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FEATURE

# Extraordinary Scientific Delusions about Metamorphosis: Frank Ryan's *The Mystery of Metamorphosis*

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No one is immune to self-deception. In *Extraordinary Popular Delusions and the Madness of Crowds*, Charles Mackay (1841) collected stories that help to explain why and how we engage in this practice. Mackay is most well known by recent readers for his colorful characterization of earlier financial manias and their parallels with the 2008 economic crisis (Roubini and Mihm 2010). However, Mackay also considered alchemy, witch trials, "magnetising," and other manias that had some kind of technological (not to say scientific) basis for the associated mass delusion. An important trait shared by the people participating in these events was a deliberate indifference to evidence that would have dispelled the mania, for example, for tulips or collateralized debt obligations or the transformation of base metals into gold.

Unlike these popular delusions, scientific delusions tend quickly to encounter the self-correcting mechanisms of independent replication and of quantitative theory, so that deliberate indifference to such evidence rarely spreads far or persists for long. However, occasional scientific delusions endure within small cliques of self-styled iconoclasts. Focused case studies of specific scientific delusions such as cold fusion (Taube 1993; Seife 2008) suggest that a critical book-length study of many diverse scientific delusions, written by a 21st-century Mackay, could have a wide readership and many potential uses and benefits.

Unfortunately, Frank Ryan has not written such a book. *The Mystery of Metamorphosis* (2011) instead is a relatively uncritical examination of one peculiar, though not necessarily popular, delusion and its progenitor, the marine biologist Donald Williamson. Metamorphosis is the more or less dramatic change in form between early larval stages (like the tadpole or the caterpillar) and later adult stages (like the frog or the butterfly) in some animal life cycles, and Williamson is the chief advocate for a distinctive line of magical thinking in which differences among larvae of closely related species (and similarities between the larvae of some species and the adults of others) arise through hybridization and "larval transfer" between species in distantly related major animal groups that are separated from each other by tens or hundreds of millions of years of evolutionary history. *The Mystery of Metamorphosis* is his story.

Parts One ("Anomalies in the tree of life") and Three ("New perspectives") review Williamson's early and late career (and the early and late stages in the development of "larval transfer"), the details of which are less tedious to relate the more likely one supposes "larval transfer" to be true. To Ryan's credit, he does not attempt a forceful argument in support

of either Williamson's general or specific claims, for example, that caterpillars are larvae added to the insect life cycle by hybridization with velvet worms (non-insect arthropods in the distantly related taxon Onychophora in which adults superficially resemble caterpillars [Williamson 2009]). Instead, the subtext of this biography seems to be that the idea of "larval transfer" may be true in the same way that some other iconoclastic ideas like the endosymbiotic theory for the origins of the eukaryotic cell were only maybe true for a while before they were confirmed through multiple independent lines of evidence and elevated to the status of textbook staple (Margulis 1970). Ryan's apparent intention is to give the reader a sense of being there as Williamson describes the genesis of his own similarly fateful idea, delivered with a bit of breathless isn't-this-exciting? This subtext is clearer from the content of chapter 6 on the role of the late Lynn Margulis in fostering Williamson's ideas, as well as from the foreword (coauthored by Margulis). Such truthiness-by-association (Rogak 2011) is helpful to Ryan's telling of the Williamson story because the reader's pulse races a little less rapidly at the thought of being present at the still-birth of an idea that has proved to be neither useful nor true. It hardly warrants biographical documentation of Williamson's life, which like so many others has included achievements, setbacks, humor, and tragedy, but has been otherwise unremarkable.

Part Two, "The butterfly's tale," stands out from the rest of the book as a clearly written account of 20th-century studies of insect metamorphosis. The subjects of these chapters are the physiologists who directly observed insect larvae transform into adults, and dispelled much of the mystery surrounding the hormonal mechanisms that control caterpillar-butterfly (and many other) metamorphoses. The purpose of these chapters, sandwiched between two servings of "larval transfer," is much less obvious but seems to be to show a successful example of careful experiments over several decades, the results of which gradually transformed radical ideas about insect metamorphosis into widely accepted scientific truths about life cycle evolution. By weaving biographical characterizations of the main protagonists (like his biography of Williamson) into his characterizations of their laboratory achievements, and layering this material with "larval transfer," Ryan indirectly implies that similar careful experiments by Williamson document the occurrence of "larval transfer" between distantly related organisms via hybridization in the laboratory.

