Hormone Mimics and their Promise of Significant Otherness

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ABSTRACT Some scientists argue that we face a worldwide reproductive crisis known as ‘endocrine disruption’, a term used to encompass the effects of hormonally active chemicals in our environment. Everyday chemicals such as plastics, pesticides and flame retardants can mimic hormones and thereby disrupt the reproductive, neurological and immunological development of humans and other animals. This surprising discovery is causing consternation in scientific, policy, academic and corporate arenas as they attempt to define, assess and control for this understudied phenomenon. How can the social sciences participate in understanding and solving the problem generated by endocrine disruption? First, there is an early history of endocrine disruption; the development of insect hormone mimics as pesticides, that has yet to be brought to bear in contemporary discussions of endocrine disruption. Second, a social science analysis of the mishaps resulting from the 1970s’ development of insect hormone mimics as pesticides offers a new way of thinking scientifically about mimesis. Employing the social science insight that mimesis is productive of social change sheds light on how insect hormone mimicking pesticides produced a number of scientific surprises. By analyzing the outcome of using mimesis in the laboratory, this paper participates in the discussion of endocrine disruption by arguing for a re-evaluation of the predominance of laboratory based sciences when dealing with epigenetic phenomena.

KEY WORDS: Endocrine disruption, epigenetics, mimesis, companion species, pesticides

We are confronting a worldwide reproductive crisis known as endocrine disruption, a term that refers to the effects of hormonally active chemicals in our
environment. Everyday chemicals, such as plastics, pesticides and flame retardants, can mimic hormones and thereby disrupt the reproductive, neurological and immunological development of humans and other animals. This surprising discovery is causing consternation in scientific, policy, academic and corporate arenas as they attempt to define, assess and control for this understudied phenomenon (Colborn et al., 1993, 1997; Krimsky, 2000; Colborn, 2004). In 2008, Canada banned the use of Bisphenol A (BPA), a plasticizer found in most clear hard plastics, from use in baby bottles because it can act like an estrogen (Layton and Lee, 2008). Similar bills have since been introduced in the United States (HR 1523, 2009).

Endocrine disruption, however, has a history stretching back many decades. This paper offers a historical corrective to the idea that endocrine disruption is a new phenomenon. In the 1950s, a researcher at Harvard, Carroll Williams, conceived of disrupting hormonal signaling in order to control pest insects. Williams proposed that an insect hormone, discovered by the British ‘father of insect physiology’ V.B. Wigglesworth, which prevents metamorphosis in insects, could be used as a pesticide. In the 1970s, the first insect hormone mimicking pesticides were produced. As Williams had suggested, these hormone mimicking pesticides were intended to trick insects into not metamorphosing. Studying both the assumptions involved in the development of hormone mimicking pesticides, and the outcomes of their use, sheds light on how endocrine disruption came to be independently rediscovered some 20 years later as an epigenetic human and environmental health crisis.

In her research on epigenetics, Hannah Landecker calls for social scientists to engage with scientists in an epochal shift occurring within the sciences to account for the role of the environment in development. Though the last century has been described as the century of the gene, science studies scholars have noted that, with the completion of the human genome, the book of life is proving not so easily read, particularly due to epigenetic phenomena (Fox Keller, 2000; Kay, 2000). Epigenetics, the study of the inheritance or expression of a phenotype, or gene expression pattern, that is not based upon the nucleotide sequence of the genome, examines how environmental factors can influence inheritance and development. Such research is now central to understanding how the genome is interpreted, activated and passed along from the level of individual cells to that of the organism and their offspring. The important question currently posed in epigenetic research, according to Landecker, is how to determine what counts as the environment. As scholars of environments, both physical and cultural, social scientists should not leave scientists to answer this question alone, Landecker argues. Social scientists have a role to play in the endeavor to recontextualize both the fetus within the mother and the genome with its environment. Science studies scholars and environmental historians have ably analyzed why environmental health problems have been hard for the laboratory sciences to see (Sellers, 1997; Allen, 2003; Murphy, 2006; Nash, 2006; Langston, 2010).
The study of pesticide exposures in Californian agricultural workers showed that laboratory assumptions made by studying micro-organisms were insufficient in identifying laborers’ chemically-induced diseases (Nash, 2004, 2006). Toxicology, which developed safe threshold limits for chemicals by looking for reproducible and gross disorders in standardized laboratory adult organisms exposed to single chemicals (Sellers, 1997), failed to predict the effects on genetically diverse human populations exposed to multiple chemicals at sub-threshold doses (Murphy, 2006). The process of epidemiological research on toxicants can often be at odds with the social justice needs of exposed populations (Allen, 2003). These studies contribute to an understanding of why laboratory methods are ill-suited for environmental problems, precisely because the laboratory cannot mimic external environments. Are there other effects of assuming that laboratory conditions can stand in for and mimic environments outside the laboratory? Informed by theoretical work from the social sciences on mimesis, this paper studies the impacts of using the laboratory as a mimetic environment without fully understanding the ability of mimesis to produce social and biological change. Analyzing the scientific process of developing juvenile hormone mimicking pesticides this paper asks: how have the scientists developing juvenile hormone as an endocrine disruptor understood and employed mimicry to manage human pests, and how can social science definitions of mimesis help explain the surprising things that went wrong with juvenile hormone mimics when they were used? By studying the specific example of the uses of this insect hormone, and the mishaps that have arisen from its use, this paper aims to show what the social sciences have to offer the sciences in the efforts to understand endocrine disruption.

