The search for knowledge and understanding in the sciences and humanities

There is much in the hard sciences that we do not understand or may never know. So writes ***Prof. Doug Rawlings****, former acting-dean of the Faculty of Science and for nearly 17 years chair of the Department of Microbiology.*

The following is adapted from his farewell address given on ***27 November 2015*** *to Faculty management – a light-hearted, tongue-in-cheek contemplation on knowledge and how it grows.*

When speaking with colleagues in the general arts and humanities, it has been surprising to discover how encouraged many are to hear that knowledge in the hard sciences is not as cut-and-dried as they thought.

At an existential level, we wrestle with similar questions as we attempt to find answers. The question 'why do I exist; why does anything exist?' is something that concerns all of humanity and illustrates the point. The first part of the question is a search for purpose and meaning and has been asked for centuries. It falls within the professional domain of theologians and philosophers and is contained within the second part. The second part is a scientific matter and the current best answer is – we do not know!

It is called the fine-tuning problem, because so many constants have had to be fine-tuned for anything we experience to exist at all. Some accept it as divine providence, while it is in the nature of science to seek an explanation based on testable theory supported by evidence.

What can we learn from the physicists?

Half of the problems in this Faculty began with the acceptance of Einstein's theory of general relativity in 1915! This viewpoint is based on the following considerations. Physics is where the big science questions lie. Everything that we do and teach in the Faculty of Science is based on physics. Physics is considered to be at the apex with chemistry being a derivative of physics. Biology is said to reducible to physics and chemistry. Even "pure mathematics" is thought, by some, to be based on properties of the universe. So we are all physicists or applied physicists of some sort.

Like every natural science student, I did physics in my first year as an undergraduate and it was the subject in which I obtained the highest marks. However, I decided not to continue with physics but rather to continue with applied physics which in my case was chemistry and microbiology.

The search after knowledge is like following a moving target

I think it is time that we who are applied physicists acknowledge some of the challenges our physics colleagues face and why we should be so grateful to them for teaching our students this important subject. Imagine what it is like to have to stand in front of a class and say – "we do not know what more than 80% of the stuff in the universe is, but let me tell you about the less than 20%"? As a physics lecturer, I would have found this rather uncomfortable, even a little embarrassing. To call it "stuff" sounds very unscientific and so we use terms like dark energy and dark matter.

But the truth is, nobody knows what it is.

What makes the situation worse is that when it comes to the less than 20%, we do not understand that either. Richard Feynman made this clear. He was arguing that there are things that we know that we do not know and there are also possibly things that we do not know that we do not know. Quantum mechanics is like the latter for a chimpanzee. We know that we do not understand quantum mechanics, whereas a chimpanzee does not know that there is such a thing as quantum mechanics to be not understood.

Quantum mechanics is the second half of where our problems in science lie. Feynman's admission that we do not understand quantum mechanics was of great comfort to me. The reason is that as an undergraduate I felt that I was on top of the subject matter of my majors except for one topic in physical chemistry – statistical thermodynamics. This is about the dynamics of molecules and atoms. It is in essence quantum mechanics and I never understood it properly. Only when reading Feynman's comment did I discover why. It is not understandable. As Heisenberg explained, one cannot know both the position and momentum of a particle such as an atom or electron. If one cannot know the position and momentum of any single atom, then how is one to know the position and momentum of a whole mole of atoms? Think of it as simple proportion: position and momentum of one atom = not possible to know, therefore, position and momentum of 6×10^{23} atoms = 6×10^{23} times more impossible to know.

The large hadron collider at CERN was built partly to investigate whether the standard model of particle physics was correct. The model had predicted that the Higgs boson existed and the Higgs boson was indeed found. However, what surprised me was to read that to many of our physics colleagues this was a disappointment, because finding the Higgs boson supported the standard model of particle physics. If the Higgs boson had not been found, it could have suggested ways in which the standard model should be modified. A suitable modification could assist us solving some of the difficulties being experienced in unifying quantum mechanics and general relativity. Since the Higgs boson was found we are more or less stuck with our standard model that does not work.

So where do we go now?

In an attempt to unify particle physics with gravity some people have developed different variations of string theory. For example, I believe that there is 10-dimensional superstring theory or a 26-dimensional bosonic string theory (plus other variations) and that the extra dimensions are required to make the mathematics work. Whatever version of string theory, they all require multiple dimensions. Some people ask where are these dimensions? We tell the non-physicists that most dimensions are tightly curled up and that only the three spatial dimensions, length, width and height, have revealed themselves to us. Of course there is also the dimension of time, but time is somewhat different and we do not understand what time is anyway. To us time seems to flow, but at what speed does it flow at?

The short answer is, we do not know.

Certainly, when it comes to handing in assignments our students don't seem to understand time and us academics are no better when it is time for a seminar to start. I have read with amazement about particles that pop into and out of existence by borrowing energy from empty space. Apparently, the more energy they borrow the quicker this 'in and out' must happen. A couple of weeks ago I explained to my wife, Janet, that this is what must happen to our car keys, her cell phone and our son's wallet. Occasionally, they pop into and out of existence. Of course this is joking but the serious question is, at what size does quantum weirdness end?

