EPISODE 5

SCIENTIFIC INQUIRY WITHOUT MATHEMATICS AND LABS

5.1 Scientific Inquiry

In Episode 1 of the series, we made a distinction between ***knowledge*** on the one hand and **knowledge system** on the other. We pointed out that what distinguishes systems of ***academic knowledge*** from other knowledge systems are the ***ways of***:

- looking for answers to questions that need investigating (methodology);
- arriving at conclusions from premises (modes of reasoning); and
- justifying or refuting claims (norms for establishing knowledge claims as true or false).

We will use the term ***modes of inquiry*** to denote these three elements that characterize the ways of constructing, critically evaluating, and justifying in academic knowledge.

In Episodes 3 and 4, we were concerned with ***mathematical inquiry.*** In Episodes 5 and 6, we will be concerned with ***scientific inquiry***.
[NOTE 5: For anyone wishing to get into the body of knowledge called 'science', as separated from scientific inquiry, there is a wealth of books and resources available online. For example, try doing a Google search on: "Introduction to Mathematics," "Introduction to Physics," and "Introduction to Neuropsychology;" or through a YouTube search for videos that would lead to sites such as Khan Academy Videos, Yale Prof. Paul Bloom's course on psychology, at
https://www.youtube.com/watch?v=P3FKHH2RzjI&t=17s ,
and Stanford Prof. Robert Sapolsky's course, *Human Behavioural Biology, at*
https://www.youtube.com/watch?v=NNnIGh9g6fA&list=PL848F2368C90DDC3D]

Anyone who has read the book, *Evolution of Physics,* by Albert Einstein and Leopold Infeld, would recognise the evolution of ideas: how both the body of knowledge called physics as well as the knowledge system that shapes that body of knowledge evolve continually. It would also be clear that such evolution of knowledge is made possible through team work by the community of physicists.

This remark applies to science in general, and generalising further, to any domain of academic knowledge. Isaac Newton said in 1675, "If I have seen further than others, it is by standing on the shoulders of giants." That statement applies not only to giants of academia, but to anyone who participates in constructing and evaluating academic knowledge.

To take a parallel to constructing and evaluating academic knowledge, the making of movies requires not only actors and directors, but also script writers, producers, cinematographers, makeup artists, costume designers,

editors, sound engineers, set designers, art directors, music directors, musicians, and so on.

Similarly, creating academic knowledge, as well as engaging in ongoing scientific inquiry, requires the teamwork of a multitude of players. It is not an activity of just professors and students. As in movie making, it requires researchers and research students with a variety of specialisations, interests, and predispositions: theoretical scientists, experimental scientists, philosophically sophisticated scientists, scientists who function at a transdisciplinary level to empower learning from one another among academics, scientists with mathematical training, scientists who are good at inventing instruments for data gathering, science educators, science popularisers, and more recently, computational scientists.

An essential component in the edifice of science is science education. Unfortunately, science curricula are largely limited to scientific ***knowledge***, with scientific ***inquiry*** receiving very little attention, if any. Even within scientific knowledge, the curricula fail to help students understand the distinction between theoretical science and experimental science. Take, for instance, what are called 'theory' classes, and 'lab' classes in undergraduate courses. In theory classes, professors *lecture* to students, occasionally asking or answering questions, but they hardly ever provide students with an understanding of what a theory is, or make clear the distinction between scientific theories and mathematical theories. The 'theory' classes, interestingly, also cover the results of experimental science such as the correlation between temperature and pressure in gases. In lab classes, under the supervision of teachers, students ***execute experiments*** designed by someone else, and are hardly ever taught how to ***design*** experiments to test scientific hypotheses and predictions. Furthermore, within traditional science education, in subjects like physics, students get the impression that mathematical equations are scientific theories, and scientific reasoning is replaced by numerical calculations.

It is unfortunate that this tradition pays little attention to helping students develop the ***capacity*** to construct theories, design experiments, and critically evaluate theories and experiment design. As a result, students do not gain an understanding of what scientific inquiry is, an understanding that comes from the experience of ***doing science,*** of ***thinking like a scientist.***

In this article, we are concerned with the following questions:

What is the nature of the thinking that goes into science as a knowledge system?