**Conceptual Background**

In biology, mimesis is commonly thought of as the practice of copying. Before the digital era, in which differences between a copy and its original are becoming less significant, copying implied the smuggling in of something slightly different from the original. Anthropological theory of mimesis pays attention to that smuggling in, not as a means of preserving similarity, but as a means of inducing social change. Drawing these definitions together through the story of juvenile hormone, this paper offers the reader a novel interpretation of how the environment of the laboratory unpredictably produces biological and social change through the relationship-transforming use of mimicry.

Taussig, an anthropologist, argues that mimesis is ‘the nature culture uses to create second nature’ (Taussig, 1993, p. xiii). Second nature is a concept used to describe the industrial landscapes, environments and organisms produced by human selection and activity (Cronon, 1991). Cronon analyzes these environments as second nature because they would not exist without human intervention and yet once produced are treated as second nature, something that becomes so commonplace that it seems innate. Did Wigglesworth, the scientist who first
identified juvenile hormone, use mimesis to create second natures? While the biological definition of mimesis focuses on the mechanism of copying, which might seem to generate similarity, Michael Taussig, in *Mimesis and Alterity*, argues that the process of mimesis is, in fact, a mechanism of producing social change. That change is brought about by a process he describes as othering, whereby an individual engages in mimicry and transforms itself into someone other than it was previously. Taussig argues that mimesis requires the mime to become other and that this opens a space in which the mime’s sense of self can be undermined and transformed in surprising ways. Alternatively, for the dupe, the party taken in by someone or something’s successful act of mimicry, their social and biological relationship with the mime can be transformed. The mime’s unstable sense of self and relationship to the dupe, can unleash what is called the ‘spirit of mischief’ (Taussig, 1993, p. 43). This spirit of mischief describes surprising transformations of both the mime and dupe that can be produced by mimicry. As we will see, the mimicry engaged in by insect physiologists, both to get organisms into the laboratory and in their resultant efforts to deploy their insect hormone mimics outside the laboratory, resulted in much mischief!

Walter Benjamin’s and Theodore Adorno’s work on mimesis stresses that mimesis is a way in which humans interact with the world not through domination but through self-transforming imitation (Adorno, 1981–1982; Benjamin, 1986). Mimesis is, in fact, a means of constructing new relationships with and new understandings of various environments through humans imagining themselves, rather than the world around them, to be other, or different than they are at present. According to Benjamin, children are particularly in touch with the mimetic faculty. Through mimesis, the ‘child plays at being not only a shopkeeper or teacher but also a windmill and a train’ (Benjamin, 1986, p. 333). This sense of mimesis, as a means of drawing researchers closer to their object of study, is discussed by anthropologist of science Myers in her study of how protein modelers mimic their computer models of proteins in order to physically embody the structure of their proteins (Myers, 2006). These theoretical arguments highlight mimesis as a human faculty that allows humans to imagine being different and inhabit the world differently, not as an observer in object–subject relationships but as part of a larger environment. Mimesis, research in the social sciences shows, is a means for humans to develop transformative relationships. Donna Haraway, historian and philosopher of science, argues that we should focus on relationships, saying that there is ‘one fundamental thing about the world—relationality’ and moreover that ‘... embedded in relationality is the prophylaxis for both relativism and transcendence’ (Haraway, 1997, p. 37). What kinds of relationships do laboratories and scientists produce when they employ mimesis?

The human characters in this story of juvenile hormone mimics are V.B. Wigglesworth, a pioneer of insect physiology, and his protégé Carroll Williams. They both employ mimesis to habituate their insect research subjects to the laboratory and they use mimesis to manipulate insect time within and without
the laboratory. The mastery they achieved over insect metamorphosis in the laboratory was misinterpreted as implying that they could achieve mastery over our insect others in the field by mimicking their hormones. The failure of juvenile hormones to be either irresistible to insects or species-specific reveals why mimicry, the tool which I argue they used to gain mastery over insects, can unexpectedly undermine that control. Furthermore, this failure exposed a disturbing biological homology between humans, insects and plants and produced a surprising change in human perceptions of our interspecies relationships.

Thinking about the laboratory and its products as mimetic in the social science sense, i.e. as social and biological change agents, lends a partial answer to thinking through how the social sciences and the sciences might work together to understand not the role of ‘the environment’, which is currently being pared down to biochemical changes to the genome or its transcription and translation, but the role of environments, like the laboratory, in shaping biological development and our scientific grasp of it. In essence this paper builds upon the insight made in science studies that the laboratory is not a space exception but rather exists in an ecosystem related to the many other kinds of ecosystems humans co-produce by offering a study of how mimesis has been used as a tool to build relationships between the laboratory and other environments.

**From Colony to the Laboratory: Embodying Juvenile Hormone in the Insect**

Juvenile hormone was first hypothesized in the 1930s by Sir. Vincent B. Wigglesworth, an English scientist, at the London School of Hygiene and Tropical Medicine. A pioneer of insect physiology, Wigglesworth transformed the study of insects, in large part by turning insects, in particular the human parasite, *Rhodnius prolixus*, into laboratory tools for physiological research (Locke, 1996). His work revealed that insects not only have hormones, but also neuroendocrine hormones (Edwards, 1998).

