Course Name: I think Biology

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Week:1

Lecture:4

W1L4_The Process of Science

Hello. Today's lecture is titled The Process of Science. This is the, I-Think Biology NPTEL course and my name is Kaustubh Rau. We will be talking about, what science is? and how people go about doing science? And in particular we will be highlighting one method which people use when doing scientific experimentation.

So let's look at what science is actually. And so when we hear this word we have a few images in our head. For instance, we tend to think about famous scientists. Einstein and Newton seem to dominate our mental images of what a scientist is or who a scientist is. It's an interesting thing to think about whether we think about any women scientists when we are asked this question. Or for instance, we have certain other images in our head about test tubes and colored liquids or microscopes, people in lab coats as seen in advertisements or movies or we associate science with technology, things we read about or watch documentaries about. Most recently there has been a lot of talk about artificial intelligence and chat GPT or gene editing via the CRISPR-Cas9 system. So these are some things that we think about and this image on the right highlights those very same things where you know you have standard pictures of science. For instance, there's a model of an atom, there's a microscope and a telescope, there's people in a lab coat, gears and beakers. But is that really what science is about?

So here's one more statement about science. So, Is science a body of knowledge or a collection of facts or actually is it something else? To so to put it at its simplest, I would say that science is a particular way of understanding the world, right. You do things in a particular way to get answers about where we are and how certain things work. And you could say that about religion too, right. Isn't religion a way of understanding the world? But science has certain terms and conditions that it uses which distinguish it from the way religion goes about trying to understand the world. And that's one big difference.

And so what are some of these conditions of science? So what distinguishes science from non-science?

So here's one such distinguishing feature. So all scientific statements must be potentially testable. So anything that you say, you must be able to go out and observe it or you must be able to go out and test it and show whether it's either true or false. And anyone else should potentially be able to do the same thing and try and arrive at the same answer, right. The other big thing about it is that there must be some observation that can falsify our theory. So what do I mean by that?

So here's an example of that. So perhaps I have a hypothesis that people who have divine powers don't get COVID. But there's no way for me to test this hypothesis, but because I can't tell or write, there's no observation or experiment that I can do in order to find out who has divine powers and who doesn't. So that's what I mean by having a testable hypothesis. And so my hypothesis must have a possible negative answer. So we must try our hardest and do several different approaches to try and answer our question and to try and disprove it in many different ways.

And only when all those ways don't succeed do we say that our original hypothesis is true. So science really works, you could say on negation. One thing to ask, what can science not say, what areas of life can science not make claims about? You know very often scientists are asked their opinion on a lot of things on which they are really not experts. And I would say the main thing here is that science cannot make any claims about the world of values. You know what we would call ethics, morality, claims of justice, and equity. These are larger human questions and they're really for everybody to debate and discuss and to figure out within their own society. And science really cannot make any judgments about that. So that's one thing to be aware of.

So given all that, can we arrive at a definition for science?

And here I've chosen one such definition by a very well-known ecologist called E.O. Wilson. He's an evolutionary biologist who was, who was an expert on ants. And in his book, Concealance, he has given this definition saying that, it is an organized systematic enterprise, that gathers knowledge about the world and condenses the knowledge into testable laws and principles. So the word testable here is very important and it tries to organize our understanding of the world into larger statements. It has a generalizability about it.

So based on that, we can say that there are certain features that science must have. One is that repeatability. So different people in different times and different locations must be able to arrive at the same values given the same starting conditions,right. Another big feature of science is quantification or measurement. So quantification is the way by which we distinguish many facets of life as non-science or science.

And then science always works on peer review. So your findings are critiqued and commented on or repeated by your peers and only then is it accepted by the wider community. So science really works on criticism. And there are some other features like science works on abstraction

but that doesn't have to do with the workings of science but largely about the way of understanding the world through abstraction.

So here what I'm going to do is take one case study to look at the scientific process. And I'm looking at one particular way of doing science, which is called hypothesis driven science. But there are other ways of going about it, without making a hypothesis. But I've chosen this one method.

So how does hypothesis driven science work?

So typically you are interested in a particular thing which is out there so you make an observation about it. It could be something in biology or another area of chemistry, physics. And then you say that, what are the parameters that affect the system? Because based on your observation you know that the system is acting in a particular way and so what are some things that could affect the system? And then via that you try and ask a relevant question about the system,right. So one example I could take here for instance again harkening back to COVID is perhaps, I observe that certain people within the same locality were not infected by the COVID virus. Whereas others were given the same level of exposure. And so what was different about these people, is that perhaps they were using drinking kashayam every day.

