Making Science Whole Again

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As a developmental biologist of over 20 years, I am still filled with a sense of awe and wonder when studying embryos. The gradual appearance of form of a zebrafish embryo for example is astounding. The fertilized egg begins to cleave and the first cells are formed, wrapping themselves around the yolk sac that will provide all the food the embryo needs. The cells move and divide in an intricate dance of creative exuberance over the ensuing several days. It is the astounding ability that the cells within the embryo have to communicate with each other that always amazes me. This is a dance and dances require co-operation and the ability of the partners to hear the rhythms in the music, creating intricate, interweaving patterns that result ultimately in something of beauty to behold. Einstein has many great quotes, but one of his best in my opinion is when he said *"The fairest thing we can experience is the mysterious. It is the fundamental emotion, which stands at the cradle of true art and true science. He who knows it not and can no longer wonder, no longer feel amazement, is as good as dead, a snuffed-out candle."*

To me, the process of embryo development is always mysterious and amazing. Ultimately, how can we explain the development of such perfect form without recognising that the embryo evolves as a whole unit, owing to the ability of the individual cells to constantly communicate with each other? In the process, the cells essentially become one indivisible whole. Sure, great strides have been made in breaking the system down to isolated individual units, whether they be cells or molecules, to try and explain the process, but then all we have are fragments whose connections still need to be explained and understood. It always seems to me there is a fundamental creative spark, a kind of ever-changing enthusiasm that the cells have to sculpt themselves into form in time and space.

So, in order to understand embryonic development, we need to integrate and assimilate the information we have. But is that all there is to it? Is it just a case of explaining the material interactions between the molecules and cells or is there something more at work here? Something perhaps even more wondrous? Can we remind ourselves occasionally to just step back and admire the beauty of the process as it is without the need to analyze and explain it with that cold objectivity that scientists are supposed to uphold as the ideal approach to science? I personally find this cold and objective approach to science rather a 'dead' one and, indeed, an unrealistic science. Science is driven by passion and personalities, by subjective experiences and feelings. But somehow this has become lost along the way, particularly in the way we teach science.

We need to develop a new science that sees the connections between the parts. A science that integrates rather than fragments and inspires students rather than suppressing their creativity. We need a science that sees the bigger picture, a science that understands its own history and philosophy. We need a science where wisdom, creativity and purpose are valued. We need to encourage students to question their preconceived, acquired ideas about what science is, to move beyond science as simply problem solving.

In order to make science whole again, we need to make scientists whole again.

A major problem in biology is that most biologists have shied away from physics in their science education. What physics they have is the old physics of Newton. It is a mechanistic physics. So, most biologists still seem to have a preconceived notion of organisms as machines, which can be dissected (at the tissue, cellular or even molecular level) to explain their function. There has been little recognition for example of quantum physics and that Einstein's famous $E=Mc^2$ changed everything in highlighting that energy is fundamental.

However, there are some glimmers of hope upon the horizon. There is an emerging field of quantum biology for example [1], which is shaking up the current view. Quantum biology, the application of quantum mechanics to biological systems, is indicating that quantum effects (call it quantum 'weirdness' or 'spookines' if you like) occur in biological systems. For example, quantum effects can explain photosynthesis, bird navigation and the structure of DNA itself (models suggest that the electron clouds in DNA are entangled [2]).

And so we might return to our zebrafish embryo. If the electrons within DNA are entangled, then it follows that each piece of DNA in each cell is entangled with each other piece of DNA in each other cell in the developing embryo. Is it just possible that quantum entanglement between DNA could be one of the missing pieces in the puzzle of explaining the mysterious connection between the cells in a developing embryo? Obviously, this is a conjecture that would need to be investigated, but it does perhaps provide a different way of thinking about the connections between the cells in an embryo that could change our entire view of embryonic development and move us to a more holistic explanation for the creative magic of morphogenesis.

So, there are some creative leaps being made that are beginning to link quantum physics with biological systems. However, science education often fails to reflect the reality of modern science and its contributions to society [3]. So, how can we go about changing both the perception of science and scientists and the way in which science is taught? In order to make science whole again we need to recognize that science is fundamentally a creative endeavour and so creativity is essential for both the teaching and learning of science.

Therefore, an emphasis on creativity is particularly important in science teaching. How do science educators take themselves outside of the 'box' in order to develop the approaches to maximise engagement in and excitement about science? How are students to realise that there are many dogmas in science and very few if any absolute truths, thus opening the door to creativity? How do educators engage students in balancing scientific rigour with an open-mind capable of recognising the need for paradigm shifts for progress? How can students be enabled to explore and expand upon the latest concepts in a given field when even the textbooks are out of date as soon as they are written?