In 1926, Wigglesworth was hired as a lecturer in entomology at the London School of Hygiene and Tropical Medicine. He was asked by the professor who hired him ‘to create order in the field, and to develop insect physiology as the basis for the control of harmful insects’ (Locke, 1996). In pursuit of this goal ‘He used all that he could obtain: cockroaches, mosquitoes, tsetse flies, fleas, bed-bugs, bird-lice, human lice, mealworms and, above all, the bug *Rhodnius prolixus*’ (Locke, 1996, p. 543). *Rhodnius prolixus* is a beetle native to South America, and the vector for Chagas Disease (Chagas, 1909). Wigglesworth enticed *Rhodnius* into their new laboratory home at the London School by rolling up his sleeve and feeding them on his own blood (Locke, 1996, p. 546). He performed a series of controlled experiments feeding *Rhodnius* on his fingers, hand, forearm and elbow. His notes from this period track the progress of the bites’ swelling and itchiness (Wigglesworth, 1927). In becoming the
beetles’ victim, Wigglesworth duped *Rhodnius* into accepting an entirely new environment. He soon realized the parasitic relationship between *Rhodnius* and humans could, in the laboratory, be used to make *Rhodnius* an ideal tool for studying insect metamorphosis.

*Rhodnius* is a hemipteran insect, and does not undergo a full metamorphosis, but instead gains adulthood via a series of nymphal stages. Transition from one nymphal stage to another requires a blood meal, whose availability previously synchronized the timing of *Rhodnius* development to the presence of its prey. By offering himself as food, rather than being an unwitting victim, Wigglesworth gained control of *Rhodnius*’s developmental on/off switch.

*Rhodnius*’s predictable, meal-dependent life cycle allowed Wigglesworth to predict and control their entrance into each phase of growth. He divided their development into five larval stages, each distinguished by recognizable markings on the cuticle (Wigglesworth, 1970, p. 2) (see Figure 1).

![Figure 1. Stages of Rhodnius development. Credit: T. Heger, 'Rhodnius prolixus (nymphs and adult)' [online]. Available at: http://en.wikipedia.org/wiki/Triatominae (accessed 14 May 2010). Permission to use this image is granted under its Creative Commons Attribution-Share Alike 3.0 Unported license.](image)

The Royal Society’s tribute to Wigglesworth and his ability to control the development of *Rhodnius* celebrates his transformation of the beetle into almost a ‘reagent’, which ‘can be kept on the shelf . . . surviving weeks or months of starvation’ (Locke, 1996, p. 546).

In 1932 Wigglesworth decapitated *Rhodnius* immediately after feeding them. He was surprised to find that, rather than molting into the next nymphal stage, the insects jumped ahead in biological time and metamorphosed into tiny adult *Rhodnius*. He reasoned that something released from the head, which he called inhibitory factor, must have been actively preventing metamorphosis (Wigglesworth, 1934). Wigglesworth then showed that inhibitory factor is produced by the brain. When a decapitated but freshly fed fifth-stage nymph is connected to an intact fourth-stage nymph, the beheaded fifth-stage nymph, under the influence of the fourth stage nymph’s brain, presumably via inhibitory factor, did not metamorphose into an adult insect, but rather into an unheard of sixth juvenile form (Wigglesworth, 1970) (see Figure 2).
Such a finding was noteworthy, as insects were not believed to possess hormones, let alone neurologically produced hormones. Indeed, at this time there had been only one demonstration of neuroendocrine cells in any organism: in 1917 a Polish researcher, Stefan Kopec, showed that, if ligated around the thorax, a gypsy moth caterpillar’s anterior end pupated, while the posterior end remained a caterpillar (Kopec, 1922; Edwards, 1998, p. 472). Kopec’s research inspired Wigglesworth’s work decapitating Rhodnius.

Wigglesworth’s final proof of the existence of inhibitory factor was accomplished by inscribing his initials on the back of an adult beetle with the neurological secretions of a nymph’s corpora allata, two small organs attached to the base of the insect brain (see Figure 3). This induced the adult cuticle to revert back to the nymphal form (Locke, 1996, p. 547).

**Figure 2.** Two beheaded Rhodnius nymphs joined in parabiosis (Wigglesworth, 1959, p. 78). Credit: Reprinted from Vincent B. Wigglesworth, *The Control of Growth and Form*, © 1959 by Cornell University; renewed © 1987 by Vincent B. Wigglesworth. Used by permission of the publisher, Cornell University Press.

**Figure 3.** Juvenile hormone causes the adult cuticle to change back to juvenile cuticle. Credit: Reprinted from Vincent B. Wigglesworth, *The Control of Growth and Form*, © 1959 by Cornell University; renewed © 1987 by Vincent B. Wigglesworth. Used by permission of the publisher, Cornell University Press.
The ability of inhibitory factor to reverse metamorphosis (rather than simply prevent it) led to its rechristening as juvenile hormone (Wigglesworth, 1970, p. 47). With this signature, Wigglesworth expressed his mastery of, indeed ownership and control of, *Rhodnius*’s very biological time. Wigglesworth’s primary goal in mastering *Rhodnius* was not to address it as a vector of Chagas Disease, but to render it an experimental medium in which to discover and demonstrate the principles of insect development. In 1939, he published and later edited eight subsequent editions of *The Principles of Insect Physiology*, which was dedicated to revealing the principles of insect biology and is now considered to be the foundational text of the field. The first edition begins: ‘Insects provide an ideal medium in which to study all the problems of physiology’ (Wigglesworth, 1939).

Previously *Rhodnius*’s relationship to humans had been only as a parasite and vector of a crippling tropical disease. In the laboratory, however, as a ‘reagent’ in the study of development, it was Wigglesworth and insect physiologists that became parasites. Making their livings at the expense of, but without wiping out, *Rhodnius*, they fit both the biological and social definitions of a parasite. An ungentlemanly reversal has taken place.