In the foreword, Margulis and her co-author Dorion Sagan call these experiments "[t]he most telling proof that Williamson is correct." This is faint praise indeed, because the evidence from these experiments leaves much (that is to say, everything) to be desired. They involve experimental insemination of the eggs of tunicates (or sea squirts, members of the phylum Chordata) with the sperm of sea urchins (members of the phylum Echinodermata), and later observation of swimming larval forms like those of sea urchins and unlike those of tunicates. The number of times this experiment has been reported to succeed (two, both by Williamson, in 1989 and 1990) is so small, the interpretation of those observations (that a haploid sea urchin sperm genome can reprogram the development of a tunicate egg into a sea urchin larva) is so outlandish, the documentation of those effects (a handful of sketchy drawings, and a few photographs of sea urchin larvae) is so poor, and the independent evidence against the occurrence of "larval transfers" either in the lab (Hart 1996) or in evolutionary history (Hart and Grosberg 2009) is so overwhelming that an essay considerably longer than this book review (and featuring observations, information,

and material not in Ryan's book) would be needed to fully describe just how shabby and pathetic is "larval transfer" as experimental science.

That future essay could also consider the enigmatic "spheroids," organisms with forms that were neither sea urchin nor tunicate, that replaced most of Williamson's "hybrids" in the 1990 experiment, and that figure prominently in the text of Part Three and literally in the intriguing graphic beneath the title of chapter 19 ("A new life-form"). After examining preserved samples of "spheroids" sent by Williamson for possible genetic analysis, one of us concluded that the "spheroids" are collections of diatoms and other benthic marine denizens of the microbial film that colonizes nearly every hard surface (including laboratory aquaria) that is covered for any length of time by seawater, and that undoubtedly grew by absorption of organic material from the decaying bodies of dead sea urchin larvae that accumulated in Williamson's cultures.

In Part Four, "The molecular age," Ryan attempts a synthesis, but without much success. He touches on the evidence for shared molecular processes that explain morphological variation across a wide swath of animal evolution from insect embryos to human brains. Understandably only the most superficial coverage of such a complex area of research is possible even over many pages (p 187–242). Only in the epilogue (p 243–264) does Ryan return to Williamson's story, but because "larval transfer" is a delusion rather than a scientific theory this closing section is limited to speculation (rather than evidence) regarding possible molecular mechanisms underlying "larval transfer."

In these ways *The Mystery of Metamorphosis* is a work of journalism, with its balanced treatment of both conventional and crackpot views of the evolution of metamorphosis, its he-said-she-said quotations of Williamson and his critics, and its emphasis on biography over biology. It is not much like a detective story (and far less a work of science), which would have developed a critical analysis of evidence and theory and a more or less strong conclusion about "larval transfer" based on the quality and weight of that evidence. A better detective (and a more interesting book) might have looked more deeply into:

**1. Strong parallels between experimental studies of hormones and metamorphosis in insects and in marine animals.**

One such parallel is the shared hormonal control of metamorphosis in diverse organisms. Part Two delves into these functional details of hormone control in insects, but the absence of such details from Parts One and Three for the organisms of Williamson's study (tunicates, sea urchins, and other marine invertebrates) implies that little or nothing is known. In fact, much of the mystery of metamorphosis in these groups has also been dispelled by careful experimental research that has many parallels to and benefited greatly from earlier and ongoing insect research like that described in Part Two. A recent book summarizes the achievements and future directions of this research on the physiology, ecology, and evolution of marine invertebrate metamorphosis (Flatt and Heyland 2011), most of which was well known long before the publication of Ryan's book, some of which could have easily been summarized without greatly lengthening *The Mystery of Metamorphosis*, but all of which was either unknown to Ryan or ignored by him in favor of "larval transfer."