Therefore, the challenge becomes how to engage and energize both science educators and students: to develop the means to teach science creatively and to engender creative thinking in the students. We need to do a much better job of embedding the concept of creativity as a fundamental underlying principle in the science curriculum and to highlight creativity in nature during teaching. We need to move away from the idea that creativity is only associated with art and music, rather than science [4].

In order to encourage and facilitate this emphasis on creativity, academic staff engaged in science disciplines need to be given the space and resources to develop a creativity philosophy as the basis of their approaches to teaching and learning. There are a number of reasons for this. Today's students belong to the 'facebook generation' having grown up interacting extensively with information technology. These students are used to active learning and so-called 'dynamic sources of knowledge' and look to be engaged actively by the content they are studying. Their learning processes themselves are naturally highly creative. Indeed, many reports now point to creativity as a fundamentally important part of both science teaching and learning. It is recognized that there is currently a battle for creativity at the frontiers of both science and science education [5] and that the pursuit of creativity should be at the heart of biology [4].

But, there is still a perception that science is not a creative endeavour [6]. Therefore, in order to engage students in creativity, we need to re-instill the sense of wonder about science and the natural world. This is as a total 're-visioning' or 're-balancing' of science teaching - an emphasis on bringing 'love and passion' back into science in a truly holistic manner, both intellectually (left brain) and emotionally (right brain).

However, this ideal concept of the well-rounded scientist, what might be identified as the 'holistic scientist' and the 'holistic science teacher' is not always the image that the public at large have about science and scientists or even the image that scientists have about themselves. This is in the context, as alluded to above, of the prevailing culture within academic science with its focus on hypothesis driven research, reductionism, absolute objectivity and narrow-specialisation, as well as the short-termism associated with the necessity to obtain grant funding and the pressure to 'publish or perish'.

There is also a fear by academic scientists of being ostracized or losing funding if they venture outside of the 'main-stream' or the accepted thinking of the prevailing dogmas and theories in their fields. This is the idea that scepticism is healthy to good scientific practice. However, in the extreme, scepticism becomes destructive, both for individual scientists and for science as a whole because it suppresses open-mindedness and creativity.

Perhaps the most iconic articulation of this scientific 'operational reality' was by Peter Medawar in his books 'The Art of the Soluble: Creativity and Originality in Science' [7] and 'Advice to a Young Scientist' [8]. Medawar proposed that those wanting to achieve success in science should focus on what became known as 'the Medawar zone' of so-called optimal difficulty. The challenge is to identify a problem that is not too simple or too difficult. Simple problems will bring insufficient rewards and attempting to solve problems that are too difficult will only lead to lack of career progression. Thus, the creative value, quality and originality of the work are not as important as the ability to impress one's peers.

This is a rather bleak view of science, which is still propagated in science education in different guises. This view of science as a safe pursuit of obtainable answers reinforces the idea that science is not a creative endeavour. This is then carried over into teaching and learning, such as an over-emphasis on rote-learning, a rigid and dogmatic adherence to the rules of the discipline and a perception of science as the domain of the elite with a specific skill set and an incomprehensible and exclusive language [6].

Thankfully, there is evidence that there are significant numbers of idealist scientists who rank creativity highly in their pursuit of knowledge. In a study on 're-visioning science' scientists were interviewed about their motivations and every day 'lived experience' [9]. The most pervasive theme to emerge was the relationship between science and creativity. The research results clearly demonstrated that privately, if not openly in their professional setting, inspiration from art and relating to art were highly important for scientists in finding inspiration and providing a wider context for their work. The words 'wonder' and 'beauty' were often used by scientists when talking about their work. So, science teaching should incorporate the links between art, aesthetics and science in order to engage and inspire students about the overall richness of nature. A wonderful quote by one scientist stands out: *"If you have science without passion, forget it as far as I'm concerned. If you have science without creativity or without insight, well you don't have science. It's about extracting order out of a chaos of information, some kind of beautiful, simple, elegant theory…"*

In turn, emphasizing such approaches can lead to greater levels of motivation and transformative experiences on the part of the students, which in turn lead to much deeper engagement [10]. In order to do this however, it will be necessary that science teachers convey to their students the fundamental role of creativity and connection in nature in creative, imaginative and inspiring ways. Only then can we truly begin to make science whole again.

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