What does it share with the kinds of thinking in other knowledge systems, such as mathematical thinking and philosophical thinking, and what is distinctive about it?

5.2 Observation and Explanation

At the heart of science as a mode of inquiry is the requirement of providing ***explanations*** for what is ***puzzling*** in our ***observations***. As an example, consider the following contrast:

1. a. Fish die when taken out of water.
b. Mice die when submerged in water.
c. Frogs survive whether surrounded by water or air.
[Do a YouTube search for terrestrial and aquatic habitats, and amphibians.]

The statements in (1a-c) are about what is ***observable*** in three ***categories*** of organisms. Why do fish die when surrounded by air but not by water? Why do mice die when submerged in water but not in air? How come frogs can survive in both environments?

To answer such questions, we construct ***theories*** composed of theoretical postulates. The logical consequences of these postulates derived through deductive reasoning are the ***predictions*** of the theory. They also provide ***explanations*** for the observed contrasts.

Let us take another example:

> If we let go a stone from a location a few feet away from the ground, it moves **down in a straight line**. It does not remain stationary, nor move sideways, or up, or down, in a curved or zigzag path. What would explain the contrast between what is observed on the one hand, and what is logically possible but does not happen, on the other?
>
> If we throw a stone up vertically, it goes **up in a straight line** and then comes **down in a straight line**. It does not go up or come down in a curved path. What would explain this contrast?
>
> If we throw a stone at an angle, it goes up and comes down in a **curved path**. Using a clever experiment, Galileo showed that the curve is that of a parabola. [NOTE 1: See "The Parabolic Path...Galileo's View," at https://math.berkeley.edu/~robin/Galileo/view.html]

In philosophy of science, a set of statements that describe what calls for an explanation is called ***explanandum***, and a set of statements that yield the explanation is called ***explanans***. The three situations described above are an example of an explanandum. We provide explanations by showing that the explanandum statements can be derived from the explanans statements through deductive reasoning.

5.3 Explanation and Prediction

As pointed out in Episode 3, ***predictions*** in scientific inquiry are the equivalent of ***theorems*** in mathematical inquiry. In mathematics, a proof is meant to show that a given conjecture in a theory is true and hence is a theorem admitted as knowledge. The demonstration that a given prediction is a ***logical consequence of the postulates of a scientific theory*** is the equivalent of a *mathematical proof*. So we may extend the term ***proof*** to the derivation of a prediction from the postulates of the scientific theory.

Now, showing that a given prediction is a logical consequence of the premises of a theory (the explanans) does not necessarily show that the prediction is ***correct***. To do that, we need to show that the prediction matches what calls

for an explanation in what we observe – the explanandum. At this stage, the postulates of the scientific theory are admitted as knowledge.

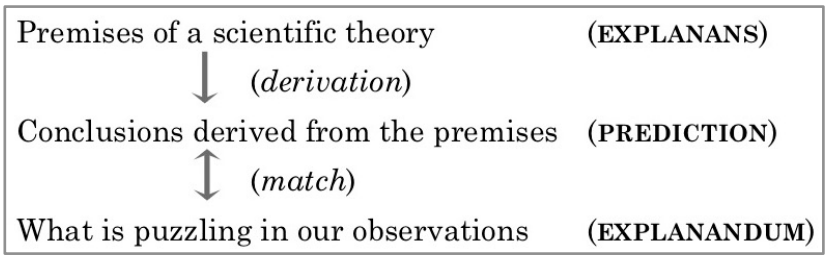

FIGURE 1

Let us take an example. In the academic knowledge of a few hundred years ago, P1, P2, and P3 given below are the central postulates of the Geocentric (i.e., earth-centered) theory of the solar system:

Geo-centric Theory

Premises

P1: The Earth is the stationary center of the universe.
P2: The Earth is spherical.
P3: The Sun revolves around the Earth in a circular orbit once in 24 hours. (The center of the Earth is the center of revolution.)

Conclusion:

From P1-3, we conclude that those who are on the surface of the earth will experience a daily cycle (24 hours) of brightness and darkness.

