Chapter 8
From Questions to Conclusions

8.1 Activities Triggered by Intellectual Curiosity

Curiosity begins when we become aware of something that we don't know, and want to find out. The desire to find out the distance between the earth and the sun, why there are no four-legged creatures with beaks, or why migraines happen, counts as *intellectual curiosity*. This is very different from being curious about, say, our neighbours' private lives (what their monthly salary is, who their visitors are, and so on); how many books someone has written; where Finland's capital is, or when exactly (date and time) Humayun was born. The desire to find out such unconnected fragments of information doesn't count as intellectual curiosity.

Suppose we are reading a book, and happen to glance out of the window. Our eye settles on a mango tree that we have seen many times before. But this time it strikes us that the trunk, branches, and twigs are brown, but the new stems are green, like the leaves. Several questions pop up in our minds. Why do trees start out green and then turn brown? Are the trunks of all trees brown? Are there trees whose trunk and branches are all green? Such questions reflect our intellectual curiosity about the world we live in.

When we face such questions, our natural tendency is to ask someone, may be a teacher, who we think may know the answer. We might also consult a document that carries the answer, say, by doing a web search. These are legitimate ways to satisfy our curiosity.

But there is another way to arrive at an answer. This way may be more difficult, but perhaps more interesting, and fulfilling. It has two strategies. One is to *gather information* that would help us find an answer. The other is to *think carefully* about what the question involves, then look for an answer ourselves. We can also combine the two strategies.

When we choose to figure something out on our own, instead of looking for a ready-made answer from someone or somewhere else, we are choosing the path of inquiry.

Systematic inquiry begins with a ***question*** that articulates *what we don't know and want to find out*. The next step is to find ways or ***methodological strategies*** to look for an answer. Applying the strategies may lead us to an ***answer*** to our question; and based on the answer, we can arrive at a ***conclusion***.

Each of these components makes its own contribution to theoretical inquiry. And they come together in different combinations for theory construction in different domains. In what follows, we will outline some of the staple strategies of rational inquiry that can help us look for an answer and arrive at conclusions and theories.

8.2 Reflection and Reasoning in Mathematical Inquiry

Mathematics is a useful place to illustrate certain strategies and concepts of inquiry. In Chapter 4, we defined a polygon as *a two-dimensional shape bounded by straight lines*. Now, in addition to having straight lines as sides, polygons also have the property of having vertices (corners). (Circles and ellipses have neither straight lines nor vertices.) This raises the following question:

(**1**) Is there a correlation between the number of sides and the number of vertices in a polygon?

One way to look for an answer to (1) is to take examples of polygons and check for their number of sides and vertices:

(**2**)

Polygons	*Sides*	*Vertices*
Triangles	3	3
Quadrilateral	4	4
Pentagon	5	5
Sexagon	6	6
Septagon	7	7
Octogon	8	8

This sample *suggests* that there is indeed a correlation between the number of sides and number of vertices in a polygon. Can we formulate a law that expresses that correlation? Yes.

(**3**) If a polygon has *n* sides, it has *n* vertices.

In (3), we have what is a called a ***conjecture*** in mathematics. Since we don't have a proof, (3) is not yet a theorem.

Suppose we formulate (3) slightly differently, as (4):

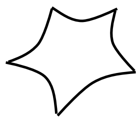
(**4**) If a two-dimensional shape has *n* straight lines as sides, then it has *n* vertices.

That makes us wonder: is the reverse true? Is (5) true?

(**5**) If a two-dimensional shape has *n* vertices, then it has *n* straight lines as sides.

Once again, it is a good strategy to consider a few examples. This time, think about examples of shapes which have vertices without straight lines. Here is one:

(**6**)



A ***conjecture*** is *a proposition* that we judge as *likely to be true, but has not yet been proved to be true*.

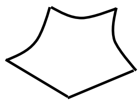
Once a conjecture is proved, it becomes a ***theorem***.

In scientific inquiry, a conjecture is called a ***hypothesis***, *an observational generalization* that we think is *likely to be true*.

We will use the terms 'conjecture' and 'hypothesis' interchangably.

