A Theory of Crispness in Banana Chips: Scientific Thinking in Everyday Life

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On a rainy morning after breakfast, my wife, our daughter and I decided to taste some fancy banana chips from a newly opened bag. I bit into a piece and said that the chips were crisp. My wife and daughter, on the other hand, said that they were hard, not crisp. This was strange, because we were making different assertions about banana chips from the same bag.

We could think of at least two different explanations for this difference of opinion. First, may be we had **different sensory experience of the chips**.[1] Alternatively, we may have had **different meanings** for the words "crisp" and "hard".[2]

Somehow, we were not satisfied with either of these explanations, so we decided to investigate further. When we tried out more chips, we agreed that some chips in the packet were indeed hard, while others were crisp. What had happened was that I had eaten a crisp chip and incorrectly concluded that the whole bag contained crisp chips, while my wife and daughter had eaten hard chips and equally incorrectly concluded that the whole bag contained hard chips. This meant that the difference of opinion was not the result of different meanings of the words "crisp" and "hard", or differences in sensory perception. It was because of the differences in the first pieces that we happened to pick. (Those who have familiarity with experimental science would recognize the situation as one involving differences due to the errors of initial **sampling**.) We discovered that we had arrived at hasty conclusions in the beginning. Such hasty conclusions are quite common in both ordinary life and scientific research.

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[1] If you are wondering how sensory experiences can be different for different individuals, see appendix 1. consider the following example. Bill and Susan are in the same room. Bill finds the room warm, while Susan finds it cold. The objective reality of the *temperature* of the room the same, but their sensory experience of *warm/cold* is different for the two individuals. Such differences in the subjective experience of *warm/cold* is quite natural if Susan has a high fever and Bill doesn't.

Had we decided that the reason for our disagreement lay purely in the differences in the subjectivity of sensory perceptions, the matter would have ended there: we would not have gone on to investigate further, and discover certain interesting things about the world. Some of the ideas associated with what has been called "relativism" and "pluralism" have precisely this property of preventing further inquiry by hastily concluding that everything depends on one's value system, frame of reference, or subjective experience. Since the Mohanan family has the habit of falling back on relativism only as the last resort, we found it somewhat difficult to believe that our disagreement was due to the differences in the experience of hardness/crispness in banana chips.

[2] Let us imagine the following scenario to illustrate differences in the meanings of words. Susan says that there is no democracy in United States. Bill says that there is democracy in United States. At first , we may think that there is a real difference of opinion between Susan and Bill. But suppose we asked Susan and Bill what they meant by "democracy". Let us imagine that Susan says that a system is democratic if people have the power to influence the decisions that affect their lives (call this democracy 1). Bill says that a system is democratic if people have the power to elect their rulers (call this democracy 2).

Under democracy 1, a monarchy may be democratic if the king always makes his decisions on the basis of the subjects' interests and demands, and there is a channel for the subjects to communicate their thoughts and feelings to the king. In contrast, the rule by an elected president may be undemocratic if the decisions are made to please the powerful minority who control multinational industries, and the interests of the majority are ignored. Under democracy 2, on the other hand, the first state of affairs is undemocratic, while the second is democratic.

Given these two meanings of "democracy", it is not unlikely that both Susan and Bill agree that there is democracy 2 in United States, but not democracy 1.

Having settled the controversy, we could have stopped at this point, and gone on to some other business. Human beings, however, have a compulsive need for making sense of their experience. Our curiosity was aroused. Why were some chips crisp while others were hard? Was the difference **systematic**, or was it **random**? That is to say, was there a **pattern** in the differences in crispness?

My wife suggested that the difference was caused by the sugar coating on the chips. Those chips with thicker sugar coating were hard, while others were crisp. This was an intuitively satisfying explanation.

We had now reached some agreement on the **data**. The packet contained both crisp and hard chips. We also had an **intuitive explanation** for the data: what caused the difference in hardness and crispness was the amount of sugar coating.

We could have stopped with this intuition. As scientifically oriented people, however, we wanted to go further. One of the problems in the explanation was that we had no way of **measuring** or even **observing** the degree of sugar coating in the chips. Whenever we found a hard chip, we could claim that it had a lot of sugar coating. Whenever we found a crisp chip, we could claim that it had less sugar coating. In the absence of some independent test, therefore, the claim that the difference in crispness was caused by sugar coating was **unfalsifiable**.[3] And scientists do not allow unfalsifiable claims in their theories.

Luckily for us, we found a way of relating the degree of sugar coating to other differences in observation. Here is how we did it. My daughter examined the chips in the bag more carefully, and found that some banana chips were darker than others. The dark ones turned out to be systematically hard. The next step in our investigation was the suggestion that the darkness on a chip was also caused by sugar coating. The greater the sugar coating, the greater the darkness. In other words, though the degree of sugar coating was unobservable, it had an observable correlate, namely, the colour.