The equivalents of P1 and P3 of the heliocentric theory, given below as P1' and P3', and accepted as true in the academic knowledge of the 21st century, are different. Yet the conclusion is the same.

Heliocentric Theory

Premises

P1': The Sun is the center of the solar system.
P2: The Earth is spherical.
P3': The Earth rotates on an axis through the center of the Earth once in 24 hours.

Conclusion:

From P1'-3', we conclude that those who are on the surface of the earth will experience a daily cycle (24 hours) of brightness and darkness.

The conclusion is a prediction of both these skeletal theories, which need to be fleshed out. To prove that the prediction is correct, we have to observe a number of these daily cycles. If confirmed on the basis of evidence, we accept the predictions as correct.

But we now have two theories, both of which correctly predict the observations under consideration. Why do we, in the 21st century, accept the heliocentric theory as true, and reject the geocentric theory as false, even though the situation was just the opposite five hundred years ago?
[NOTE 2: Anyone keen to pursue this further may get a sense of choosing between these theories from the YouTube video, "IIE 2015 Session 16 - Heliocentric Theory," at https://www.youtube.com/watch?v=aJXXiYYvOME&t=637s . This video discusses

how to clearly state what needs to be explained, and how the postulates of two theories derive explanations for the generalisations.]

5.4 Reasoning in Scientific Inquiry

5.4.1 Science vs. Mathematics

In addition to the derivation of predictions through deductive reasoning, discussed in section 3, scientific inquiry also employs what is called ***inductive reasoning*** to arrive at and justify observational generalisations from samples of observations. Hence we need to expand Fig. 1 in the previous section as Fig. 2 below:

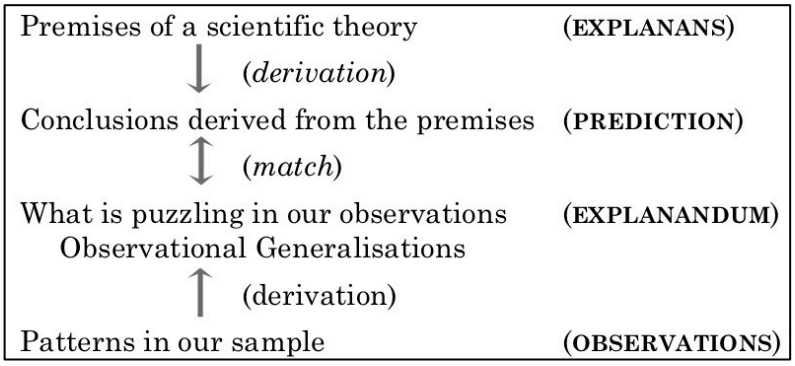

FIGURE 2

Compare the expanded diagram of ***explanandum*** and ***explanans*** in scientific inquiry in Fig. 2, with the corresponding diagram for mathematical inquiry in Fig. 3:

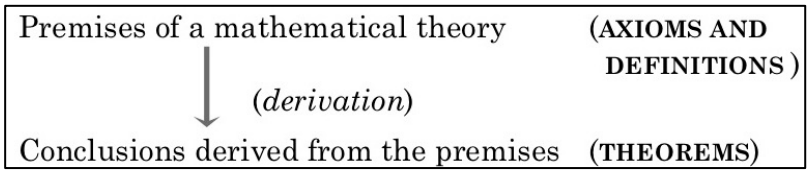

FIGURE 3

Mathematical inquiry does not have the requirement that the logical consequences of the theory match what we observe. Reasoning in mathematical inquiry does not involve an empirical component.

Inquiry in both mathematics and science employs deductive reasoning to derive logical consequences from theoretical postulates. However, as we will see in the following sections, scientific inquiry employs a greater range of deductive logics than mathematical inquiry.

In addition to the derivation of predictions through deductive reasoning, scientific inquiry also employs inductive reasoning to arrive at and justify observational generalisations, as signalled in Fig. 2.