In this new relationship, Wigglesworth generated forms of *Rhodnius* only possible in a laboratory such as tiny premature adults, nymphs joined in parabiosis and adult beetles with juvenile cuticles. Second natures abound in Wigglesworth’s laboratory: they are second nature not only because they become possible only in the lab, but also because, once realized in the lab, they become second nature, the commonplace explanation for insect physiology in the world beyond the lab. Wigglesworth’s manufacture of these previously nonexistent forms of *Rhodnius* illustrates how mimesis can be used to transform not only the relationship between the mime and dupe but also the mime and the dupe themselves. Wigglesworth formed a new relationship between humans and *Rhodnius* in his laboratory by convincing the insect that it was an environment like any other. To dislodge *Rhodnius* from its tropical home where it parasitized unwilling South Americans, and habituate it to his laboratory in London, Wigglesworth had to understand their historical relationship of parasite and host. He played the part of host. However he changed that relationship in one very significant way: he chose to be a host. Indeed he studied the side-effects of hosting *Rhodnius* on his own body. In order to convincingly act the part and change their relationship, he literally had to change himself and become like *Rhodnius*’s prey.

Taussig argues that Cuna shaman become other and control spirits through chanting stories that generate an environment which shows their knowledge of the spirits’ habits, for instance, by covering their bodies with scents attractive to the spirits. This enactment by shaman creates a seductive mirror of the spirit reality that draws the spirits in and directs their power (Taussig, 1993, p. 106). Wigglesworth created such an environment for *Rhodnius*, a mirror of its
prior environment where it had humans to feed on. However, like the shaman, Wigglesworth was consciously creating this environment to habituate *Rhodnius*, in order to take control over the beetle. Ironically, for this mimetic trick to gain control over the beetle’s very development demanded that Wigglesworth at least temporarily lose control of himself: he literally had to become the victim and put himself at biological risk. Wigglesworth’s last step, the moment of contact when *Rhodnius* bit him, created a physical interlinkage between host and prey. Given that *Rhodnius* is a vector of Chagas Disease, such an action entailed serious risk for Wigglesworth. The possibility of such a biological interconnection where the insect and human bodies are physically interconnected, suggests a deep biological similarity, an ability to literally become for a moment one entity. Wigglesworth was thus in three places at once: he was a victim; he was physically connected to *Rhodnius*; and, in some manner, he was outside it all, observing the scene as he orchestrated it and willingly participated in it.

In analyzing how a Cuna shaman mimics an environment attractive to powerful spirits so that the spirits will be duped into ceremonial practices, Taussig argues the shaman is in a ‘strange position, inside and outside’, which as Taussig points out ‘... is not to be confused with liminality because it is both positions at one and the same time’ (Taussig, 1993, p. 111). Wigglesworth can also be seen to occupy this strange position. Through mimesis, a spatial relationship of being part of and separate from each other develops between the self and the other. For a mimetic trick to work, this position of simultaneous self and other must be maintained. The act of miming however, risks the very separation between self and other on which mimesis is predicated. In this moment of contact, the mime Wigglesworth became a victim and risked Chagas Disease and the dupe *Rhodnius* unwittingly accepted a wholly new environment, the laboratory, in which Wigglesworth could take control of its biological development.

Wigglesworth’s transformation of the *Rhodnius*–human relationship allows the production of second natures within the laboratory, from those that accept his arm as prey to those responding to the hormone he painted on their backs. Though it may seem that these mimetic tricks make a parasite pliable, the questions made possible by this development, the questions this experimental system poses to Wigglesworth about insect development and metamorphosis, are not accidental. They emerge from the historical relationship between parasite and host which controls the timing of *Rhodnius*’s development. It was easy, in Wigglesworth’s moment of mastery, to forget that this relationship is predicated on similarity and the unstable possibility of becoming other. This mime and dupe share biological and social relationships that *Rhodnius*, by dining on Wigglesworth’s arm and reverting to childhood at his brushstroke, could not forget. Humans would be later reminded of these relationships when juvenile hormone, distilled and deployed to infiltrate enemy lines and disrupt their biological time, disobeyed human direction.
From Laboratory to Laboratory and Insect to Insect: Williams Copies a Master to Master a Copy

Wigglesworth never managed to isolate enough inhibitory factor to determine its chemical structure, nor did he conceive of a clear use beyond the laboratory for his ability to manipulate insect biological time. Such knowledge came out of Carroll Williams’s experiments at Harvard University on metamorphosis in *Hyalophora Cecropia*, the giant American silkmoth (Tefler, 1992; Pappenheimer, 1996; Kafatos et al., 1997). In this different social and biological context, Williams found not only a ‘cache’ of juvenile hormone but also a clear use for this ‘insect invention’ beyond the laboratory (Williams, 1958, p. 72; 1967, p. 16).

Williams, like Wigglesworth, first took control of the moth’s developmental cycle by exploiting its need as a pupa (a developmental stage entered following four cycles of growth as a caterpillar) to experience a cooling period of two to three weeks with temperatures between 3 and 5°C in order to metamorphose into a moth. Without this cooling period, the *Cecropia* remains a pupa. Although *Cecropia*’s development was not controlled by the presence of food, like *Rhodnius*, it was linked to particular environmental conditions conducive to its survival, in this case the passage of winter. By mimicking cold conditions in the laboratory, Williams tricked *Cecropia* into entering developmental cycles divergent from those possible outside the laboratory. His analogous mastery of insect metamorphosis was featured on an April 1950 cover of *Scientific American* (see Figure 4). The cover, like Wigglesworth’s earlier work on *Rhodnius*, shows that the hormones controlling metamorphosis originate in neuroendocrine glands and travel down the body.

