ON THE PHILOSOPHY OF SCIENCE

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1 Testing the Waters

Before I begin my talk, I would like to know how many of you have read into Philosophy, be it general or scientific philosophy, so that I can gauge what kind of language I should use to present the ideas I have in this talk to you.

A warning here: most of the ideas covered in this talk would be rather mathematical. I will try my best to keep abstraction to the minimum, but if I keep out abstract ideas altogether, then there might be nothing to talk about but the Scientific Method, which I believe would be very well covered by Prof Ip's manual for SP802. For those less versant in mathematical logic, please bear with me. As a matter of fact, please stop me to clarify any terminology I use that you are unclear of as I am giving the talk.

Another point I would like to make: my talk would be controversial in some aspects because I feel that controversy is the fuel to critical thinking. Science IS controversial, if you did not already know, and I feel that getting to be able to come into terms with controversy is an important stage in maturing intellectually.

2 Structure of Talk

Now, to let you have an idea of what to expect during this one-hour talk, I would first try to convince you that Science is not built on a philosophical fortress by presenting you an attack on one of the pillars of scientific inquiry, which is objective reality. On this, I would try to just spend 15 minutes. Then I shall spent the next 15 minutes talking about scientific modelling of this objective reality, where I will give an analogy on the relationship between Science and Reality. Next, being a Physics major, I would like to share with you on one of the philosophical underpinnings of Physics, which would be related to the mathematical modelling course Dr Chan Onn would be teaching you. If I haven't dragged beyond the one-hour allocation for the talk, I would like to draw some parallels between models in Biology and Physics.

3 On Philosophy

Everybody is a philosopher. You are a philosopher, the person sitting next to you is a philosopher, and the average person on the street is a philosopher by the virtue of all of us being alive and thinking. ...Well, at least for a brief moment in our lives, we would have wondered:

"WHY?"

Once the QUESTION is asked, we expect an ANSWER. We don't know what form this ANSWER takes, but for most of us, we demand that one must exist. Of course, there are those of us who might hold that not every question has an answer, or that not every question needs an answer. These people may think that they have evaded the QUESTION, but by taking this intellectual position, they have already provided a partial answer to the QUESTION. Then there are also a handful who would boldy declare, "There is no ANSWER." and would have then indirectly answered the QUESTION. In fact, there is no running away from the QUESTION.

Some uncertainties then arise: for every QUESTION asked, is there just one unique ANSWER or are there many different ANSWERs? With this QUESTION on the uniqueness of ANSWERs, we have actually found a way to classify our QUESTIONs!! We say then, well, there are QUESTIONs which have unique ANSWERs and there are QUESTIONs that have no unqiue ANSWERs. A good example of the latter would be: "Is that girl sitting there pretty?" and chances are I would not get an unanimous answer YES or NO. But then again, there is some probability, which Dr Chan Onn likes to muse about, that I would actually get just one answer, in which case I would have chosen a bad example.

Okay, so we have classified our QUESTIONs. Science is mainly concerned about the first type of QUESTIONs, those we deem to have unique ANSWERs. But do these QUESTIONs exists? Can we be sure that there are QUESTIONs we can ask that the ANSWERs would be unique? Logically, these QUESTIONs can exist, there is no problem with that, as unique ANSWERs are a necessary condition for these QUESTIONs to exist, but unfortunately, this condition is not sufficient, and we are forced to conclude that there is no need for the existence of such QUESTIONs, although we have no objections to them actually existing.

This puts us in a dilemma: Where would we put Science if such QUESTIONs do not exist? I mean, for Science to be a legitimate intellectual pursuit, there must be at least one such QUESTION to answer. Thus far, I have assumed that these QUESTIONs do exist, beyond the shadow of a doubt. But before I tell you why my confidence in this belief shook, I have to introduce to you three friends of mine.

I have three friends by the name of CONVENTIONALIST, IDEALIST and CONVERT (of course these are not their real names!). CONVENTIONALIST and IDEALIST are from the Arts & Social Sciences while CONVERT is an Engineering graduate. We often dine together and exchange views on philosophy, politics and popular music.

Well, because I am a Science student, I am by and large, a REALIST. As a result, when a heated debate on philosophy flares up among us, I would be the sole person defending view points that we Science students take for granted. You might expect that CONVERT, being an Engineering graduate, should position himself closer to Science, but then why did you think I chose the metaphorical name of CONVERT.

