complex or complicated change?

What might biology education learn from disciplinary biology? Asks *Rosemary Hipkins*, NZCER, and keynote speaker at Biolive 2009.

At the 2009 Biolive Conference in Dunedin I suggested that biology educators could look to the cutting edge of biology when searching for ways to manage the complex changes in teaching and learning signalled by the phrase 'a 21st century education'. This article sets out my argument for those biology teachers who were not able to be there, but I believe the deeper message is relevant to all teachers, given the curriculum challenges that confront us as we work out how best to implement the New Zealand Curriculum in our various schools.

I began my talk by comparing challenges facing biologists and biology teachers. Researchers in any area of science can't afford to be left behind, especially where their research field is fast-moving and changing. Neither can teachers!

Education is changing, but it's not easy to see that when you are immersed in it day-to-day, and when the job requires a certain 'presentism' that demands instant decision-making and little time for reflection (Hargreaves and Shirley, 2009). Complexity theory has been a key theoretical influence in biological research, and its influence on the ways we think about the challenges of educating students for an uncertain future is growing. In this article, I take one tiny slice of the curriculum – the part that relates to teaching key ideas about genetics – to consider how ideas about complexity, drawn from current research in cell biology, might change not just the genetics we teach, but also some of our deepest metaphors about life and learning. This in turn might change the way we think about 'the curriculum' and how to implement it.

Complexity thinking in the context of genetics

The American physicist Fritjof Capra, has been writing about complex systems for more than thirty years now. In the preface to *The Hidden Connections* he comments:

At the beginning of the 1980s, when I wrote The Turning Point, the new vision of reality that would eventually replace the mechanistic Cartesian worldview in the various disciplines was by no means well articulated. I called its scientific formulation "the systems view of life", referring to the intellectual tradition of systems thinking, and I also argued that the philosophical school of deep ecology, which does not separate humans from nature and recognizes the intrinsic values of all living beings, could provide an ideal philosophical, and even spiritual, context for the new scientific paradigm. Today, twenty years later, I still hold this view (Capra, 2002, p. xvii).

Systems thinking is not a minor adjustment to the way we see the world. It is nothing less than a new view of *reality*, a change of *worldview*. It goes to the very heart of our deepest assumptions about what 'is' and can 'be'. The turning point that Capra refers to here is indeed a paradigm shift – a move from seeing the world in terms of a linear, and hence predictable, mechanics of cause and effect, to non-linear dynamics of complex systems where the outcomes of interactions cannot be predicted in advance, but rather *emerge* as the system evolves and learns. Systems can be socially constructed as well as formed in the natural world. For example, we've all had a sharp and nasty lesson about what this can look like with the recent crisis in the world's financial system and it is by no means clear how this will continue to play out.

What's all this got to do with genetics? Quite a lot actually. Some years ago the science philosopher Evelyn Fox Keller wrote a slim but powerfully argued book called *Refiguring Life: Metaphors of Twentieth-Century Biology* (Fox-Keller, 1995). In this book she argued that we are teaching outdated metaphors of life while we continue to teach the simple mechanical genetics of the middle of last century. As the sometime author of a widely-used genetics textbook (Hipkins, 1990), one that purported to represent what was 'new' in genetics at the time, this argument struck me with some force! I knew I had unwittingly contributed to perpetuating a worldview that was now being questioned.

Back then I wrote with such confidence that genetic control of bacterial activity is much simpler than in humans because their genomes are much smaller than ours. This was the prelude to describing the well-known Lac operon, which is still taught and examined in the senior biology curriculum. (I hope this will change with the shift of the gene expression achievement standard from Level Three to Level Two, along with signals that it will be refocused on gene-environment interactions.)

For those of you who don't teach genetics, here's a typical diagram.

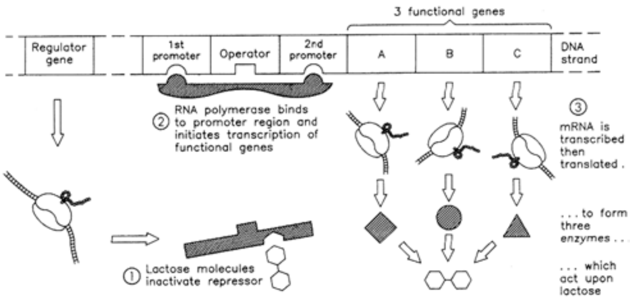

Figure 1: The diagram shows the Lac Operon when Lactose is present in the cell.
Ref: Hipkins (1990), pg 28.

Systems theorists contrast complex and complicated models. The latter are understood as being the sum of their many parts – to know the bits is to know the whole. Complex systems, by contrast, are more than the sum of their parts so they can surprise us by doing unexpected things in response to change; sometimes doing seemingly nothing at all until they reach a 'tipping point' when many things change dramatically. You can see that the Lac operon belongs in the complicated worldview. Via a linear, predictable series of mechanical events it regulates lactose metabolism in bacterial cells. So far, so good. I'm not for one moment suggesting this doesn't happen. Operons are apparently found in some eukaryotes with a relatively simple body structure, but are most common in prokaryotic cells. If we give the impression that all parts of any genome, including our own, could be understood in this way – if only we could unravel the complications – then we are doing our students a great disservice.