In what follows, we will explore the logics needed for the different types of inductive and deductive 'proofs' in scientific inquiry, without attempting a big picture or structure here. Those who wish to see a big picture before going through the examples are encouraged to take a look at the diagram in section 6 before proceeding to section 4.2

5.4.2 Experiential vs. Propositional Inferences

At the outset, it is important to point to a form of inferences which, while central to our daily lives, cannot migrate to academic inquiry. In Episode 2, we made an important distinction between making inferences from our experience on the one hand, and reasoning from propositions on the other. The example we used involved the relation of 'being taller'. Recall: suppose we look at Vika and Tron standing side by side, and notice that Vika is taller than Tron. We store that experience in our memory. Another day, we see Tron and Somi standing side by side, and see that Tron is taller than Somi. From these two experiences, we infer that Vika is taller than Somi. Neither these experiences and memories, nor the inference from them, need to be expressed in sentences, as propositions.

Suppose you read the following sentences in a letter from a friend:

Vika is taller than Tron. Tron is taller than Somi.

From the propositions expressed by these two sentence, you arrive at a conclusion that can be expressed as:

Vika is taller than Somi.

Reasoning from propositions expressed by sentences is something that only humans are capable of. As far as we can tell, inference from experience is something that crows and dogs are capable of. If you are familiar with Pavlov's experiments with dogs, you know that on the basis of the experience of the sound of a bell, dogs anticipate the arrival of food: they associate the experience of receiving food with the experience of hearing the sound of a bell.

Let us use the terms ***experiential inferences*** and ***propositional inferences*** to distinguish between these two forms of inferencing. Propositional inferences involve ***propositional reasoning.***

5.4.3 Deductive Reasoning with Categories

Let us move on to details of deductive reasoning from premises to conclusions. Most introductions to reasoning begin with Aristotle's syllogism as an archetypal example of deductive reasoning. Recall from Episode 4 that a ***syllogism*** has three parts, namely, a major premise, a minor premise, and a conclusion. Here is a familiar example:

All men are mortals.	(Major premise)
Socrates is a man.	(Minor premise)
Therefore, Socrates is a mortal.	(Conclusion)

Here is an example that belongs more clearly to scientific inquiry:

Every animal has an alimentary canal.	(Major premise)
My pet butterfly is an animal.	(Minor premise)
Therefore, my pet butterfly has an alimentary canal	(Conclusion)

Terms like *men, women, humans, primates, mammals, vertebrates, butterflies, insects, worms, animals, plants,* and so on denote categories of organisms (forms of life).

Syllogism is a specific form of reasoning with categories in which

- the ***major*** premise is a statement about a category (e.g., mortals) and its subcategory (e.g., humans); and
- the ***minor*** premise is a statement about a particular entity (e.g., Socrates) being a member of the category (e.g., human).

C-2 is a subcategory of C-1	(Major premise)
X is a member of C-2	(Minor premise)
Therefore, X is a member of C-1.	(Conclusion)

We can now use the term ***Extended Syllogistic Reasoning*** to denote reasoning with categories, subcategories, and category membership, with multiple major premises, like the one below:

Humans are a subcategory of primates.	(Major premise)
Primates are a subcategory of mammals.	(Major premise)
Mammals are a subcategory of vertebrates.	(Major premise)
Vertebrates are a sub-category of animals.	(Major premise)
Every animal has an alimentary canal	(Major premise)
Therefore, humans have alimentary canals.	(Conclusion)

To this, let us add a premise about category membership, and state a conclusion:

Socrates is a human.	(Minor premise)
Therefore, Socrates has an alimentary canal.	(Conclusion)

It must be noted that the conclusions in deductive reasoning with categories can be either "X is a member of category A," or "X has property P." The conclusion: "Socrates ***is a human***," is about a category that Socrates belongs to, while "Socrates ***is human,***" is about a property of Socrates.

5.4.4 Inductive Reasoning from Samples to Categories

Number of Hearts

Let us take another example:

All humans have exactly one heart.	(Major premise)
Socrates was a human.	(Minor premise)
Therefore, he had exactly one heart.	(Conclusion)

Since Socrates died more than two thousand years ago, we have no way of checking if it is true that he had exactly one heart. However, if we accept the two premises, we are forced to accept the conclusion that is derived through classical deduction. Not doing so would be irrational.

But why should we accept the premises? What if Socrates was a humanoid with no heart? If a sceptic were to ask that question, we would need to respond with evidence and arguments to prove that Socrates was a human.