One evening after dinner, one such debate took life. Instead of the usual broad and sweeping maneuvers which CONVENTIONALIST and IDEALIST are used to, and are very good at, they concentrated their rhetorics on a very particular subject: REALITY.

I, of course, argued that objective reality exists independent of an observer and forms the basis of all Sciences. CONVENTIONALIST and IDEALIST argued otherwise. Their stand is that material reality, something very close to the objective reality that we Science students talk about, do not exist. According to the dynamic duo, only IDEALs exist, but these are a product of our existence. Logically then, ideals vary from person to person and people are very SUBJECTIVE, in case you don't know. When two or more people get together, a new type of reality is born: CONVENTIONAL REALITY defined through consensus of the individuals involved in the intellectual agreement. In short, reality exists through convention.

For example, we say that the Pepsi can in front of us is blue because we had previously agreed that the visual sensation we all perceive is connected by convention to the IDEAL colour blue. It is unlikely that our brains are wired up in exactly the same way that the visual signal transmitted to the brain is the same for everyone of us present. In fact, if I can rewire your optical nerves to my brain, I would probably be unable to form a coherent image, much less make out the colour of the Pepsi can.

They enforced this point by claiming that conventional reality is lost when the criteria for differentiation is degraded. Place a blue can next to a red can and any idiot would be able to tell the difference, but ask a person to chose the corresponding blue colour of the Pepsi can in an artist's colour palette by relying on his impression and he would not be able to pick the correct one, unless by chance.

Naturally, at this point of the debate, I was very much agitated. Not wanting to lose the debate, I flashed my ace, or so I thought. I brought up the example of the existence of the Moon: whether I look at it or not, the Moon is there. It is there by virtue of being confirmed by billions of people around the world and must represent objective reality, even when half the world is not watching. At this point I was feeling proud of myself until CONVENTIONALIST and IDEALIST unleashed the *coup d'etat*.

What about the blind, they asked, they cannot see the Moon, what of them? They are oblivious to the phases of the Moon, and even if a billion people tell them that the Moon is real, they cannot help but be skeptical. In fact, they are the perfect SKEPTICS. Tell them about the gravitational effect of the Moon, make them stand at the coast during the rising and ebbing of the tides, and they would still think that you are playing some tricks on them. Try as you might, to them, the Moon does not exist. Thus, to the QUESTION on whether the Moon exists, there are now two ANSWERs. Does this mean that the QUESTION have no unique answer? If a QUESTION that we are so sure of returning an unique answer now seems otherwise, how can we be sure that all the other unique-answer QUESTIONs that we have constructed thus far are viable in the presence of disjoint sets of observers? In other words, is Science just "chasing ghosts"?

I was so disturbed by this line of argument that I came back and consult my friends in Science. They have enlightened me to the loopholes that is present in the arguments of CONVENTIONALIST and IDEALIST. Therefore, Science is not void of content: it is legitimate in that unique-answer QUESTIONs do exist (or cannot be proven to be nonexistent) and it is still okay to assume that there is an objective reality out there somewhere.

As for you, think about the argument put forth by CONVENTIONALIST and IDEALIST and identify the loopholes in their argument. But don't do this now as we would have plenty of time during the tutorial session.

4 On Scientific Inquiry & Modelling

At this stage we have established that it is not logically flawed to assume an objective reality, and Science is about discovering it. Or is it?

Does Science, as we know it, describes reality completely? I claim not. Is Newton's laws reality? Do objects REALLY move in space according to these mechanical laws? What about Quantum Mechanics? Does the bizzare interpretations of the quantum theory reflects what reality truly is? And the atom? Are they real in the sense that they are not just convenient to talk about? The truth is, Science may not even be a passable representation of reality. But more about this in the tutorial.

Here's a bold statement:

Science is a only a model of Reality.

To illustrate this, I would like to use the analogy of the Earth and the globe. Now, when I point to a globe and say Singapore is here and this is where I am standing you don't exclaim, "You mean you are standing on this plastic ball!?" Have you ever met a person who is confused between the globe and the Earth. Probably not, so I see no reason why anybody should mix up Science and Reality.