So that's one parameter which may affect the system. So then you formulate a hypothesis. You could say a hypothesis could be a reasonable guess. And so a hypothesis is really about the process not about the end result. And so my hypothesis could be that people who drink kashayam do not get COVID. And then the next steps will be for me to formulate an experiment or a study in order to test my hypothesis. And I should try to falsify my hypothesis by trying to do different kinds of experiments around it.

And another feature of an experiment or a field study is the quantification or measurement. So you are collecting data and these data are analyzed for you to arrive at a particular conclusion. So you interpret and arrive at a conclusion which may prove or disprove your hypothesis.

And so that is one way of going about it. And actually I should say the whole process doesn't end here. The step after this is equally important. You might have done the world's best experiment but until you communicate it to your peers and they look at it and comment on it, it is not really useful. So writing and communication is an equally important part of the whole scientific process. Because really science will not work in a vacuum but it works, it's very much a human endeavor and it depends on this kind of community participation in it.

So let me now take one case study to illustrate this process and I've chosen the study which is about wind turbines in the Western Ghats. So these are, this is an image of these wind turbines at one location in the Western Ghats. So what is the study about?

So the authors of the study, Thaker, Zambre and Bhosale, they investigated the environmental impacts of wind farms in the Satara district on these Western Ghats plateaus. And so the relevant reference is given here and the journal in which it appeared. So the authors, the observation that they made was that wind farms or windmills seem to influence migration patterns as well as populations of birds and other animals. And this has also been seen around the world that windmills and wind farms seem to affect bird populations and usually in a negative way. And I should mention here that the observation here is really about that wind farms seem to negatively affect the population of birds. So then, what is the hypothesis that these researchers could have come up with?

And here is a hypothesis , that wind farms have a positive impact on populations of small reptiles. So these would be the prey for certain bird populations, more specifically predatory birds, right like buzzards, eagles and kites. So if the population of these birds drops, then one would expect that the population of their prey would increase and so that would be the hypothesis. So how would you go about trying to test this hypothesis?

So first you would have to decide if you have a community of prey, which particular species that you will concentrate on, and then how will you go about doing the actual experiment? So this is what the researchers did. They focused on the main prey for certain predatory bird species. This is the aptly named Sarada superba, the fan-throated lizard.

It has this fantastic dewlap which can be seen here in the image. Now you want to look for the population of these lizards on these Sayadri plateaus and you want to look at the effect of windmills. But you can't go back in time and find a plateau without windmills and say okay we'll look for the population of lizards on this without windmills and then we'll put the windmills on that. So the authors here what they did was what they call a space for time substitution. So they found two plateaus, one with windmills and one without.

And in pretty much every other respect they were the same except one had windmills on it. And so you would say that okay this is my control area without windmills and the one with windmills is my experimental site. And now what you would try and do of course is you would try and conduct your experiment in which you would like to assess or measure the population of predatory birds and the population of their prey. And so the way, and of course this is going to be an estimation because you're not going to try and count every bird of prey that is out there or every lizard that wouldn't be humanly possible. So what you would try and do is an estimation.

And the way it's normally done in ecological sampling is via this method called transex where you basically walk along straight lines at a particular pace, at a particular time and then note down visually the particular species that you would be interested in. And then this has to be repeated over a number of times and perhaps over a number of years for you to correctly estimate what is the population of the species that you are interested in. And this is what the

researchers did. So this is one of the main findings of their study is that if they looked at birds of prey and their abundance, places that had the plateaus with wind farms had much less predatory bird abundance than plateaus without wind farms. And that's clearly shown here in this graph.

And consequently the population seen for lizards is the opposite. In plateaus with wind farms lizard population density was high and that was without wind turbines the population was low. So that seems to make sense, right? You're removing the predator species so the prey species now has a chance to grow in population. So this was the findings of their study, is that the abundance of predatory birds was four almost four times lower in sites with wind turbines than those without. And similarly the density of the fan-throated lizard or their population was three times higher in sites with wind turbines compared to those without.

So that's the primary level of the result. And what the researchers also did was they did some secondary tests also to kind of strengthen their findings. So, in sites which had wind turbines the lizards were more relaxed, because they had less predation pressure or at least the perception was less. And how would they test a relaxed response to the stress?