The jar has fallen over. Out of it emerges a mature *Cecropia* moth. Illuminated by the burning flame of an alcohol lamp, it encounters a living hall of mirrors in its spatially and temporally dislocated kin whose disjointed bodies reflect the process of its own metamorphosis. First, we see a temporal-chimera, whose body, though whole, moves in three biological times. By virtue of strings constricting the passage from head to thorax and thorax to abdomen, its head, abdomen and thorax are in three different biological stages: advanced pupa, pupa and caterpillar. In the foreground, a pupa rests, this one bisected and reconnected by a plastic tube. Though physically separated because of the fragile tissue bridge that has grown down the tube, the two halves of this pupa move toward metamorphosis in synchrony. The *Scientific American* cover depicts living demonstrations ‘that the substance controlling metamorphosis originates in the thorax’ and travels down the body. With this scientific still life, the reader is offered a window into the laboratory of Williams.

Through careful cutting and pasting with sterilized, surgical tools, the Williams laboratory, this picture shows, brought the process of metamorphosis out of the jar and into view. While the moth confronts the twisted and, from an anthropomorphized perspective, terrifying reflections of itself, a human inspecting the cover is given the sense of peeling back the cocoon of the Williams laboratory to marvel at the transformations taking place inside. Analogically, this picture
establishes the laboratory as a cocoon-like environment in which metamorphosis is itself transformed from a process hidden to the human eye to one illustrated by these living demonstrations.

Figure 4. The April 1950 cover of *Scientific American* by Stanley Meltzoff. Credit: Reproduced with permission, © 1950 *Scientific American*, a division of Nature America, Inc. All rights reserved.
From the Insect to the Oil: Williams Bottles Dreams of Mastery Beyond the Laboratory

Combining surgical techniques with *Cecropia*’s on/off switch allowed Williams to distill useable quantities of juvenile hormone (Williams, 1958, p. 72). Interested in the differences between hormonal expression in pupal and adult silkworms, Williams joined a headless adult moth and a chilled pupa in parabiosis. To his surprise, when a headless male moth was attached to a pupa ready to metamorphose, the pupa failed to undergo metamorphosis: ‘... the pupa behaved as if it had received a rich dose of juvenile hormone’ (William, 1958, p. 72). Figure 5

Figure 5. This image is Figure 1 from C. William (1963) *Biological Bulletin*, 124, pp. 355–367. Credit: Reprinted with permission from the Marine Biological Laboratory, Woods Hole, MA.
shows the experiments leading to the discovery of this surprising source of juvenile hormone (Williams, 1963, p. 358).

In the upper left corner, a headless male moth is attached to the body of a chilled, and therefore ready to metamorphose, pupa. However, as shown in the lower left photo, three weeks later the pupa has molted its cuticle and entered another pupal stage showing only traces of adult characteristics—the slightly raised primordial wings, for instance. The remaining photos show that the same effect can be achieved with only the abdomens of male moths. By grinding these up, Williams recovered what he called ‘caches’ of juvenile hormone (Williams, 1963, p. 355). Purification of this hormone from moth abdomens meant that the insects no longer had to be used as experimental ‘living factories’ for the hormone—the power to intervene in insect biological time could be bottled and kept on the shelf (Williams, 1958, p. 68).

It is 1958 and the picture shown in Figure 6, like the times, has changed. Instead of the clutter of the Williams lab on the 1950 cover of Scientific American, we see neatly arranged ‘symbols’ of the study of juvenile hormone against a sanitized, white background. In this picture, the moth is neither active nor inquisitive: it is displayed as an object, visually equated with an orderly row of mutants and three new items, two glass vials and one long syringe. As a parallel to the isolation of each object, this picture conveys an important advance in the study of juvenile hormone: its extraction and purification. The two glass vials, one larger and darker than the other, represent a crude extract of the hormone and a purified, lighter form. The syringe bisecting the drawing is full; at its tip a small drop bulges. Using such syringes, ‘test animals’ have been produced to attest to the power of the hormonal extract. One insect, treated with the extract as a caterpillar, grew to an unusually large size and metamorphosed late into a mega-moth. In contrast the miniscule moth to its right, with its corpora allata, the source of juvenile hormone, removed as a caterpillar, has metamorphosed prematurely into a midget. Above the syringe, three other ‘test animals’ are represented: the insect on the far right, treated with an ‘inactive’ extract, has metamorphosed into a moth (its wings furled); the hybrid in the middle, treated with a small dose, bears both pupal and adult characteristics; and the subject receiving the largest dose, on the left, has been stripped of half of its cuticle to reveal a nascent second pupa (Williams, 1958, p. 4). In form and content, this picture expresses the fact that organization has been achieved; cause and effect established. The cause—juvenile hormone—has come under the control of human beings through its extraction.

This easily accessible extract made possible the achievement of another emerging mimetic desire, which Williams expressed in his brief letter to Nature:

Therefore in addition to the theoretical interest of the juvenile hormone, it seems likely that the hormone, when identified and synthesized, will prove to be an effective insecticide. This prospect is worthy of attention because
Figure 6. The February 1958 cover of Scientific American painted by John Langley Howard. 

Credit: Reproduced with permission, © 1958 Scientific American, a division of Nature America, Inc. All rights reserved.
insects can scarcely evolve a resistance to their own hormone (Williams, 1956, p. 213).