Let's expand on this analogy. We know that the Earth is not perfectly spherical: it is flattened at the poles and bulges at the equator, but have you seen a globe made that way? The manufacturer of globes would bark at you if you wanted one with the bulge and flatten poles. The next thing he will ask is whether you want mountain ranges on your globe, with Mount Everest moulded to scale. I mean, do you also want your globe to have such embellishments as forests, updated every month for logging activities and reforestation? How about throwing in microscopic cities sculpted to scale, complete with street signs and traffic lights?

This is the same predicament faced by scientific theories. As the level of details increase, so does the level of complexity of the theories, which are themselves no more than models of reality. There would come a point where we ask: why do we want such a detailed model? Do you WANT a globe that is correct up to the street signs level? I mean, it is impressive if it sits on your desk, but what do you want to use it for? If you are interested in studying the geographical relation of countries, such a globe would obviously be too cluttered up by details, rendering it useless for your purpose. If you are interested in studying in the detailed effect of air pollution due to traffic exhaust emission in Bangkok, why would you want the entire globe?

Suppose now you just have one globe which is a perfect replica of the Earth itself. It is placed in a vacuum chamber and allowed to revolve around a model of the Sun, which does not have to be exact because we are not so much interested in the Sun. We also have a model of the Moon orbiting our perfect model of the Earth. This globe has an atmosphere that has the exact composition of our real atmosphere and all meteorological processes take place on this globe like they would in the real life. The oceans on this model Earth are put in to reflect tidal movements and ocean currents, and the freezing and thawing of the polar ice caps on this globe would be identical to that happening on Earth. The forests are grown on this globe and the growth rates and felling rates are to scale with that happening in the real world. We even programme earthquakes and volcanic eruptions into this globe.

But do the botanists want to use this globe? They are flabbergasted that the meteorologists wants to set up cyclones and hurricanes now and then to study how such atmospheric phenomena are formed and how they pick up strength by crossing the equator, destroying a lot of model forests in the process. They are also pissed off by the seismologists, who programmed frequent earthquakes to study low frequency waves propagating through the Earth's crust. Meanwhile, the chemists aghasted marine biologists by proposing to start an oil slick in the North Pacific to study the environmental impact of a large scale oil slick and to test out a new chemical degradation process invented to control oil slick. This is amidst protests against the astrophysicists' plan to turn back the clock and study the formation of the Earth during the infancy of the Solar System. In the end, nobody is happy because their experiments always get disrupted by someone else's experiment. So they decided to each have one such globe so that they can do their own isolated experiments.

As things turn out, the entomologists, in a bid to study the migratory behaviour of the Great Monarch butterfly, deliberately stop all earthquakes and hurricanes, shortened the period of the year so that they waste less time waiting for individual migrations to occur. And the seismologists? They threw away all the model forests and cities because they want to see the faultlines forming more clearly while the oceanographers found the continents obstructing the placement of their instruments and shaved off whole mountain ranges and island groups. After some time, the physicist took a look at the zoologists' globe and found it totally alien, while the biochemists sold off their globe to the karang-guni and placed all their subjects into neat compartments instead to facilitate better monitoring.

If you are now following the drift, you will probably begin to see why there is one universe that we are living in but there are Physics, Chemistry, Botany, Zoology, Geology and various other sciences. They are just 'globes' tailored to model different aspects of reality!!

5 On Physics

Physics is a very broad subject. Paralleling it to a globe with regards to the aspects of reality that it models is at best naive. You can think of it as a computer application software that is menu-driven where each menu has many sub-menus and the sub-menus has their own sub-sub-menus and so on. In the short time I have for this talk, I cannot possibly cover all the different philosophies weaved into Physics. I would concentrate on one that I think is very important for any proper study of the subject: the relationship between physical reality and mathematics.

In philosophy we talk about objective reality, but such a notion is too all-encompassing to be of practical use to the study of Physics. Therefore, in Physics we talk about physical states.

Now, what is a physical state? Think of it as a snap-shot of reality at some instance of time, but not necessary with visual properties. To define it in simple words, we have

> A **physical state** at any one time is a set of **measurable** properties of a subset of reality.

There is just one problem: do I need to know **everything** about that subset of reality before the physical state so defined is useful. I argue that complete knowledge is not necessary for the definition to work.

Think of this: you are here because I can see that you are here. Doesn't make sense? Let me put in this way: you must represent something real because by being here, you are disturbing the light field in this room. My eyes pick up the disturbed light field and my brain then interprets the disturbed light field as caused by a real object in this room. In fact, I don't think it is anywhere near easy to con myself into believing you are here when you are in fact not, or that you are not here when you actually are.