And what if the sceptic accepts the minor premise but not the major premise? How do we prove that all human beings have exactly one heart?

To defend the major premise, we cannot use deductive reasoning. Instead, we need to employ ***inductive reasoning***, which involves information in a ***sample***. Here is a way of responding to the sceptic:

> ***Inductive Reasoning: Samples and Categories***
>
> We have taken a large random ***sample*** of humans, and examined the number of hearts they have.
>
> Every human in the sample has exactly one heart.
>
> Therefore, until we find evidence to the contrary (i.e., until we find a human with more than or less than one heart), it is reasonable to conclude that every member in the ***category*** of humans has exactly one heart.

Placement of Hearts

Why do we need to specify "*until we find evidence to the contrary*"? Consider a very similar argument for the conclusion that the heart of every human is on the left side of the body.

> We have taken a large random ***sample*** of 10,000 humans, and have examined where their heart is located in the body.
>
> Every human in the sample has a heart on the left side of the body.
>
> Therefore, until we find evidence to the contrary, it is reasonable to conclude that every member in the category of humans has a heart on the left side of the body.

As it happens, one out of 10,000 humans have their heart on the right side of the body. (See: https://en.wikipedia.org/wiki/Situs_inversus) Given that a sample cannot exhaust the population, a random sample, no matter how large, need not necessarily contain counterexamples even if they exist in the population. As we increase the size of the sample, at some stage, the counterexamples may appear. In that situation, we discover that our conclusion is false. It is to take care of such situations that we add the specification, "until we find evidence to the contrary."

An alternative to that specification is to formulate the conclusion in terms of ***probabilistic reasoning***:

> Conclusion: Almost all human beings have their heart on the left side of the body.

To formulate it in quantitative terms:

> Conclusion: 99.01% of human beings have their heart on the left side of the body.

The specification, "*until we find evidence to the contrary*" signals a form of ***defeasible reasoning***, that acknowledges the possibility of an error in the conclusion. In this case, when we did find counterevidence, we switched from ***defeasibility*** to ***probability***, and formulated the conclusion in terms of ***probabilistic inductive reasoning.***

Now, what is the status of our conclusion on the number of hearts? Notice that in this case, we do not have any counterevidence: we have not come across a single case of a human being with no heart or more than one heart. Yet, we cannot rule out the possibility of the existence of a human with two hearts somewhere in the world. Hence, to accommodate this possibility, we must use defeasible reasoning in the case of the number of hearts. This acknowledges the possibility that our conclusion might turn out to be false.

Defeasible Inductive Reasoning

We have taken a large random ***sample*** of humans, and examined the number of hearts they have.
Every human in the sample has exactly one heart.
Therefore, ***until we find evidence to the contrary*** (i.e., until we find a human with more than or less than one heart), it is reasonable to conclude that every member of the ***category*** of humans has exactly one heart.

5.4.5 Causal Reasoning

Causal reasoning appeals to the relation of causation, expressible as:

X CAUSE Y (where X is a cause, and Y is its effect).

Let us take an example. Suppose we are told that Zeno was bitten by cobra a week ago. Given the causal generalisation about cobra bites in P1 below, we can conclude that Zeno must have died from the bite.

P1: Cobra bites cause the bitten person to die.
P2: A cobra bit Zeno two weeks ago.
C1: Therefore, the cobra bite must have caused Zeno to die.

The above forms of causal statements are ***discrete***. We now turn to causation involving ***continuous*** processes. For this, let us look at some correlations. Consider this sentence, called Charles's Law in textbooks:

If the pressure of a given body of gas increases, while the volume is constant, its temperature increases.

This statement is of the form:

"When X increases, Y increases."

The statement is of a positive correlation, and is expressed in a graph as a straight line with an upward slope.

The sentence:

If the pressure of a given body of gas increases, while the temperature is constant, the volume decreases.

is a statement of a negative correlation, called Boyle's Law. It is of the form:

"When X increases, Y decreases,"

and is expressed in a graph as a straight line with a downward slope.

The causal counterparts of these correlational laws would be:

When the volume of a given body of gas is kept constant, increase in its pressure causes an increase in its temperature.

