a Testable Theory

M: So, saying that sugar-coating causes hardness is like saying that headache demons cause headaches?

T: Unless there is some independent way of observing sugar-coating.

KP: Suppose you asked me, “How come a crow can fly but a cow can’t?” And I said: “Living things with high life force can fly, those with low life force can’t. A crow has high life force, so it can fly. A cow has low life force, so it can’t fly.”

M: What’s ‘life force’?

KP: Let’s just say, it is the intensity of life. But it doesn’t matter. The point is, you can’t challenge my claim, because you can’t observe life force. If you observed an elephant fly, I would simply say that elephants have high life force. Nothing stops me from making arbitrary statements about life force such that they fit the observed data. There is no way to prove the theory to be wrong.

Now, suppose I give you a different explanation.

“Only living things with wings can fly.”

We know that owls have wings. According to the principle, owls should be able to fly. We know that camels don’t have wings; so by the principle, camels shouldn’t be able to fly.

What kind of a situation would be a counterexample to the principle?

M: What’s a counterexample?

KP: Suppose you found a living thing, say X, that doesn’t have wings but can fly. The principle says X can’t fly. So X’s ability to fly would prove the principle false. X is a counterexample to the principle.

T: Here is a different situation. Suppose you found a living thing that has wings and yet cannot fly, like ostriches and penguins. What does the principle say about them?

M: Is that a trick question?

KP: *(laughs)*

M: Okay, let me think. The principle says that only living things with wings can fly. It doesn’t say ALL living things with wings can fly. So it doesn’t say anything about ostriches and penguins, does it?

KP: Good point. So it doesn’t cover ostriches and penguins, right? It doesn’t explain why they can’t fly.

M: No, I guess not.

T: So you know, this example wouldn’t be a counterexample. It’s simply that we expect ostriches and penguins to be able to fly, but they don’t. But it doesn’t make the principle wrong, it’s just that there’s something missing, or incomplete. We just have to find an explanation for why they can’t fly.

KP: Yes, the principle is inadequate by itself. This is why a theory is mostly not just a single proposition, it is a set of propositions that together provide an explanation.

Coming back to, “Only living things with wings can fly.” This statement is admissible in science, because it is empirical, and falsifiable. That it is false is a different matter. By the way, it’s important to remember that ‘false’ and ‘falsifiable’ are not the same.

But the statement, “Only living things with a high level of life force can fly.” cannot be entertained in science, because it is not empirical, and it is not falsifiable.

T: But we can make it falsifiable by adding a statement. So we could have two statements:

- (i) Only living things with a high level of life force can fly.
- (ii) The level of life force in an organism is inversely proportional to its size.

Then we are treating 'life force' as a hypothetical construct in science, as we did earlier with the property of sugar-coating.

KP: If you do that, then you are connecting 'life force' to something observable. If we make this move, it becomes possible for us to test the theory on the basis of observations. The theory becomes falsifiable. What we are doing is to provide empirical substance to the theory on the basis of independent evidence.

We can now determine the level of life force of an organism independently of its ability to fly, and use it to test the validity of the first principle (Only living things with a high level of life force can fly). Under the two principles, it makes sense that a crow can fly and a cow cannot: a cow is larger than a crow, and hence it has less life force than a crow.

Together, the principles make a prediction:

- Given two living things, X and Y,
if X is larger than Y, then we may find that:
- (i) both X and Y can fly (like sparrows and eagles);
 - (ii) neither X nor Y can fly (like elephants and cats); or
 - (iii) Y can fly, but X cannot (like crows and cows);

- but it will never be the case that
- (iv) X can fly, but Y cannot.

If you find a pair of living things where the larger one can fly and the smaller one cannot, the life force theory will be proved to be false.

The way we provided empirical substance to the 'life force' theory was by adding 'size': the theory now predicts a correlation between the size of an organism and its ability to fly. This is a falsifiable prediction that can be tested on the basis of observation. Hence, the theory is now admissible in science. Can you find a relevant counter-example to the theory?

M: What about an eagle and a mouse? The eagle is larger, but it can fly, and the mouse can't. So the theory is wrong!

KP: Excellent. So it is falsifiable, and it also happens to be false.

4 Testing the Predictions of the Theory

M: Phew! That was quite a lecture. Now I want to eat some more chips. (*Eats some, and examines several others carefully.*) Look at these, some chips are more dark brown. (*eats a few*) Hey, the dark ones are all hard, and the light ones are all crisp!

T: Hmm. I wonder if that has something to do with the amount of sugar. Could it be that the ones with thicker sugar-coating are darker? That's not implausible. If that's the case systematically, the unobservable sugar-coating has found an observable *correlate*: its color...

- KP: This looks like the beginning of a banana-chip-crispness theory. Can we crystallize the intuitions so far into an explicit testable theory? Amz, what are the patterns we've found?
- M: The harder chips are darker.
- T: What else?
- M: The darker chips have more sugar-coating.
- T: Anything else?
- M: The sweeter chips have more sugar-coating.
- KP: Let me write down these intuitions. (writes) Our theory has three hypotheses or laws:

- (1) Theory 1
- a. The darker the chip, the more the sugar-coating.
 - b. The more the sugar-coating, the harder the chip.
 - c. The less the hardness, the greater the crispness of the chip.

- KP: The advantage of stating an intuition as a set of *precise* and *explicit* propositions is that we can *test* our theory by checking the predictions that follow from it.
- T: Then we can check if our intuitive understanding is on the right track, or if we are completely wrong.