With quantum uncertainty there are apparently two options for events at the atomic scale and either can occur with roughly equal probability. We are all aware that Edwin Schrödinger used the illustration of a cat that is both dead and alive to explain this curious but well-established phenomenon. Some of us physicists have proposed that in fact both states “dead” and “alive” do occur but in different “universes”. With each quantum event having two options, the number of universes needed to allow for an endless string of quantum events becomes infinite.

This created a difficulty for me when my postgraduate students and I tried to do some research in microbiology. On occasion a postgraduate student would describe to me an experiment that had not worked out the way we had expected. As an applied physicist, I was always troubled by the possibility that the experiment may have worked perfectly well but in a different universe. I found that a little unsettling but never admitted this to the student. If I had, what were we to believe, had the experiment worked or not?

The search for knowledge continues

I am nevertheless very proud of what has been achieved based on what we *do* know about non-quantum physics. A few months ago, the New Horizons space mission flew very close to what used to be the planet Pluto. The images it sent home were stunning and left me wondering, given all of the uncertainty described, how did we manage to do that? Even more remarkable is that we were able to launch the lander Philae from the spacecraft Rosetta and land it on the surface of the duck-shaped comet, 67P/Churyumov-Gerasimenko, that was tumbling in space. There was a minor difficulty in that Philae bounced a couple of times on landing, ended up in the shadow of a cliff and temporarily lost its solar energy supply. Even the non-physicists would agree that although the landing was a little less than perfect, this is a most impressive achievement. Most of us who travel would have experienced less than perfect landings, but the landing of Philae was spectacular. Due to the low gravity of the comet, the first bounce by Philae was calculated to have been about 1 km high!

With respect to quantum physics, although how it is related to the rest of physics is not properly understood, quantum computers (where a qubit can be both a ‘1’ and a ‘0’ at the same time) have been built and work with a steadily increasing level of sophistication. Similarly, the more general field of quantum engineering is forging ahead. So both quantum and non-quantum physics appear to be working out rather well, just not coherently.

If we think physics has its challenges, I am even more grateful that I am not a lecturer in economics, even though I admit to being as fascinated by the subject as by physics. Retirees have to decide on where to invest their pension funds. I had mistakenly thought that I might be able to approach this challenge scientifically. However, having tried, I soon realised that economics is in a much worse situation than physics. In economics it is not unusual to have two people, both considered to be world experts in a given field, who totally disagree with each other. They both think that they know what is going on whereas in physics, at least we admit that we don’t know. If one expects to live a few years after retiring, one would hope to be able to get some advice as to how economic matters might unfold in the future. What I found rather disconcerting was a statement attributed to Ezra Solomon, the late Dean Witter Distinguished Professor of Finance at Stanford University: “The only function of economic forecasting is to make astrology look respectable.”

As an applied physicist I don't mind getting financial advice from an astronomer but had thought that I may be able to avoid getting financial advice from an astrologer.

There seems to be no end to all the questions to which we have no answers. One would think that to ask how the universe began is not an unreasonable question. We are told that it all began with something as small as a pin-prick. So how did everything in the universe fit in there? The answer is that nothing that we now know (or think that we know), applied then. The questions continue – is the universe infinite, what exactly is gravity and so on and so on?

An article in a recent *New Scientist* entitled "So you think there's a multiverse. Get real" made me think to myself – now this sounds like common sense for a change. It is based on a book, *The Singular Universe and the Reality of Time,* by Lee Smolin, a theoretical physicist at the Perimeter Institute for Theoretical Physics in Waterloo, Canada. He makes three points.

The first is that there is just one universe. I think – yeah great. The third is that mathematics is not a description of some separate timeless Platonic reality, but rather of the properties of one universe. I think – well alright, that is interesting. However what threw me was the second point: that time is real and the laws of nature are not timeless but evolve. I think – well I hope that the lecturers in chemistry know when to update their lectures given that the first and second laws of thermodynamics are evolving!

After a lifetime in science

After all of these considerations and a lifetime in science, I have gained the following profound insight. There are a lot of things that we know that we do not know and there seems to be a lot that we do not know that we do not know. So, fellow applied physicists, you will now understand my concern about the future of the Faculty of Science. How will we, physicists and applied physicists alike, be able to prosper given that we understand so little about our apex subject?

In closing, I want to reiterate my gratitude for the sterling work of our physics lecturers. It is not their fault that the big unanswered questions are so disproportionately clustered in physics.

I have learned a lot by reading every issue of *New Scientist* for the past 15 years or so and this is where much of my general knowledge of science comes from. I am not sure whether I should recommend to members of the Faculty that you read *New Scientist* because, as you will gather, finding out about what we do not know about science can be unsettling. Personally, I have decided to keep on reading *New Scientist* in the hope that things will become clearer.

I wish you well.

Prof. Doug Rawlings

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