With the clear foresight borne of deep thought, Fox Keller lamented the neglect of the older, less dramatic, field developmental biology and embryology once physicists had brought exciting new techniques of analysis to DNA sequencing. There was, she said, more to an organism than could be predicted by its DNA alone. This is a criticism of 'reductionism', which is a way of thinking that belongs with a complicated worldview.

Reductionist thinking assumes: the parts are the whole; the individual rather than the group should be the focus of attention; there is an obvious separation between an entity and its environment; and this in turn leads to the false dichotomy between nature and nurture. At this point you might be getting a hint of where I'm taking this argument with respect to education in general, but let me stick with genetics just a bit longer.

Peter Dearden opened the 2009 Biolive Conference with an enthralling and memorable overview of his research team's work. He leads a University of Otago team of scientists who study *developmental genetics*, thus bringing together the techniques of molecular genetics and the previously neglected field of developmental biology. He couldn't have illustrated more vividly the perils of the reductionist viewpoint that we are simply what our DNA dictates we will be. For example, he discussed a cluster of ancient developmental genes called 'Pax6' that control eye formation.

Pax6 genes have been found in every animal whose genome has been sequenced, including the human genome. In the fruit fly, Drosophila, this cluster of developmental genes controls the formation of an insect eye. In mice, the very same cluster of genes controls the development of a vertebrate eye. Put the mouse Pax6 complex into a fly and what will develop is fly eyes, not mouse eyes. So these genes do not operate independently of the environment in which they are located. They are part of a system, and the overall interactions of the systems' many parts determine what gets made and what happens next. Gene and cellular environment interact as a whole.

The reductionist view that our DNA makes us who we are is very pervasive in the media. For example, during the week I was putting my Biolive talk together our local newspaper ran an article that declared our genes make us 'hard-wired' to get fat. Such an argument takes no cognisance of the ways we have altered our food *environment*, as discussed in popular books such as The Ominvore's Dilemma (Pollan, 2006), to name just one. Another article that same week proclaimed that scientists had extracted DNA from ancient feathers to 'rebuild' moa in the laboratory, allowing them to tell us more about what individual species looked like. Reading between the lines (for example picking up on the cue that the feathers had faded) I correctly guessed that what they had actually done was to match feathers to bones, thereby determining which moa species had shed the feathers while alive. That's a far cry from 'rebuilding' a whole moa, but that's how the science was portrayed.

There are two immediate educational implications here. The first and most obvious one is that we need to update our approaches to teaching gene expression. The second is that we also need to help students read reductionist accounts of our DNA 'destiny' more critically. The curriculum certainly provides the necessary flexibility. Indeed, lining up its various components sends strong signals that this could be a really productive context for senior students to explore. So, for example, helping students to become 'lifelong learners' is one of four aspects of the vision statement; subsumed under that heading we find becoming an informed decision-maker (p. 8). This aligns with critical thinking as a key competency (p.12) and, arguably, integrity (being honest, responsible, accountable and acting ethically) as a value (p.10). One can't argue here "my genes made me do it!"

In the science learning area at Level Seven we find DNA/environment interactions in gene expression as one of the achievement objectives, and at that same level the Nature of Science communication achievement objective points to the need to study the implications of representations of science ideas. I read this as including the deep metaphors coded in the language we use to describe phenomena, and this is where the DNA example gets really interesting. There is more at stake here than just how we understand DNA itself.

Why systems thinking matters for education more generally

In a series of radio talks in the early 1990s, well known geneticist Richard Lewontin picked up similar themes to Evelyn Fox Keller, for similar reasons. Here in a nutshell is his argument about the very deep roots of reductionist thinking, and its soulmate biological determinism:

It is usually said that genes make proteins and that genes are self-replicating. But genes can make nothing. A protein is made by a complex system of chemical production involving other proteins, using the particular sequence of nucleotides in a gene to determine the exact formula for the protein being manufactured. Sometimes the gene is said to be the "blueprint' for a protein or the source of "information" for determining a protein. As such it is seen as more important than the mere manufacturing machinery. Yet proteins cannot be manufactured without both the gene and the rest of the machinery. Neither is more important. Isolating the gene as the "master molecule" is another unconscious ideological commitment, one that places brains above brawn, mental work as superior to mere physical work, information as higher than action. (Lewontin, 1993, p.48, emphasis in the original).

Lewotin's book is called *Biology as Ideology: The Doctrine of DNA*. The ideological position he has in his sights is often called biological *determinism*. He says this ideology rests on three key ideas:

- We differ in our fundamental abilities because of innate differences
- Those differences are biologically inherited
- Human nature guarantees the formation of a hierarchical society.