When the temperature of a given body of gas is kept constant, increase in its pressure causes a decrease in its volume.

In general terms, causal statements about continuous processes look like this:

Increase in X causes increase in Y (result: positive correlation)
Increase in X causes decrease in Y (result: negative correlation)

5.4.6 Defeasibility and Probability in Causal Reasoning

Let us return to the example of a cobra bite that illustrates causal reasoning:

P1: Cobra bites cause the bitten person to die.
P2: A cobra bit Zeno two weeks ago.
C1: Therefore, the cobra bite must have caused Zeno to die.

Now, suppose we are told that Zeno was given an antivenom serum as an antidote to cobra venom, immediately after the cobra bite. Then we would not conclude that the cobra bite must have caused Zeno to die:

P1: Cobra bites cause the bitten person to die.
P2: A cobra bit Zeno two weeks ago.
P3: Antivenom prevents death due to cobra poisoning.
P4: Zeno was injected with antivenom immediately after the cobra bite.
C2: Therefore, the cobra bite did not cause Zeno to die.

When we are given only P1 and P2, our conclusion is that Zeno is now dead. The derivation of the conclusion that Zeno died is perfectly valid. But when P3 and P4 are added to the set of premises, that derivation is no longer valid: we now conclude that Zeno did not die.

This example illustrates ***defeasibility in causal deductive reasoning***.

We can now define ***Defeasible Reasoning*** (also called ***Non-monotonic Reasoning***) as the form of reasoning in which a given conclusion is legitimate under a set of premises, but can cease to be legitimate when more premises are added.

In classical deductive reasoning, addition of premises can result in logical contradictions which leads to logical inconsistency:

P1: Cobra bites cause death.
P2: Zeno was bitten by a cobra two weeks ago.
C1: Therefore, the cobra bite caused Zeno to die. (P1 and P2)
P3: Antivenom prevents death due to cobra poisoning.
P4: Zeno was injected with antivenom immediately after the cobra bite,
C2: Therefore, the cobra bite did not cause Zeno to die. (P1, P2, P5, P6)
C3: Therefore, the cobra bite caused Zeno to die and did not cause Zeno to die. (C1 and C2)

When confronted with a logical contradiction in the course of a derivation, defeasible reasoning 'defeats' one of the two offending propositions, and yields

a conclusion that is not contradictory. In science, ethics, law, and particularly medicine, and even in ordinary life, reasoning crucially requires defeasibility.

Suppose the anti-venom was administered to Zeno not immediately after the snake bite, but a few minutes, a few hours, or a few days after the event. Did Zeno die? That depends on how long the delay was.

We can state the probabilistic generalisation as follows:

> The ***greater the time*** that elapsed between the snake bite and the administering of the anti-venom, the ***greater the probability of death***.

What we have here is the combination of deduction, defeasibility, and probability, acting in conjunction.

As you may have guessed by now, causal reasoning from theory to predictions is best illustrated in the sciences of life, illness, healing, and prevention. Our intention in this discussion was to sensitise you to the distinction between mathematical reasoning on the one hand, and reasoning in other domains on the other hand, and to help you have an appreciation of the diverse forms of reasoning. If you now find yourself wanting to master the art and craft of different systems of logic, you may want to take a full length course in logics, with sufficient exercises for practice built into it.

This is not sufficient for mastering the art and craft of different systems of logic. For that, you will have to take a full length course in logics, with sufficient exercises for practice built into it.

We defined ***Defeasible Reasoning*** as the form of reasoning in which a given conclusion is legitimate under a set of premises, but may cease to be legitimate when more premises are added. Another way of looking at this is as follows:

> Given a set of premises that yield conclusion P, and another set of premises that yield conclusion not-P, the combination of the two sets yield the conclusion 'P-and-NOT-P", which is a logical contradiction. Given the prohibition of logical contradiction, we need to do something to prevent this outcome. One strategy is to modify one or both sets of premises, such that the conclusion is not logically contradictory. Another strategy is to use defeasible reasoning, assign strengths to the premises, and remove ('defeat') the conclusion from the weaker set of premises such that the final conclusion is no longer logically contradictory.