Our intuitions were now approaching what looked like a theory of crispness in banana chips. Therefore we decided to take the next step and crystallize the intuitions into an explicit testable **theory**. Our theory consisted of three **hypotheses**:

(1) Theory
   a. The greater the sugar coating, the greater the hardness of the chip.
   b. The darker the chip, the greater the degree of sugar coating.
   c. The lesser the hardness, the greater the crispness of the chip.

The advantage of converting a vague intuition into a set of **precise** and **explicit** propositions of this kind was that we could **test** the theory by checking the **predictions** that follow from it.[4] This would help us find out if our intuitive understanding was on the right track, or whether it was only an illusion of understanding. The combination of premises (1a) and (1b) predicts a **correlation** between the observable colour of the chips and their hardness:

[3] If you do not know what "unfalsifiable" means in this context, read appendix I before you proceed.

[4] If you are not sure of the meaning of "prediction" in this context, read appendix II before you proceed.

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

We found this prediction to be correct. There were no dark chips which were crisp. Now, the combination of (1b) and (1c) makes us *expect* the following result, even though it does not *predict* this result:

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

This expectation led to further observation. One of the qualities of a good theory is that it points us in the direction of new and interesting observations. Unfortunately, we found this proposition to be false. There were indeed some light chips which were crisp, but there were also some light ones which were hard. What accounted for this contrast?

Faced with the mismatch between the expectation arising from the theory and the actual observations, there were two paths open to us. One was to conclude that dark chips were systematically hard, but the light chips were randomly hard or crisp. There was no pattern in the latter group. The alternative path was to refuse to accept randomness, and look for a further pattern. Like any determined scientist, my wife decided to take the latter option. On further examination, we discovered that some of the light chips were thicker than others, and these were harder. Therefore we modified our theory by adding the following hypothesis:

(1) d. The thicker a chip, the greater its hardness.

The addition of premise (1d) makes us expect the following result:

(4) Expectation 2
A light chip that is thin will be crisp.

Further observation confirmed this expectation. Now, even though we had originally examined the thickness of only the light chips, principle (1d) predicts that the difference should be observable even in dark ones. That is, even though dark chips are harder, the thick ones among them should be extra hard. When we checked this prediction, we found it to be correct. The **verification** of the prediction from the new data, which was revealed only after the theory was formed, therefore increased our **confidence** in the theory.

It now becomes clear that there is an added advantage to the strategy of stating our understanding in terms of explicit, logically connected, testable hypotheses. If we hadn't converted our intuitions in the form of (1a-c), we would never have looked for the relation between thickness and crispness, and come up with (1d). We were forced to look at thickness because our initial theory was inconsistent with our observations, and we needed to make it work better. Scientific theories thus have the effect of triggering the examination of domains which have not been looked at before.

Theory (1a-d) is falsifiable, because we can tell under what conditions it will have to be modified or abandoned. For example, had we found that there were chips which were thin and light and yet are hard, it would have constituted a **counter-example** to the theory. Another counter-example would have been chips which were thick and crisp, or one those which were dark and crisp. Our theory of chips is **empirical** because it makes falsifiable predictions on observable reality.

Suppose one of the predictions had been wrong. Suppose we had found that thickness did not create any difference in crispness among the dark chips. Would we have rejected the theory as false? Not likely. A false prediction shows that the theory is **defective**, and that at least one of its hypotheses is false. But it does not show that every one of its hypotheses is false.

Had we found that, as mentioned above, thickness did not create any difference in crispness among the dark chips, we would have modified principle (1d) as follows, in order to avoid an incorrect prediction:

(1) d' The thicker a light chip, the greater its hardness.

In general, we do not reject a theory which has had some degree of success simply because it makes one or two incorrect predictions. Instead what we do is to add some extra hypotheses to the theory, or modify or abandon some of the existing ones. Of course, if we can find a **better** theory, we will abandon the old one and accept the new one. Useful theories, like other useful things in life, are not usually thrown away unless we can find better ones.

Appendix I: Falsifiability

When we were trying to develop the theory, my daughter asked me what "unfalsifiable" meant. I gave her the following explanation. Suppose you were to ask me, "How come that a crow can fly, while a cow can't?" Let us imagine that my answer is: "Living things with a high level of life force can fly, while those with low level of life force cannot. A crow has a high level of life force, hence it can fly. A cow has a low level of life force, hence it cannot fly". What is "life force"? Let us define it as the intensity of life. Now, this kind of explanation cannot be challenged on the basis of any observation. One cannot even imagine what kind of situation would prove the theory to be wrong, i.e., what would be a counter-example to the theory. If you discovered that an elephant can fly, then I would immediately respond that elephants have high level of life force. There is nothing that prevents me from making arbitrary statements on the level of life force so as to fit the observed data.