In the context of the evolving agricultural and industrial battle with pests, this tactic was extremely appealing. Despite self-confident declarations by chemical corporations that the war against pests was being won, by 1958 pests’ resistance to DDT was fully fledged. In the 1958 issue of *Scientific American* alone, American Cyanamid Co. and Shell both advertise the effectiveness of their new pesticides, Malathion and Aldrin (American Cyanamid Co., 1958, unmarked; Shell, 1958, p. 62). By 1952, DDT resistance ‘had been developed by important pests of apples, cabbages, potatoes, tomatoes and grapes [as well as] the body louse, the bedbug, two species of fleas and several species of mosquitoes’ (Brown, 1977, p. 22). Furthermore, resistance to the second round of synthetic chemical pesticides, including Aldrin and Malathion, was also increasing. Aldrin, part of the ‘cyclodiene group of organochlorines’, was introduced in 1948, and resistant pests were already emerging by 1955, three years before this advertisement (Brown, 1977, p. 23). Meanwhile resistance to organophosphorus pesticides like Malathion had been seen as early as 1949 (Brown, 1977, p. 24).

An arms race, in which a cycle of action and reaction between opponents produces an escalating spiral, was forming between humans and pests. In this context, juvenile hormone offered a novel solution to the problem: Williams believed that because he had isolated an ‘insect invention’, something crucial to their very process of development, a mistimed signal from juvenile hormone would be impossible for insects to resist (Williams, 1967, p. 16). It was imagined to be perfect because it would not kill the adults, but would stop a whole generation from reaching reproductive maturity. This mistimed biological signal, it was hoped, would derange insects’ sense of biological time, thus creating leagues of juvenile adults incapable of reproducing.

In an irony typical of mimetic relationships, the humans who took this step became strangely like insects, in that they invested in developing large quantities of insect hormones. Such an acquisition of insectoid attributes aligns with literary theorist Rene Girard’s insight about mimesis: Girard argues that desire for another always begins with the recognition that something else desires an object. In this triangle, both humans and insects desire plants as food. Attempts to attain the object from the rival inevitably leads to a mimetic race between rivals, where one attempts to attain the object by copying the other. Humans, in this case, begin producing insect hormones and covering themselves and their crops with them in order to forestall the insect others’ attempts to eat crops first (Girard, 1978).

Williams’s idea caught on and, by 1967, he reported in *Scientific American* that a researcher from the University of Wisconsin, Herbert Roller, had described the chemical structure of juvenile hormone. This article did not make the front page, however, perhaps because the structural formula for juvenile hormone, while intelligible and meaningful for experts, did not make an interesting picture for a
less specialized audience. In the article, Williams called the concept of hormone-mimicking insecticides ‘Third Generation pesticides’ and contrasted them to ‘Second Generation’, or chemical, pesticides, specifically on the basis of their potential for biological mimicry.8 Juvenile hormone mimics, Williams supposed, would not only be foolproof because they were ‘of’ the insect and therefore impossible to resist, but also because they would be a more targeted means of pest control (Williams, 1967, p. 13).

DDT, in Williams’s lineage of pest control, is the paradigmatic Second Generation pesticide; Williams calls it an ‘an avenging angel’ that, sweeping in from the heavens, wipes out good and bad insects alike (Williams, 1967, p. 13). Reiterating Rachel Carson’s arguments from Silent Spring, published in 1962, that synthetic pesticides’ environmental persistence led to collateral damage in non-target populations, Williams adds that they were easily resisted because they were not proper to the insects themselves. Not so of juvenile hormone—here was a chemical that could be distilled from the very target insect. Continuing the Cold War metaphors it was a perfect mole. In characterizing juvenile hormone as ‘of’ the insect, Williams almost sounds as if he is claiming, that he had bottled the very source of insect otherness. This bottled otherness could be wielded to separate us from them. By covering the crops that both human and insects covet, humans would trick insects, and only insects, into thinking they were encountering their own hormone.

Historically, pests, particularly insects, are one set of organisms that industrial societies have had no problem imagining as completely unlike or other than humans. Indeed, industrial societies have generally regarded insects as completely insignificant to humans, except when they invade human homes or eat human crops. The war humans have fought with pests, particularly over the course of industrialization, has been described by the environmental historian Edmund Russell, and attests to the perception of absolute difference between insects and humans (Russell, 2001). From lice to fleas to grasshoppers, insects have been treated as interlopers, insignificant others whose utter difference justifies their ruthless extermination.

The supposed endgame of that battle, the synthetic production of insect hormones to disrupt pests’ reproductive processes, however, rests on the transformation of insects, through mimesis, into what Haraway would call companion species. Companion species are, for Haraway, organisms who share and shape each others’ evolutionary trajectory. Wigglesworth’s and Williams’ companions, Rhodnius and Cecropia, were shaped by and shaped the scientists’ research questions and goals. Companion species help determine the kinds of humans we can be and the ways we approach the world. Just as dogs help humans to herd sheep and to sleep soundly knowing they will be alerted to danger, companion laboratory species determine both the kinds of research questions scientists can ask and their research timetables. This process is adeptly described by Kohler in his historical study of the scientific domestication of Drosophila, which helped
produce the modern field of genetics (Kohler, 1994). Haraway argues that companion species have relationships founded on their significant otherness, which means that it is precisely their species differences that make them important to one another: that dogs have a more refined sense of smell and hearing makes them a great ally to humans. Based on this Haraway advocates that we recognize and encourage our companion species’ differences to flourish rather than anthropomorphizing them (Haraway, 2003). As this story illustrates, humans have had no problem refraining from anthropomorphizing insects. Indeed if insects have been anthropomorphized (as occurred in American propaganda posters produced during World War II which equated the Japanese to insects) it was generally to dehumanize human enemies (Russell, 2001). However, by attuning themselves to the responses of their insects to hormone mimics, Wigglesworth and Williams were poised to learn more about themselves and their environments. They learned that parasites can be companions who bear similarities as well as differences. Mimicking insect hormones to master insects reveals that just as humans and insects have always shared social spaces, so they also share biological homologies.

