The rewards of interdisciplinarity are not worth the costs. Discuss, using either small world networks or chaos and complexity research as an example of transdisciplinarity.

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Abstract. This report describes how chaos and complexity research can have many applications throughout different disciplines and thus how it promotes interdisciplinarity. Interdisciplinarity is also considered for its worth to the scientific community.

1 Introduction

Science, the great human endeavour in understanding the world around us, has lost its way. Its very structure has been fragmented into so many different disciplines that no one discipline really has a sense of what other disciplines are doing, or the overall picture.

The promotion of Interdisciplinarity will help disciplines work together so that they may understand parts of nature, within their own understanding, that other disciplines cover.

2 Interdisciplinarity

Specialisation has not always been a strong theme in modern science. In the early years of western science, specialisation was uncommon. A 'man of science' was expected to be knowledgeable in all fields of science. Michael Faraday, for example, was famous not only for his work in electricity, but he also did significant research into benzene. As the corpus of scientific knowledge grew, it became so large that some specialisation became a necessity. Disciplines formed and university departments were set up which concentrated on each discipline.

The problem with the new disciplines is that they are inherently flawed. Many natural phenomena cannot easily be classified as only important to one discipline. The boundaries between disciplines are not clearly defined. Benzene is important in many different disciplines: Organic Chemistry, Biochemistry, and Medicine, to name a few. There are many topics that live on the boundaries between disciplines. Research in these topics can draw input from many disciplines and can have significance in many disciplines.

Interdisciplinary work occurs at the intersection of multiple disciplines. It is of mutual interest to the disciplines. If science is the study of nature then, as much of nature falls outside of (or on the intersection of) traditional disciplinary boundaries, we must have interdisciplinary research.

Many of the barriers against the promotion of interdisciplinarity are political. Disciplines are traditionally holed up in their own departmental buildings and not encouraged to talk to others. Generalism has been out of favour in science since specialisation became popular. Jose Ortega Y Gassett argues in his book 'The Revolt Of The Masses'[1] that such specialisation leads to people becoming 'Learned Ignoramuses'. He puts forward an argument that if people were more widely trained then they would be able to produce science more effectively. He doesnt really seem to have any particular reason as to why he believes this, other than that specialised people are not of the calibre of more widely trained people. Specialisation has served much of science well however and many specialised people have and continue to work well in their fields.

When multiple disciplines collaborate it is not generally the case that they look at the subject matter in similar ways. A chemist does not view a protein in the same way a biologist does. A physicist does not view a molecule in the same way a chemist does. They all look at these things on different levels.

A geneticist studies genes; she may look at how different genes affect the way a persons eyes are coloured. The geneticist looks at genes on a purely functional level: while there is a need to understand how genes work, it is not necessary to understand the chemical structure of Deoxyribonucleic acid (DNA). In fact, thinking about the structure would waste her time. She only needs to look on the functional level and in this case her 'specialisation' is vital to her project's success. However, without the interdisciplinary research into DNA and its *functional* relevance to genetics, that research would not be possible.

It is not always the case in interdisciplinary research that one discipline takes a functional stance while the other discipline takes a structural stance. Biomechanics is involved in building artificial joints. Both disciplines are interested in both the function and structure of an artificial joint. The mechanical engineer plays an advisory role in the project, helping the medic design and manufacture the joints. An interesting aside is that the resulting manufacturing processes may actually be useful outside the medical application and the benefits may be mechanical as well as medical.

3 Chaos and Complexity

The functional / structural dichotomy is interesting within the field of complexity. Some systems are structurally so complex that it seems impossible to take a functional stance. Genetics is an important example. There are approx 10^{30000} different potential activity states for the 100,000 genes in the human genome, thats more than there are hydrogen atoms in the universe[3]. How might one understand the DNA molecule and how it acts as the building block of life given its complexity?

A Chaotic system is essentially an unpredictable system. Taking two very similar starting positions the two resulting paths of the system will diverge rapidly. A popular example of a chaotic system is the world's weather system. In the early 1960s Edward Lorenz was trying to model weather with his computer. He had succeeded in generating a model of winds that behaved like a real weather system, yet it was still unpredictable. One day he accidentally typed in a wrong figure (the difference being that of the effect of a butterfly flapping its wings) while restarting the system and watched in amazement as his system diverged much more wildly than he should have expected. The 'Butterfly effect' had been discovered.