This shape has five vertices, but no straight line. Hence, we must conclude that the conjecture in (5) is false. This conclusion should ring alarm bells in our mind. We had hastily concluded that conjecture (4) is true. But isn't it possible that a two-dimensional shape has n straight lines but has more or less than n vertices? Suppose we replace two of the curved lines in (6) with straight lines:

(**7**)



This shape has two straight lines but five vertices. It is a counterexample to (4), making (4) false.

Does this mean that (3) is also false? No. Since (3) is a conjecture on polygons, and (7) is not a polygon, (7) is not a counterexample to (3). We now realize that contrary to what we had implicitly assumed earlier, (4) is not a re-statement of (3).

The above exploration illustrates the mode of inquiry through systematic reflection, bringing up examples and counterexamples in our mind, and arriving at conclusions through reasoning and generalizing. This methodology is characteristic of mathematical inquiry. Using this mode, we came up with three conjectures, and proved two of them to be false. Conjecture (3) is highly plausible, but we have not proved it to be true.

To summarise, then, we began our investigation with a number of ***questions***, reflected on them, and ended up with the following ***conclusions:***

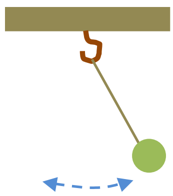
Conjecture	Conclusion
• Every two-dimensional shape with *n* straight sides has *n* vertices.	False
• Every two-dimensional shape with *n* vertices has *n* straight sides.	False
• Every polygon with *n* sides has *n* vertices.	Likely to be true, but not yet rationally justified

Let us now look at another set of strategies to investigate a different kind of questions, those that fall within the mode of scientific inquiry.

8.3 Data Gathering in Observational Inquiry in Science

We are sitting in a children's park, watching children climbing up a slide and then sliding down, swinging back and forth on a swing, chasing one another, and laughing. Our eyes happen to settle on the swing. It strikes us that *a swing is a simple pendulum*, an object suspended by strings or chains or rods, swinging freely in the air.

Simple pendulum



In this picture, the green circle is the bob of the pendulum — the heavy object that is suspended. The slanting straight line represents the string/rod on which it is suspended.

There seems to be a pattern to the movement of the pendulum. We are not sure what the exact pattern is, but as we keep observing, a ***hypothesis*** forms in our mind:

(**8**) The bob of the pendulum swings the same distance on both sides.

As we continue to observe, another hypothesis occurs to us:

(**9**) The pendulum swings back and forth at regular intervals of time.

Suppose the swinging bob of a pendulum comes to one end and is about to reverse direction. At that moment, the time is 5:51:22 am. It moves to the other end, reverses direction, reaches the first end, and is about to reverse direction again. At that moment, the time is 5:51:24 am. It has taken two seconds for the pendulum to complete a *cycle*. This is called a *period*. The substance of hypothesis (9) is that *the period of a given pendulum is constant*. We haven't checked this yet.

Now yet another thought strikes you. Do all pendulums have the same period? Suppose we compare the period of our first pendulum — the swing in the children's park — with the period of a string-and-bob pendulum. We find that their periods are not the same. So the period is not *constant* across pendulums: it is *variable*.

This makes us ask: What does the period depend on? To use the terminology in Chapter 3, what is the *variable* that the period of a pendulum depends on? Does it have to do with the bob? Its weight? Its size? The material it is made of? Or does it have to do with the suspending string or rod? Its length? Its rigidity? The way it is suspended? It could be any one of these.

Suppose we say that the period depends on some variable *X*. We can state this hunch as:

(**10**) There is a correlation between the period of the pendulum and *X*.

Our task is to find out what that *X* is. It could, of course, be more than one factor. Further investigation might reveal the correlation. We can then express the correlation as a mathematical equation. If we use the symbol *P* to refer to *period*, for instance, a possible equation may be:

(**11**) $P = c.X$ (where c is a constant)

How would we find out if conjectures (8), (9), and (10) are true? If they are true, how would we discover the value of c in (11)?

These questions we leave for you to pursue. For now, let us step back and reflect. Unlike the mathematical conjectures in the previous section, the conjectures on the pendulum require you to gather ***data***. In scientific inquiry, it is not always enough to observe and reflect, think of examples, and arrive at conclusions through reasoning. Hypothesis (8), for instance, requires us to measure the distance that a pendulum travels in one period. For hypotheses (9) and (10), we need to measure the time taken for the pendulum to complete each cycle, along with the value of whatever variable we would like to observe — the *X* in (11).