From Within the Oil into the Paper: Juvenile Hormone Slips Out of and Into Our Grasp

A series of unexpected events in the Williams laboratory revealed that juvenile hormone is not only an insect invention and that humans are not alone in this mimetic game. In 1964, Karel Sláma, an entomologist from Prague, and his model organism, Pyrrhocoris apterus, visited the Williams lab (McElheny, 1964, 1966). Much to their surprise, when Pyrrhocoris was ‘reared in the biological laboratories at Harvard’, all but one of the 1,215 founder insects entered an unusual sixth larval stage (Sláma and Williams, 1966a, p. 235). Rather than metamorphose into adulthood these insects were developmentally stuck as giant babies (see Figure 7, taken from Sláma and Williams, 1965, p. 412). In 10 years of raising Pyrrhocoris larva in Prague, Sláma had never encountered this effect. Thanks to Williams’s attunement to the influences of juvenile hormone, they realized that ‘the bugs had access to some unknown source of Juvenile Hormone’ (Sláma and Williams, 1965, p. 412). An audit of their laboratory conditions revealed the source to be the most mundane of objects, the tissue paper placed in the jars of the reared insects: ‘When the toweling was replaced by Whatman’s filter paper, the entire phenomenon disappeared and all individuals developed normally’ (Sláma and Williams, 1965, p. 412). Williams and Sláma were shocked: ‘The above mentioned finding seemed incomprehensible’ (Sláma and Williams, 1966a, p. 237). How could a juvenile hormone mimic reside in the toweling? Further research revealed that the juvenile hormone activity came from the wood of Balsam Fir, the primary constituent of American paper pulp, and was present in many American newspapers and journals, including The New York Times, Science, and Scientific American. Journals made from European
woodstock, such as Nature and The London Times, were inactive (Sláma and Williams, 1965, p. 412; 1966a, p. 239, 1966b).

Following their discovery, Williams and Sláma (and readers of Williams’s 1967 Scientific American article) were disoriented. In the article, Williams proclaims the infallibility of juvenile hormone mimics as insecticides and names them an insect invention, as well as relating his remarkable discovery that plants can also produce juvenile hormone mimics, one of which was embedded in the very paper of the magazine (Williams, 1967, p. 16). Is juvenile hormone really just an insect invention? It seems plants are also playing at this game of producing insect hormones. Are we perhaps not masters of the game but merely participants who have unwittingly spread the message of juvenile hormone with our massive paper industry? Plants are also signaling to insects; they, like humans, are also more than they appear.

Not unlike Williams’s insects, humans have been duped into believing that paper is blank. Discovering otherwise is somewhat like stumbling across a message that is not meant for you, in that it uncovers a whole sensory conversation to which humans had not previously been privy, though they had clearly become its unwitting instruments. Through mimetic laboratory engagements with their companion species, Williams and Sláma entered humans consciously into the conversation. This discovery is notable as one of the first examples of plants mimicking insect hormones as a defensive strategy and is recognized as important to the foundation of the field of Chemical Ecology, which began to emerge from 1960 to

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**Figure 7.** Sláma and Williams’ figure showing the abnormal development of Pyrrhocoris when they are exposed to paper extract. Note: The second larva moulted into an abnormal 6th stage larva rather than a normal adult, like the third Pyrrhocoris shown, when it was exposed to the paper extract. The final Pyrrhocoris is a more abnormal 7th larval stage which was produced by exposing the abnormal 6th stage larva again to the paper extract (Sláma and Williams, 1965, p. 412). Credit: Permission to reprint this image was granted by the author Karel Sláma.
Both Sláma and Williams further investigated the signaling relationships between plants and animals; Williams made discoveries regarding signals released by oak leaves, while Sláma explored the production of estrogens by plants, most famously the sterility induced in New Zealand sheep after exposure to an estrogen mimic-producing clover (Williams and Riddiford, 1967a, 1967b; Sláma, 1979, 1980, 1999, p. 11). By pretending to be something they were not, the historical home for these insects, Williams and Sláma unwittingly made a receiver for the paper’s hidden message. This illustrates the first lesson about mimesis: everyone/thing could be miming. If even a blank page can hold messages unreadable to humans until a set of unpredictable agents align in an unpredictable fashion, how can we know or trust even the most mundane objects at a molecular level?

This lesson helps us understand the next shock to Williams and his colleagues: juvenile hormone-mimicking insecticides once on the market appeared to misbehave. Despite the resistance of one of Sláma’s insects to the paper’s instruction not to metamorphose and *Cecropia’s* own evident decision to ignore the memo, Williams still believed himself to be in possession of an unbeatable mimetic weapon. A company named Zoecon (life control) produced the first, intentionally hormone-mimicking pesticide, Methoprene, registered for use in 1975 (Henrick *et al.*, 1973; Henrick, 1990, p. 14). Incorporated on 30 August 1968 in Delaware, Zoecon was spun off from Syntex Corporation, a small Mexican company, made famous through the synthesis of the first birth control pill by their director of research, Carl Djerassi. Djerassi, in fact, saw reproductive control of humans and insects as analogous problems (Djerassi *et al.*, 1974). The fact that synthetic hormones produced by the birth control pill are now found in waterways interfering with fish development provides another example where an attempt to gain biological control through mimesis produced unexpected results (Kolpin *et al.*, 2002; Timms *et al.*, 2005; Kidd *et al.*, 2007; Barnes *et al.*, 2008).