Weather is a complex system: immense numbers of Nitrogen, Oxygen, Water, Carbon Dioxide and other molecules all interact on a molecular level and it is not possible to even imagine a way of collecting the data to build a fully accurate model. However there are patterns in weather that are recurrent. There are more occurrences of light showers in April in the UK than there are in August. There is a large red spot on the planet Jupiter that has been there as long as we've looked at it. Where do such patterns come from?

The answer is that even chaotic systems have order within them. A metal ball swung on a piece of string over two magnets will show chaotic behaviour, but it will still loop within a certain circuit. The system is stable and confined, but will never do the same thing twice. This is an example of a system working under a 'strange attractor'.

Another example of a system that works within a strange attractor is a slowly dripping tap. James Gleick's book Chaos[2] describes how Robert Shaw set out to analyse the apparently chaotic time periods between drips. He built a simple mathematical model to try and explain it using springs. A weight on a spring slowly gets larger over time. Once it gets beyond a limit part of the weight drops off, the rest bounces up and down. It was impossible to show that the model reflected the real system because there was no obvious correlation between the two systems as they were both obviously chaotic. Shaw tried plotting each time period against the next time period, ingeniously changing the output of the system to be two-dimensional. Sometimes he had to go to three-dimensions by plotting a third period, but he began to see patterns emerging. The patterns in his spring model closely resembled the patterns in real life (which were fuzzier) - he had successfully modelled a dripping tap. More importantly he had shown that by expanding the number of dimensions of the output of the data meant that he could show some order in what had initially appeared to be an order-less system.

4 Chaos and Complexity and Interdisciplinarity

Chaos and complexity are important in interdisciplinary analysis. Not many disciplines look at phenomena on both a micro and a macro level. The macro level is normally more interesting to one discipline and the micro level is interesting to another. Take weather for example: weather patterns are interesting to meteorologists while the behaviour of gasses is physical chemistry. The actual application of chaos and complexity is neither meteorology nor physical chemistry. It is a branch of mathematics and computer science. Note how many disciplines are involved!

Chaos and complexity are a set of principles which help scientists to visualise, on a macro level, systems that are complex on a micro level. Or, to put it another way, see function in systems where they can only describe the internal structure. It can be applied to many disciplines and is as such transdisciplinary.

This points towards another benefit of interdisciplinarity. Earlier on in this report I talked about how systems can be viewed on a structural level or a functional level. A third way of looking at a system is a meta level. When Isaac Newton realised that force equals mass times acceleration he also worked on some maths that describes the actual mechanics of the system. He developed calculus. Calculus is not physics; it's a transdisciplinary idea. It soon became obvious that calculus had applications in many other disciplines. Interdisciplinarity allows for the movement of these transdisciplinary ideas across disciplinary boundaries.

Chaos and complexity do not involve traditional scientific method. Traditional scientific method rejects induction (the idea that just because something has always worked one way it always will). Karl Popper[4] argues that the best science is that for which circumstances can be identified which will prove a theory to be false. One starts with a theory and then one devises an experiment to show that it is false. Evolution was not viewed to be good science as there is no experiment to show it to be false. Complexity and chaos are also what I'd like to call 'Backward Science'. Backward in that one takes data and then one tries to show what meaning there is in that data rather than taking meaning (a theory) and then trying to generate data to prove that meaning. Methods of working with data are not special to any particular discipline, so specialisation looks like becoming less relevant where modern methods are concerned.

5 Conclusion

There is already much interdisciplinarity in the modern scientific world. Magazines such as the New Scientist inform many scientists what ideas have found success in other disciplines. University coffee rooms and pubs allow for scientist to get together and discuss their work. However, there is still much going on in some disciplines that could be of relevance to other disciplines that is not being discussed.

Without interdisciplinarity, a lot of modern science would not be prevalent. Specialisation tends to lead towards the more traditional (Popperian) way of doing science whereas interdisciplinarity helps us find new approaches through looking at the ways other disciplines approach things.

There are costs to interdisciplinarity. Much time may be wasted teaching physicists about stickleback reproduction, for example. What is important is that the most relevant ideas are passed between disciplines. Some ideas are obviously related to another discipline and these are easily identified, but also those which are more abstract such as chaos and complexity are best passed between disciplines as well. These more abstract ideas have the potential to become transdisciplinary and affect science as a whole.

References

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