Making measurements that are precise enough to test our hypotheses is not trivial. But we will leave that challenge for a later occasion, and turn to a different example.

Winter is almost here. You have an early morning class. You put on your clothes, swing your backpack over your shoulders, and rush out of the door to catch your bus. The smell of winter is in the air. You breathe in deeply, enjoying the smell.

You suddenly become conscious that winter comes in with a distinct smell. You knew this all along, but had never paid attention to it. Now you turn that idea in your mind, like a dog gnawing on a bone. Is there actually a difference in the smell? Has the drop in temperature affected, say, the vegetation, so plants emit a different smell? Or is it simply that the change in temperatures has an effect on your own sense of smell, and the air just appears to smell different?

You realize that this is a research question, with two competing conjectures, one having to with the physical reality, and the other with our perceptual reality. How will you look for an answer? Smell is the human brain-mind's interpretation of the information of molecules in the air that our nose detects. To find out if winter actually changes the molecules, you would need to find out if the air has a different molecular composition in winter. For this, you will have to collect several samples of both summer air and winter air, see if there is a difference, and if there is, conduct experiments on humans to study if the molecular difference in the composition of air has a corresponding effect on what we perceive as the smell of winter.

If it turns out that there is no difference in the composition of air, our conjecture that winter has an effect on the physical reality is false. You now need to pursue the second conjecture. Does the drop in temperature change our sense of smell?

To find out, you would need to conduct experiments on people by changing the temperature of the room they are in, and find out if there is a corresponding change in their perception of smell. You would have to consult a neuroscientist who knows about how the brain perceives smells, and get his professional advice on designing an experiment to test your hypothesis.

Let us step back again. We have been talking about ways of arriving at answers to our questions, and conclusions arising from them (what we call research ***methodology***). In scientific inquiry, the basis for answers to questions is ***evidence***: data or information we have gathered, or observational generalizations that have been previously established on the basis of data or information. Such use of data and information distinguishes scientific inquiry from mathematical and philosophical inquiries.

The gathering of data naturally calls for the use of observation via sense perception, counting, measuring, use of instruments, experimentation, and so on. In this section, we had a short stroll through some of these elements of the methodology of observational science. We began with a number of questions, and identified many methodological strategies to look for an answer and arrive at a conclusion. But we have not implemented these strategies and gathered the relevant evidence, so we are not in a position to articulate our conclusions.

It would be useful therefore to find out for yourself if the following propositions about the pendulum are true:

- The period of any particular pendulum is constant, i.e., it is invariant. (The actual measurements may vary, but those variations are due to the fluctuations in measurement.)
- In a population of pendulums, the period of individual pendulums is variable.
- The period of a pendulum depends on its mean amplitude.
- The period of a pendulum depends on the weight of its bob.
- The period of a pendulum depends on the shape of the bob.
- The period of a pendulum depends on its length.
- The period of a pendulum depends on the material of the bob.

The conclusions that emerge from this investigation would count as descriptions of the phenomenon, but not an explanation for why it happens the way it does. As the next step, the conclusions require us to look for a theory that explains the behaviour of pendulums, which in turn would become integrated into a more general theory of gravity and motion.

8.4 Reflection and Reasoning in Theoretical Inquiry in Science

At the beginning of this chapter, we distinguished between observational science and theoretical science. In our discussion of the simple pendulum and winter smells in the previous section, we illustrated the methodological strategies of observational science. That naturally leads us to ask: what are the strategies of theoretical science?

If we reflect on the strategies we used in Chapter 7, we already have an answer. We begin with one or more observational generalizations, and ask, "Why?", thereby demanding an explanation. Why does the temperature on earth go up and down in a daily cycle? Why does it go up and down in a yearly cycle? Why is it winter in the Southern hemisphere when it is summer in the Northern hemisphere? Why do we percieve a special winter smell?

Such questions call for *theoretical conjectures* such as: "The earth revolves around the sun," "The earth rotates on an axis," "The earth rotates 365 times during one revolution," and "The axis of rotation is tilted to the plane of revolution," and so on. We show that the logical consequences deduced from these conjectures match the observational generalizations we seek to explain. When the two match, we say that we have explained the generalizations. Since we demand that observational generalizations must have explanations, we conclude that the theoretical conjectures that yield the explanations are 'true' until they are shown to be false, or until better explanations become available.