A different sort of parallel involves other "larval transfers" among insects. For example, the life cycles of some Neotropical moths and butterflies include caterpillars with spectacular

morphological and behavioral traits (including large eye spots, head-shaped abdomens, and undulating movement) that mimic the structures, coloration, and movement of snakes. At least one species is reported (Nentwig 1985) to mimic several different models during different parts of the life cycle, including bird feces during an early caterpillar stage, followed by a rolled plant leaf and a cobra-like snake during subsequent stages. The physiology and evolution of such metamorphoses is understudied. To a conventional mind they suggest parallel evolution of superficial similarities (for camouflage of caterpillars that live among birds, plants, and reptiles), but for those inclined toward "larval transfer" these metamorphoses could be considered to be evidence as strong and convincing as anything else in Ryan's book showing that ancient moths hybridized with coprolites, trees, and snakes as well as with velvet worms.

**2. The scientific and popular responses to Williamson's (2009, 2010) most recent attempts to expand "larval transfer" to additional groups of organisms and types of metamorphosis.**

Ryan blandly notes in passing (p 248) that the most significant publication of Williamson's career, in *Proceedings of the National Academy of Sciences*, "would prove to be the most controversial expansion." This comment hardly does justice to related subsequent events, most of which happened long before Ryan's book went to press, and included:

- extensive coverage in venues ranging from the popular science magazines, to the national newspaper *USA Today*, to the website of the Institute for Creation Research;
- designation as "The Worst Paper of the Year" by the blogger and past president of the Society for the Study of Evolution, Jerry Coyne;
- the demise of the backdoor submission route (formerly called "Track 1") by which National Academy of Sciences members were able to "communicate" otherwise unpublishable manuscripts for publication in *PNAS*;
- rumors of editorial misconduct by Lynn Margulis, who "communicated" Williamson's 2009 paper and reportedly violated editorial policy by soliciting a long series of reviews until two came back with positive recommendations;
- a rebuttal (Hart and Grosberg 2009), published in *PNAS* at the same time as Williamson's (2009) paper, that refuted each of its predictions (about the genetic evidence from genome size comparisons between groups that Williamson hypothesized to have been the source or the recipient of a 'transferred' larval form and its associated paternal genome); and
- retraction by the editors of *Symbiosis* of Williamson's (2010) last paper, cited by Ryan (p 262) as in press, the flaws of which were reported by us to the journal editors and included inadequate or previously published diagrams, tedious repetition of previously published (and refuted) claims, and lack of new data or observations.

**3. The transformation of tunicate eggs into sea urchin larvae.**

This is the single most important and potentially interesting "metamorphosis" in Ryan's book (and Williamson's research). The transformation must be visually astounding given the morphological and developmental differences between the eggs and embryos of the

tunicate and sea urchin species used in Williamson's experiments (Gilbert 2010). For example, tunicate eggs are surrounded by complex layers of cells and extracellular coats; the early development of the embryo and the tadpole larva occurs inside these extraembryonic cell layers; that early development includes cell division patterns that are strikingly different from sea urchins, and leads to the formation of tissues and organs without large persistent internal spaces; these embryos and larvae lack a functional digestive tract, cannot feed, and do not swim using ciliary propulsion. In contrast, Williamson's sea urchin eggs have simpler acellular coats; the early embryo undergoes multiple rounds of cell division to form a hollow ball of cells called a blastula; the blastula becomes ciliated and swims within its fertilization envelope before hatching; the first internal structure to develop is the digestive tract, which becomes functional shortly after the larva hatches and becomes free-swimming. Spectacular examples of these differences, in the form of both still images and time-lapse videos, are readily available (see, for example, http://celldynamics.org/celldynamics/gallery/timelapse.html).

A more inquisitive detective might have asked at what point in the sequence of tunicate development did Williamson's experimental hybrids (fertilized by sea urchin sperm) become less tunicate-like and more sea urchin-like? How did that transformation unfold? What combination of tunicate- and sea urchin-like traits did the "metamorphosing" embryos display? For example, did the cleavage-stage tunicate embryos come to resemble the hollow sea urchin blastula early in development while still inside the extraembryonic cell layers of the tunicate egg? Or did "metamorphosis" occur later, after hatching, by transforming the muscle-powered tadpole larva of the tunicate into the ciliated feeding sea urchin larva? Such questions appear never to have been asked, because Williamson has not claimed to have watched the progress of this transformation in order to answer them, and has only claimed to witness its fulfillment in the form of fully fledged sea urchin larvae swimming in a dish of seawater previously populated only by tunicate eggs. The need to photograph, or draw, or at least narrate a text description of the progress of this most significant "metamorphosis" seems astonishingly obvious to the reader of Ryan's book (and of Williamson's books and papers). One can only conclude that this was more of a nuisance than an imperative to Williamson, and not worth a mention to Ryan.