Taken together these three ideas lead to very familiar metaphors of a meritocracy – for example 'survival of the fittest'. This is an ideological commitment that runs very deep. To take just one example from the history of science, the story of why the discoverers of the so-called 'Piltdown man' fossil were so readily duped hinges on their expectation that intelligence (and hence large brain size) would be a necessary enabler of other aspects of human evolution such as walking upright (Barker, 2006). Many other similar stories from the history of science could be told.

The three linked ideas of this ideology lie at the very heart of the way modern societies have structured schooling and the high stakes assessment of learning (see for example Gilbert, 2005). But, Lewontin says, this idea ignores the impact of learning and culture on how our biological potential is expressed. It's the same argument against reductionist thinking as the gene/environment one – but this time at the level of the whole person in their societal context. He is specifically critical of determinist assumptions that some students are better able to learn than others, and his argument has interesting resonances with the way sociocultural theories explain the nature of learning.

Sociocultural theories say that all learning is *situated*: it takes place in contexts that can be manipulated to maximize learning benefits. It is *mediated*: the extent and efficacy of our learning depend at least partly on the supports that are provided – both by people and other

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human ethics guidelines for schools

The human ethics guidelines for schools: Ethical Practice When Doing Research: Guidelines for Students and their Supervising Teachers (2009) are for students and teachers in classrooms in New Zealand who are engaged in school research and other projects that involve people, such as other students, family, and members of the community, as *Rosemary De Luca* and *Bev Cooper*, both from University of Waikato, explain:

This article describes the background to the development of these guidelines, the process of development, the composition of the guidelines, and some particular features.

Background to the development

Formal ethics review of school-initiated research that involves animals preceded formal acknowledgement of the need to review research that involves persons. With the introduction of the Animal Welfare Act 1999, advocacy from the Royal Society of New Zealand (RSNZ) and the New Zealand Association of Science Educators (NZASE) resulted in acceptance by the Ministry of Education of the need for a unified Code of Ethical Conduct and an ethics approvals process for all schools using animals for research and teaching.

Initially, schools used a range of committees managed by individual schools, local science teachers' associations or science advisors, or used the ethics committee of other organisations such as a tertiary institutions to gain ethics approval. To ensure consistency and accountability under the Act, RSNZ was contracted in 2003 to develop the Code of Ethical Conduct approved by the National Animal Advisory Committee of the Ministry of Agriculture and Fisheries (MAF); establish protocols and implement an Approvals Committee; manage compliance on behalf of all schools, teachers and students in New Zealand; and provide them with advice.

Partway through the contract, MAF noted that the RSNZ was not the appropriate organisation to hold such a Code on behalf of schools. The RSNZ continued to administer and support the approvals committee to implement the Code, and NZASE became the Code holder. The development of the Code of Ethical Conduct was completed and approved in December 2004, and is now being successfully promulgated and monitored by the Animal Ethics Committee (AEC), a committee of NZASE funded by the Ministry of Education (MOE).

Schools need to follow a formal approvals process for projects and research involving animals. Entries are not permitted into science fairs unless there is proof that an approval had been given by the AEC. An assumption was made, understandably by teachers in schools, that science fair entries that involved human participants also required ethics approval and this became de facto policy and practice. Because the AEC is not accredited or entitled to deal with ethics approvals relating to humans, the approvals application process for science fair entries involving humans was initially dealt with on a case-by-case basis by one or more of the Ministry of Health's regional Health and Disability Ethics Committees.

While these committees are accredited by the Health Research Council Ethics Committee (HRCEC) to give ethics approval for human research, the nature of their role is particular to health research as defined by the Health

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resources in the learning environment. It is *distributed* across the whole learning network of people and things (think for example about how much easier it is to read an instruction manual when you have the machine to which it refers ready to hand). It is *participatory*: new learning *emerges* in the interactions that unfold. The links to systems thinking should be evident here, and indeed there is a growing body of literature that discusses classrooms and schools as complex systems, and how best to manage them so that all students can learn. One very easy to read example is *Engaging Minds: Changing Teaching in Complex Times* (Davis, Sumara, and Luce-Kapler, 2008).

It is my view that the New Zealand Curriculum should be read in this sociocultural, systems framing if we really do want it to be a curriculum for the twenty-first century. Earlier in this article I gave just one example of how the various parts of the curriculum should be read together, in interaction with teach other. If we read key competencies in a more determinist frame, it is easy to see them as personality traits – something the student brings to school, or not. Then it can't be our fault if they don't learn – can it? But if we read the key competencies in a sociocultural frame, and in interaction with the vision, values, principles and advice about pedagogy sections of the new curriculum, then it's really important to think about the ways in which we provide opportunities for students to learn and grow (Hipkins, 2006). We can't change their genetic inheritance, but we can change the environment in which each individual expresses their potential!

Working through these ideas takes a lot of reflection. One challenge of the metaphors on which our language, and hence our thinking, rest is that we use them without knowing we are doing so. We can't all be philosophers, but we do need to keep abreast of contemporary thought if we truly believe our school system needs to be transformed so our students are ready for the uncertain times ahead.

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