Thus, theoretical inquiry involves reflection and reasoning as in mathematical inquiry, but here they are based on observational generalizations, unlike in mathematical inquiry. Do go back and re-read Chapter 7 from the perspective of this methodology of theoretical science.

8.5 Reflection and Reasoning in Conceptual-Philosophical Inquiry

Suppose we want to inquire if breaking a promise should be considered immoral. We could begin with principles such as these:

(**12**) a. Causing harm to others is morally undesirable.
b. Not taking measures to prevent/reduce harm to others is morally undesirable.

We might then go on to explore the logical consequences of our foundational moral principles in (12). What happens when they are combined with other premises which, based on our experience, we accept as correct? For instance, we may agree that:

(**13**) a. When we break a promise to x, we cause distress to x.
b. Causing distress is causing harm.

From (12a) combined with (13a, b), it follows that breaking a promise is morally undesirable.

As (12a, b) serve as the grounds for the above conclusion, we may view these propositions as part of a universal moral theory.

(12a, b) would be acceptable to most of us. However, if someone were to question these grounds, and ask for justification for the theory itself, we would need to delve deeper. For this, we may ask members of our inquiry community, including ourselves, whether we judge the following actions to be morally good, netural, or bad:

(**14**) a. Samo's favorite pastime is torturing little kittens by burning their tails.
b. Lina enjoys insulting her students in class. She calls them 'stupid', 'idiot', 'dumb', and so on. In almost every class, at least one or two students break down and cry.

If we agree that Samo's and Lina's actions are morally undesirable, then we need to look for a general theory from which these particular judgments would follow. (12a) is a good candidate, because, given (12a), it follows that (14a) and (14b) are morally undesirable.

Thus, the kinds of shared judgments we make on the moral status of situations like (14a) and (14b) constitute the grounds for a moral theory. Such grounds in a theory of what is moral are parallel to the axioms and definitions that form the grounds in mathematics, and the data that form the grounds in science. Our judgments that (14a) and (14b) are morally undesirable do not constitute data: they are subjective judgments. But to the extent that there is 'intersubjective' agreement on these judgements across humans in different cultures and societies, and across time, we can take them to be legitimate grounds for building a theory of morality.

Similar methodological strategies can be used when we address questions like:

i. What is circumscription?
ii. What is solidity?
iii. What is a species?
iv. What is democracy?
v. What is knowledge?

These questions call for the investigation of abstract concepts — some of them in math, others in the physical and biological sciences, and yet others in the human sciences and humanities. The strategy shared across them is the combination of reflection and reasoning. If you look back at the definitions of concepts in the previous chapters, you will get an intuitive sense of the kinds of strategies we use in this kind of inquiry.

Question (i) is an instance of conceptual inquiry in mathematics. The essence of the question is: "What concept of circumscription ***should*** we adopt in geometry?" Obviously, the answer depends on the purpose of creating the concept. In mathematics, the purpose is that of discovering interesting theorems. We choose concepts that serve this purpose, and reject those that don't.

Questions (ii) and (iii) are instances of conceptual inquiry in physical and biological sciences. In science, as in mathematics, the value of a concept depends on the purpose it serves. The purpose of observational concepts is to provide the basis for identifying and formulating observational generalizations. The purpose of theoretical concepts is to provide the basis for explanations for the observational generalizations.

Questions (iv) and (v) are examples of conceptual inquiry in philosophy. Why do we want to define the concept of democracy? Perhaps it is because we have some intuition on the ***value*** of democracy to humanity, and we want to promote it; for this we need to first understand the concept. Or perhaps we want to apply that concept in socio-political action, such that it guides us towards valuable action. Likewise, we may wish to define what knowledge is, either because we want to pursue and clarify what we think 'knowledge' is, or use the concept for a valuable pursuit in academic inquiry.

In this chapter, we have looked at some of the core methodological strategies of inquiry as well as guidelines of evaluation in mathematics, in observational science, and in theoretical science, and concluded with the strategies of philosophical inquiry. It would be good to read this chapter again, with this overall perspective on how we discover questions to investigate, and arrive at answers and conclusions.