But I don't know your name, your age, your telephone number, your hobbies and the works, attributes that describe the real you. The reality of YOU should comprise all these that I have incomplete knowledge of. But when I just talk about seeing you, does that make you any less real?

So we have defined a useable physical state. Great! But are we going to write it down in words? There is absolutely nothing wrong with that, but it might not be the most convenient of ways to communicate a physical state. Instead, using mathematics as a language, we define a **mathematical state**.

What's that? In short, it is a collection of numbers. Oh yeah? What so great about that? Well, I would reveal the brilliance of such a notion to you in a moment.

First, we draw a one-to-one correspondence between one such number in the mathematical state and a measurable property of the physical state. In this way, we can claim that we have drawn a one-to-one correspondence between the mathematical state and the physical state. Here may I remind you that the physical state is the real thing, while the mathematical state is totally fictitious.

Now, Physics is interested in dynamical behaviours, which is how physical states evolve in time. For example, if the physical state is the geometrical you, I would like to know when you stand up and how you leave the room. To me, the whole sequence of geometrical postures at different time constitutes your dynamical behaviour. The question then is, can I discover the rule to your dynamics, something like you walk by placing your left foot ahead of your right foot and then your right foot ahead of your left foot?

Difficult, to do so within a short time. I need more time, but then you are not always around to demonstrate how you walk. Recording you on video tape would be nice, but then the information is only visual, hmm, very restrictive indeed. But hey, haven't we defined mathematical states that are in one-to-one correspondence with the sequence of physical states? Why don't I study these instead?

Of course, the dynamical rule have to be recasted in mathematics as well, and if I do discover it by going through the sequence of mathematical states, I would have to draw a one-to-one correspondence back to a physical rule. Now, can I do that? Very often, it is easy to deduce the mathematical rule of the dynamical behaviour, because we have useful guidelines like Newton's laws, Maxwell's equations and conservation principles, afterwhich it is purely a mathematical exercise to solve the **mathematical equation** and obtain **mathematical solutions**, which are most often in the form of the measurable properties as a function of time.

Great! This means that at any time, all we have to do is substitute the value of the time into the solutions and we would obtain a mathematical state. Question: is this mathematical state in one-to-one correspondence with the physical state at that same time? We don't know for sure, but when in doubt, we always compare the two. If they agree, hey, fine! If they don't, then something must be wrong with my mathematical rule, provided we did not translate our physical state into the wrong mathematical state before the comparison was made. Here two things are important:

1. Accurate modelling of physical state by mathematical state, so that no misinterpretation arises.

2. Accurate modelling of the dynamics of the physical system. That is, the mathematical state evolves according to a mathematical rule that correctly traces out an ensemble of mathematical states, each in one-to-one correspondence with the physical state at any one time.

Now, I'm sure all this sound a little abstract to some of you, so let us consider an example: the example of identical indistinguishable particles.

Suppose there are just two of these, for convenience we label them 1 and 2, and we want to put them into two distinguishable boxes A and B, then we form our mathematical states as

$$|1,2\rangle = |1\rangle_A \otimes |2\rangle_B$$

which corresponds to particle 1 in box A and particle 2 in box B and

$$|2,1\rangle = |2\rangle_A \otimes |1\rangle_B$$

which corresponds to particle 2 in box A and particle 1 in box B. Here we have used the notations of Quantum Mechanics. For those not familiar with the language of QM, just think of these two as a mathematical way of writing the two statements.

However, the two particles are truly indistinguishable, so whether it is 1 in A or 2 in A we would not know. In fact, to us, any linear combination of the two mathematical states

$$|\psi\rangle = c_1|1\rangle_A \otimes |2\rangle_B + c_2|2\rangle_A \otimes |1\rangle_B$$

represents the same indistinguishable state.

Problem: How can an infinite number of mathematical states describe just one physical state? This is in blatant violation of the ground rules that we laid down earlier. So either our mathematical states are inadequate or we did not pick out sufficient properties of the physical system to describe it.