Two Meanings of 'Prediction'

- M: What do you mean, check the predictions? You mean the theory can foretell the future? (Points to the 'horoscopes' section in the Sunday magazine on the dining table.) Look at this. They are making predictions about what's going to happen next week for everyone... So is that a scientific theory?
- T: No, Amz, the predictions of a theory are not the same as predictions about the future.
- M: But when you say, "I predict that it will rain today," and it actually rains, you say that the prediction came true. It's like a prophecy, right?
- T: Yes, sweetie pie, but the word 'prediction' has a different meaning here. It doesn't mean 'to foretell' the future.
- KP: That's right. In the context of scientific theories, for example in linguistics, or physics, a prediction is a proposition about the observable state of affairs that follows as a logical consequence from the hypotheses of the theory or analysis.
- M: Papa!!! I don't have a clue what you're saying!
- KP: See if an example from physics helps. the logical-consequence meaning is the one implicit when we say, "Newton's theory of gravitation correctly predicts the facts known to astronomers before Newton."
- Or an example from linguistics. "In the English sentence *John admires him*, the pronoun *him* cannot refer to John. The hypothesis that an object pronoun cannot take the subject of the same clause as its antecedent correctly predicts this."
- Take a better example. Remember when were talking about why water is called H₂O, we mentioned valence? We said: hydrogen has a valence of one,

oxygen has a valence of two, the atomic weight of hydrogen is one, and the atomic weight of oxygen is sixteen. With these four statements, or propositions, can you tell the ratio of hydrogen to oxygen when they combine to form water?

M: Yep. The ratio is 1:8.

T: So the four propositions 'predicted' that ratio. You were able to deduce the ratio on the basis of those statements. That is what prediction means in scientific theories... So when we say, "The theory predicts X," we mean "Given the hypotheses of the theory, we derive the consequence X as the outcome of a logical derivation, and we can check whether X is observationally correct." When a soothsayer foretells the future, the statements are not deduced from a set of hypotheses: he or she may simply have had a psychic vision of the future!

M: Oh, okay, I think I get it...

5. Towards a Theory of Crispness in Sugar-coated Banana Chips

KP: So now, getting back to what we started writing:

- (1) Theory 1
- a. The darker the chip, the more the sugar-coating.
 - b. The more the sugar-coating, the harder the chip.
 - c. The less the hardness, the greater the crispness of the chip.

If we put together the first two statements in our theory, that the darker the chip, the more the sugar-coating, and that the more the sugar-coating, the harder the chip, we get a prediction. Can you state it?

M: The darker the chip, the harder it will be.

T: Excellent. And we found this prediction to be correct. All the dark chips were also hard. The darker the chip, the greater its hardness.

KP: So premises (1a) and (1b) together predict a correlation between the observable color of the chips and their hardness. (writes)

- (2) Prediction 1: The darker the chip, the greater its hardness.

M: That's right. There are no dark chips that are crisp.

T: Given the second and third statements, we expect that the lighter a chip, the greater its crispness.

KP: That's right, this is an expectation, not a prediction. (writes)

- (3) Expectation 1: The lighter a chip, the greater its crispness.

T: Let's check if this is true.

M: Oh oh I just had a light chip that wasn't crisp at all, it was actually hard. So it's not true that the lighter, the crisper.

KP: Don't be disappointed by the mismatch between the expectation arising from the theory and the actual observations. One of the qualities of a good theory is that it points us in the direction of new and interesting observations.

May be the dark chips are systematically hard, but the light ones show no pattern, they're randomly hard or crisp.

- T: M-kmmm, that's a cop-out. It can't just be random like that. Let's see. What about the thickness of the banana slices themselves? Oh, no. I was beginning to think we're done, we've already eaten too many chips this morning. Now we'll have to eat some more. (examines more chips, and is excited, and groups some light chips into two sections). Look at the two mounds of light chips, Amz. Do you see a difference?
- M: Cool! You're right, Ma, I just ate a thick one and a thin one, both light ones. The thick one was hard, and the thin one was crisp. (eats some more) The thick ones are all harder, the thinner ones are all crisp!
- KP: Excellent! We're getting somewhere with our theory. Let's modify it by adding the new hypothesis. So this is what we now have. (writes)

- (4) Theory 2
- a. The darker the chip, the greater the amount of sugar-coating.
 - b. The more the sugar-coating, the harder the chip.
 - c. The less the hardness, the greater the crispness of the chip.
 - d. The thicker a chip, the greater its hardness.

- KP: Now this yields an expectation: A light chip that is thin will be crisp. (writes)

- (5) Expectation 2: A light chip that is thin will be crisp.

- M: And that is correct! Yippy, I was the one who figured out that pattern!
- T: (smiles at her) Actually, shouldn't this expectation extend to the dark chips too, because of our fourth statement? Among the dark chips too, the thinner ones should be crisper, and the thicker ones harder...
- M: (examines dark chips) Yes, that's true! The thick dark ones are extra hard!
- T: Nice! So the theory makes falsifiable predictions. Thick-dark-crisp chips, or thin-light-hard ones, would be counterexamples to the theory. We haven't found any in our data. If we do, we'll have to either modify or abandon the theory.
- KP: See, Amz, we wouldn't even have thought of looking for the relation between thickness and crispness before constructing the theory. So, we formed the falsifiable theory based on the patterns we saw; the theory lit up new patterns by making a new prediction; we verified that prediction from new data, and the verification has increased our *confidence* in the theory.
- It's only because of stating our understanding in terms of explicit, logically connected, testable hypotheses that we explore factors and domains that we wouldn't have considered otherwise.
- This is exactly how we construct scientific theories. Our theory of banana chips is *scientific* because it makes falsifiable predictions on observable reality.
- M: (pretends to snore)
- KP: (stops)
- M: Can we continue reading the book from where we stopped last night?
- T: YES, please!!! Go get the book...

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