5.5 Proving and Evaluating Scientific Theories

In Episode 3, as well as in section 3 of this Episode, we had mentioned that in mathematical inquiry, we prove conjectures within a theory, but there is no requirement that the theories themselves must be proved. In scientific inquiry, as mentioned earlier, we need to prove theories as well.

To defend a scientific theory, we use an argument of the following pattern.

> We have observed a set of phenomena, and based on the reports of those observations, have arrived at a set of observational generalisations .

Our observational generalisations [Explanandum] call for an explanation.

Our theory [Explanans] explains what is puzzling in the explanandum.

Therefore, until we find evidence to contrary, or an alternative explanation, we must accept the theory we are considering.

[NOTE 3: This form of argument is called "Argument to the Best Explanation," or "Inference to the best explanation." See "Inference to the Best Explanation" by Peter Lipton, at https://www.hps.cam.ac.uk/files/lipton-inference.pdf.]

By way of illustration, let us go back to an example mentioned in section 2:

How do we explain why

1. (a) fish survive when surrounded by water, but die if surrounded by air;
   (b) mice survive when surrounded by air, but die if surrounded by water, and
   (c) frogs survive when surrounded by either water or air.

Here is an explanation:

2. All animals need oxygen in order to survive; without oxygen, they die.
3. a. Fish use gills to take in oxygen dissolved in water; they do not have lungs.
   b. Mice take in oxygen from the air through their lungs; they do not have gills.
   c. Frogs take in oxygen through their lungs and their skin; neither fish nor mice can take in oxygen through their skin.
4. The contrast in (1) follow logically from (2) and (3).

Given the structure of the above example, and what we have learnt about Newton's laws of gravity and motion, we can now construct an explanation for the observed trajectories of stones being dropped from above the ground, thrown up vertically, and thrown at an angle (discussed in section 2). [1]

A proof is a response to a rational open-minded sceptic's question of the form, "Why should I accept it as credible/true?" When the 'it' in that question is a scientific theory, the answer is: "Because it is the best explanation for the set of observational generalisations that we seek to explain and predict."

The question, "Why should I accept the claim?" is also the starting point for critical evaluation. Critical thinking and rational justification, in other words, are two sides of the same coin. In the context of the publication of an article, rational justification of claims is what the writer provides in order to convince the reader to accept the claims. Critical reading is what the reader does when evaluating the claims and the justification.

5.6 Concluding Remarks

In this article, we have taken the position that the term *proof*, prototypical of mathematical proofs, can and should be extended to any rational argument for a claim. We generalised the concept of proof from mathematics to science. Many philosophers think that scientific theories cannot be proved, that they

can only be refuted. [NOTE 4: See the Wikipedia entry on Karl Popper's book, *The Logic of Scientific Inquiry*.]

What we have done in the preceding section is to show that scientific theories can indeed by rationally justified, and extending the term 'proof' to refer to that form of justification, they can be proved as well.

Such extension allows us to engage with the question, "What are the similarities and differences between mathematical and scientific proofs?" That question and its answer are fundamental to the exploration of the similarities and differences between the knowledge systems of mathematics and of science.

Let us summarise the discussion of the typology of the logics of scientific proofs as follows:

PDC STRUCTURE	LOGICS	PREMISES & CONCLUSIONS
Premises **Derivation** **Conclusion**	Deductive **vs.** Inductive	Theory to Prediction Observation to Generalisation
	Probabilistic **vs.** Non-probabilistic	
	Defeasible **vs.** Non-defeasible	
	Causal **vs.** Non-causal	

FIGURE 4

Alongside that generalised concept of proof, we believe that we have also been able to shed light on the core components of scientific inquiry, involving reporting particular observations, making observational generalisations, explaining and predicting observational generalisations, establishing the credibility of each of them, and critically evaluating the claims at each level and evaluating their proofs.

We hope you now see how scientific inquiry can be done without mathematics or laboratories, as suggested in the title of this article. We will explore their role in scientific inquiry in the next episode.

Acknowledgements

We are grateful to Rahul Kulkarni, Malavika Mohanan, and Vigneshwar Ramakrishnan for comments and discussions on a draft of this article.