**4. An alternative explanation for Williamson's experimental "larval transfer" observations.**

As a more famous fictional detective is supposed to have said, "[w]hen you have eliminated the impossible, whatever remains, however improbable, must be the truth" (Doyle 1890). "Larval transfer" by hybridization between tunicates and sea urchins is as nearly impossible as any such event can be declared through scientific inquiry, but *The Mystery of Metamorphosis* betrays no corollary interest in exploring improbable alternative truths. One candidate is the perpetration of an unfortunate practical joke on Williamson. Under this alternative hypothesis, the supposed metamorphic transformation of tunicate eggs into sea urchin larvae was instead a more prosaic transportation of sea urchin eggs or embryos into Williamson's tunicate cultures in 1989 and 1990. We have explored this alternative hypothesis in correspondence with Williamson (who understandably rejects it out of hand), and with some of his contemporaries at Port Erin, but without much success so far in either testing that hypothesis or soliciting an admission from the practical joker(s). We hope that, by publicizing this effort and alternative hypothesis, the "larval transfer" delusion might

have a denouement like other more popular delusions such as crop circles, in which the hoaxsters eventually felt compelled to come forward and admit their role in propagating the joke partly in order to limit the embarrassment to those who willingly chose to participate in the delusion and its more fantastical interpretations (Sagan 1996). Until such a happy end is realized, "larval transfer" is likely to persist in the minds of a deluded few, and be otherwise widely ignored. And *The Mystery of Metamorphosis* will be relegated to the lower division of science biographies, "a chapter only in the great and awful book of human folly which yet remains to be written" (Mackay 1841).

## References

Doyle AC. 1890. *The Sign of Four*. London: Spencer Blackett.

Flatt T, Heyland A, editors. 2011. *Mechanisms of Life History Evolution: The Genetics and Physiology of Life History Traits and Trade-Offs*. Oxford: Oxford University Press.

Gilbert SF. 2010. *Developmental Biology*. 9th ed. Sunderland (MA): Sinauer Associates.

Hart MW. 1996. Testing cold fusion of phyla: Maternity in a tunicate x sea urchin hybrid determined from DNA comparisons. *Evolution* 50:1713–1718.

Hart MW, Grosberg RK. 2009. Caterpillars did not evolve from onychophorans by hybridogenesis. *Proceedings of the National Academy of Sciences* (USA) 106:19906–19909.

Mackay C. 1841. *Extraordinary Popular Delusions and the Madness of Crowds*. London: Richard Bentley.

Margulis L. 1970. *Origin of Eukaryotic Cells*. New Haven: Yale University Press.

Nentwig W. 1985. A tropical caterpillar that mimics faeces, leaves and a snake (Lepidoptera: Oxytenidae: Oxytenis naemia). *Journal of Research on the Lepidoptera* 24:136–141.

Rogak L. 2011. *And Nothing but the Truthiness: The Rise (and Further Rise) of Stephen Colbert*. New York: St Martin's Press.

Roubini N, Mihm S. 2010. *Crisis Economics: A Crash Course in the Future of Finance*. New York: Penguin Press.

Ryan F. 2011. *The Mystery of Metamorphosis: A Scientific Detective Story*. White River Junction (VT): Chelsea Green Publishing, 2011.

Sagan C. 1996. *The Demon-Haunted World: Science as a Candle in the Dark*. New York: Ballantine Books.

Seife C. 2008. *Sun in a Bottle: The Strange History of Fusion and the Science of Wishful Thinking*. New York: Viking.

Taubes G. 1993. *Bad Science: The Short Life and Weird Times of Cold Fusion*. New York: Random House.

Williamson DI. 2009. Caterpillars evolved from onychophorans by hybridogenesis. *Proceedings of the National Academy of Sciences* (USA) 106:19901–19905.

Williamson DI. 2010. Larval genome transfer: Hybridogenesis in animal phylogeny. [Retracted article.] *Symbiosis* DOI: 10.1007/s13199-011-0106-6.

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