The solution turns out to be the latter. Since the particles are indistinguishable, we would not be able to tell if somebody interchanged the particles behind our backs. So there is a special type of symmetry we called parity which must be a property of the physical state. We then translate this property into a mathematical rule as

$$\mathcal{P}|1,2\rangle = |2,1\rangle$$

where, if we perform two interchanges, we would have

$$\mathcal{P}^2|1,2\rangle = \mathcal{P}|2,1\rangle = |1,2\rangle$$

which means doing the interchange twice is the same as doing nothing, that means, mathematically, $\mathcal{P}^2 = \mathbf{1}$ and after some proving, we have

$$\mathcal{P}|\psi\rangle = \pm|\psi\rangle$$

This allows us to eliminate all but two possible combinations

$$|\psi\rangle_S = |1\rangle_A \otimes |2\rangle_B + |2\rangle_A \otimes |1\rangle_B$$

and

$$|\psi\rangle_{AS} = |1\rangle_A \otimes |2\rangle_B - |2\rangle_A \otimes |1\rangle_B$$

Try as we might, we cannot further reduce our set of mathematical states, so does this mean that two mathematical states represent one physical state? Actually, physicists found a clever way out of this dilemma, postulating that there are in fact two types of physical states, one displaying positive parity and the other negative parity. Physically, this postulate is vindicated by the discovering of two distinct types of particles: fermions and bosons!!

6 On Biology & Complex Physical Systems

Actually, I don't know enough about Biology to talk about the underlying philosophies of this branch of Science. In fact, I don't know much about complex systems either, except for the fact that they have certain behaviours which are very much like those in biological systems. This is why I have decided to talk about it anyway.

Now, there is this book on mathematical biology that I read about, entitled "From Newton to Aristotle: ... ". This sounds weird, because Newton was born about one and a half millenia after Aristotle died, so the time order was obviously wrong. It is only after I read the first part of the book that I realize the implications of the title: the authors were dismayed by the mechanistic and deterministic world view which could not be reconciled with observations on biological systems, and they sought to return to the Aristotlelian world view of various levels of causes. Of course, if I know these authors, I would have cautiously put in a word: "Have you heard of complex physical systems? ... "

What? Complex systems = systems of many parts, whose summed behaviour can be markedly different from the individual behaviour of the parts. As opposed to the long established history of Newtonian Mechanics, complex systems as physical systems only began to be studied in the last twenty to thirty years, so it is a relatively new field in the physical sciences. It is intricately linked to nonlinear dynamics, is mathematically forbidding but exhibits that intriguing ability to self-organize, to form complicated structures through seemingly straightforward dynamical rules.

Here's another bold statement:

Biological systems are Complex Systems

Even the simplest cell is many-fold more complex than the simple pendulum, not only because of the number of atoms and molecules present, but also because they form complex substructures which are themselves difficult to understand.

In Physics, we also study systems with very large number of particles. But these are usually simplified by having them contain only one type or two types of particles which interact through very simple rules. It appears that the distinction between complex behaviour and simple behaviour lies in the existence of feedback, which means that the system collects information about itself to influence future development. This generally allows the system to organize itself into very large structures and an example of such complex behaviour would be autocatalysis of certain biological molecules, like the DNA.

This is just one possible direction to understand Biology in the language of mathematics and physics. Another one is the study of the dynamical behaviour of ecological systems. In fact, a particular branch of chaos theory originated from the study of yearly populations of a certain species of fly in a region. This culminated in the study of chaotic maps in nonlinear dynamics.

However, such a mathematical model describes only the dynamics of one species which is immutable. To study more complex evolutionary ecological systems, where speciation, mutation, extinction and natural selection occurs, it is probably convenient to use to language and techniques of quantum field theory, where each species can be considered a dynamical degree of freedom, their respective populations another degree of freedom and the whole system would become a quantum field. In the language of QFT, extinction would then be governed by an annihilation operation a and speciation by a creation operator $a^\dagger$ while death of a member of a certain species by an annihilation operation b and birth by a creation operator $b^\dagger$. This then becomes a $2 + 1$ quantum field theory, which is still a hot area of research in Physics. Mathematical modelling would be complete when we deduce the Hamiltonian

$$H = H(a, a^\dagger, b, b^\dagger, t)$$

of the ecological system, after including the dynamical rules of speciation, extinction, mutation and natural selection as interaction potentials. As a note of interest, because of the presence of mutation as a dynamical rule, the dynamics of the ecological system would have to be a stochastic quantum field theory, which I think has never been studied before yet.

I have come up with two examples of linking models in Biology and Physics, but there can obviously be many more. This I leave to those who are interested to explore, possibly as an essay or computer project.