In contrast to the unfalsifiable principle using life force, suppose I were to give the following explanation, "Only living things with wings can fly, those without wings cannot." Now we know that eagles have wings and therefore the principle predicts that eagles can fly. Similarly, we know that camels do not have wings and therefore the principle predicts that camels cannot fly. What kind of situations would be counter-examples to the principle? Here is one type. Suppose you observed a living thing X which does not wings, and yet can fly. Since the principle predicts that X cannot fly, X's ability to fly would prove the principle to be false. Here is another situation. Suppose you observed a living thing Y which has wings and yet cannot fly. Since the principle predicts that Y can fly, Y's inability to fly would prove the principle to be false. As it happens, we do not know of living things of type X, but we do know of living things of type Y (e.g. ostriches, penguins).

From the point of view of the scientist, the principle "All and only living things with wings can fly." is admissible in science, because it is empirical. That it is false is another matter.[5] The principle "All and only living things with a high level of life force can fly." is not a principle that can be entertained in science because it is not empirical. That is, the former is falsifiable while the latter is not.

There is a way of making the life force theory testable/falsifiable, thereby providing it **empirical substance** on the basis of **independent evidence**. In addition to (5a), suppose we also stipulate (5b):

(5) a. All and only living things with a high level of life force can fly.
b. The level of life force in an organism is inversely proportional to its size.

What we have done in (5) is treat life force as a hypothetical construct in science, as we did with the property of sugar coating in the earlier theory. In both cases, the hypothetical construct is ultimately connected to something observable. By making this move, it has become possible for us to test the theory on the basis of observations. This is what I meant by providing "empirical substance" to the theory.

(5b) says that larger organisms have less life force than smaller organisms. This principle allows us to determine the level of life force of an organism independently of its ability to fly, and we can now use this measurement to test the validity of (5a). For example, a cow is larger than a crow, and hence by (5b) it has less life force than a crow.

[5] It is important to distinguish between "false" and "falsifiable".

Hence, under (5a) it makes sense that a crow can fly and a cow cannot. The combination of (5a) and (5b) makes the following prediction:

(6) Prediction

Given two organisms X and Y such that X is larger than Y,

one may find that

(i) both X and Y can fly.

(ii) neither X nor Y can fly.

(iii) Y can fly, but X cannot.

but it will never be the case that

(iv) X can fly, but Y cannot.

Crows and eagles belong to type (i): eagles are larger than a crow, and both can fly. Elephants and cows belong to type (ii): elephants are larger than cows, and neither elephants nor cows can fly. Cows and crows belong to type (iii): cows are larger than crows, crows can fly but cows cannot. Now, if you found a pair of living things such that the larger one can fly and the smaller one cannot, theory (5) will be proved to be false. Can you identify the relevant counter-example to (5)?

Another way of thinking about the "theory" in (5a,b) is as follows. The addition of (5b) to (5a) 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 combination (5a,b) can be entertained in science, even though (5a) by itself cannot.

Appendix II: Two Meanings of Prediction

Another word that my daughter had difficulty with was “prediction”. In the ordinary sense of the word, “to predict” means to foretell. Thus, *BBC English Dictionary* defines the words predict and prediction as follows:

> If you **predict** an event, you say that it will happen.
> If you make a **prediction**, you say what you think will happen.

These are the meanings of the words predict and prediction in everyday language, where a prediction is a statement about an event in the *future* , a prophesy. This is the meaning found in the following example:

> “The soothsayer predicted that the fifth child of the king would be a baby girl with red hair and green eyes. Lo and behold! the prediction has come true”

This use of the words “predict” and “prediction” are also found certain forms of academic discourse. For example, when a writer says "I predict X", what (s)he means quite often is "I think that X will happen", “My guess is that X will happen” or “My guess is that if you check, you will find that X is true.”.

The words predict and prediction have somewhat different meanings in the context of scientific theories. In both physics and linguistics, for example, 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. This is the meaning implicit in the following examples:

> Newton's theory of gravitation correctly predicts the facts known to astronomers known before Newton.
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> The hypotheses that (a) hydrogen has a valency of one, (b) oxygen has a valency of two, (c) the atomic weight of hydrogen is one, and (d) the atomic weight of oxygen is sixteen, correctly predict the ration of 1: 8 when hydrogen combines with oxygen.
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> The hypothesis that an object pronoun cannot take the subject of the same clause as its antecedent correctly predicts that the pronoun *him* in the English sentence *John admires him* , cannot refer to John.

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 or not." In contrast, when a soothsayer foretells the future, his statements are not deduced from a set of hypotheses: he may simply have had a psychic vision of the future!