By two ways. One was a physiological measurement so they caught lizards extracted some blood and actually tested stress hormones within the lizards and the other was by human test where they would try and approach the lizard and figure out the distance at which the lizard would have a fleeing response. So in sites which had wind turbines in some sense the lizards were braver and they would allow the observer to approach closer because they were less stressed. So all this is kind of in line the results seem to agree with each other. But science is always surprising and they also found something which you wouldn't expect. So what were some of the indirect effects of a reduced predation pressure? So in sites which had wind turbines the lizards had a lower body condition, I mean they were thinner. And the coloring of that brilliant dewlap was less, it was duller. So what they said was that this was probably due to increased competition. So now you have more lizards and so they have less access to food. So their body condition has reduced and perhaps they have to spend more time foraging for food or hunting.

And so they cannot put that much energy into producing a brighter dewlap. So this would be something that you normally wouldn't think about but this study highlighted that. So then the authors said that both population level and individual level changes in lizards were driven by direct effects which means less predation pressure and indirect effects from the top predator grid which means the birds of prey. And so the conclusion was that by reducing the impact of predatory birds in the area, wind turbines cause a cascade of changes in terrestrial prey. So this is an example of what's called predator release.

So you remove the top or the apex predator from that area and so the prey experiences an increase in population. In some sense they're saying that the windmill becomes the apex predator in that area. And because these results are extremely relevant to a variety of topics such

as development, economy, energy, so they say in the paper, that since the locations of wind farms are mainly determined based on economic rather than environmental considerations, we stress that the consequences of wind farms are greatly underestimated. So their study demonstrates that we actually may not be fully understanding what are the downstream effects on the whole trophic cascade of these wind farms and we really need to think about those parameters when we decide where to put our wind farms and so not just do it based on economic considerations. So this is one way by which we can think about doing science and in this case I should highlight that the findings were almost immediately relevant or applicable to the so-called real world but that needed to be the case because, for instance you could be studying something in the lab, say the interactions between two cell types and you may have found something about these interactions which is new and interesting but that may not have any kind of immediate application and it's not necessary that it needs to have an application.

You could be doing it just to find out because you are interested in it. So let me end this talk by showing you a study which actually we could think about doing ourselves right. So the windmill study which I showed you would require us to go out there and would require enormous amounts of resources and training before we can try and attempt something like this. But are there some things which are simpler which we can actually think of doing, even perhaps within our homes or neighborhoods. So I'm going to show you one such study.

So the title of the study is Cues of Being Watched Enhance Cooperation in a Real-World Setting and so what did these researchers do which is given here?

We examined the effect of an image of a pair of eyes on contributions to an honesty box used to collect money for drinks in a university coffee room. So if you imagine a coffee station which is unmanned and you have unlimited coffee but you are expected to pay a little bit of money every time you get a coffee from there because it's like a common resource for everybody. So how can you nudge people to give a fair contribution every time they drink coffee? So this is an experiment you could say in psychology and so how could you go about doing such an experiment and so this is the way these researchers did it. So on this graph what you can see is on the x-axis is the amount of money people paid for their coffee and the y-axis is just the amount of time they did this study for.

So here is what they did. So you have a coffee percolator and above that they stuck they just stuck the image of a pair of human eyes and so in the first week they stuck this image which has this kind of angry looking gentleman at it and this is the average contribution they got from people. In the next week they stuck the image of flowers and this is the contribution they got. In the third week they stuck a person who perhaps has a more gentler look. So this is the contribution and so in the same manner. So they alternated these flower images with images of human eyes but human eyes showing different kinds of emotions and then asked, what is the level of contribution they got?

So are these people doing science? What would be your answer to this question?

Because it is very different from the earlier case. Although there are certain similarities they may have had an hypothesis, they also tried to do quantification of some kind and they did an experiment even though they were experimenting on human subjects in this case. So you can also think of doing scientific studies in a very simple fashion in your environment whether at home or at college or within your friend's circle and there are many there is a lot of interest in studies actually of this kind, for kind of nudging people towards behavior which is towards the good of a particular community right and one area which immediately springs to mind is that of the climate crisis where you're trying to nudge people towards behavior which is less wasteful or consumptive and more sustainable. And this is the reference for this study. So I hope through this lecture, I've tried to illustrate what science is? And then via that case study, how we might go about doing the whole process from an observation to a question to a hypothesis to the actual experiment.

And I hope that you can try and do this in your environment, wherever you are and I look forward to any interaction with you on this topic in the tutorial. Thank you.