Methoprene, the first biorational pesticide (a term coined by researchers at Zoecon) was approved by the FDA for use against floodwater mosquitoes under the trademarked name, Altosid Insect Growth Regulator (FDA, 1975, cited in Henrick, 1990, p. 14). Sprayed onto waterways, fed to cattle and squeezed onto pets’ backs, Methoprene has become a common signal in our environment. It is the active ingredient in Frontline™, the flea control ointment, and it is added to cattle feed to forestall the development of biting flies in their excrement. It has also been successfully developed for combating whitefly infestations of cotton (Ellsworth *et al.*, 1996; Palumbo, 1998; Agnew *et al.*, 2000). Despite these successes, Methoprene’s message has largely been ignored, resisted or misunderstood.

First, Williams’s conviction that insects would not be able to develop resistance to mimics of their own hormones has proved false. By 1977, after merely two years on the market, ‘cross tolerance’ to Methoprene was found in the housefly, the flour beetle and the tobacco budworm and, by 1998, resistance to Methoprene was even reported in two species it was developed to combat against, mosquitoes.
and whiteflies (Brown, 1997, p. 31; Ashok et al., 1998). The ability of insects to evolve resistance to mimics of their own hormones illustrates the second lesson revealed through mimesis: that insects are inessential. Even their very processes of reproduction and development can change over time. This suggests that organisms are determined by their relationships and, like those relationships, change over time. There are important ramifications in this lesson for other organisms. For example, could or should human and other animals’ processes of reproduction and development also be considered as biologically inessential? Such a question is vital to ask today, given the current concerns that environmental exposure to estrogen and testosterone-mimicking chemicals will produce intersex animals that are incapable of reproduction.

Finally, Williams’s conviction that juvenile hormones are insect inventions that rarely occur in ‘higher organisms’ also proved false. By 1959 Williams himself reported in Nature that ‘most, and perhaps all, mammalian tissues contain demonstrable amounts of a substance the biological activity of which in the insect assay is indistinguishable from that of juvenile hormone’ (Williams et al., 1959, p. 405). In 1973, juvenile hormone analogues were found to inhibit oxidases in rat livers (Mayer et al., 1973). Methoprene has been implicated in the die-off of lobster populations on the east coast of the United States (Walker et al., 2005; Zulkosky et al., 2005). Finally, Methoprene and juvenile hormone mimics have been recognized as analogs of retinoids, molecules that ‘play essential roles in many aspects of metabolism, development and reproduction in vertebrates’ and which can ‘activate mammalian retinoid-response pathways’ by binding to retinoid receptors (Harmon et al., 1995, p. 6157). It has also been hypothesized that the retinoid-mimicking property of Methoprene explains its teratogenic effects, which include limb deformities, at high doses in mice (Harmon et al., 1995, p. 6160). Thus Methoprene is a potential culprit causing frog limb deformities in regions of agricultural production, although studies also suggest the involvement of parasites (Blaustein and Johnson, 2003).

This illustrates a third lesson of mimesis: it is a two-way street. Because mimesis is based on relationships of similarity, we are all potentially, as Taussig terms it, spacing out, becoming similar to other organisms, such that the boundaries between self and other are indiscernible—mimesis can always backfire. While the man-made Methoprene signal was duping non-target organisms, the plant-created signal of juvenile hormone was rediscovered in the run-off of paper pulp factories and implicated in the sex reversal of fish (Mahmood-Khan and Hal, 2003). The relationship between natural and man-made endocrine disruptors is a source of much debate between industrial and environmental advocacy groups as they battle over the definition of slippery terms: safety, natural and synthetic. As has been shown, however, the line between natural and synthetic juvenile hormone is impossible to draw unilaterally. According to Sláma, by 1999 over 4,000 chemical mimics of juvenile hormone had been synthesized or discovered. This proliferation of mimics, the diversity
of their chemical structures and the higher potency of man-made versus insect or plant derived compounds, all lead him to argue that the true juvenile hormone for insects had still not been discovered (Sláma, 1999). I would argue however, that it is impossible to come to rest on a true or singular juvenile hormone in this maze of mimics. Rather, the activity and meaning of a juvenile hormone is determined within the context of an organism and by its relationships.

From the paper you are holding, to the meat we eat and the pets on which we lavish love, juvenile hormone mimics have been embedded in our daily lives socially and biologically. First realized in the bodies of Chagas Disease-carrying human parasites, juvenile hormone was transformed into a written symbol on the page, only to be betrayed by the matter of the page itself. In weaponizing juvenile hormone as a chemical mimic and forgetting the two-way relationship of mimesis on which it is based, we have reached the endgame in the arms race between pests and humans: implosion into a paranoid whole in which the self can no longer be extricated from the other. This implosion is illustrated by the contemporary crisis over endocrine disruption, in which it is being recognized that many pesticides are also biologically active as human hormone mimics. Returning to the first 1950 Scientific American cover, which establishes a relationship of readership between the audience and the laboratory, we are invited to glimpse inside. We discover, however, that we are no longer simply readers of the story but participants in it. If all human tissues have receptors responsive to juvenile hormone, we too have become part of the story, though we may have been unaware of it consciously until now. Coming to grips with the matter of the page itself, we find ourselves to be other—not reader but protagonist! Looking through this window onto the Williams laboratory we realize that we are participating as experimental objects in the story. Displaced from the position of mere reader, we are part of the lab, like the moths confronted with the process of our own transformation.

**Conclusion**

This story is unique perhaps in the physical linkage between the paper, its reader and juvenile hormone, but it is not unique as a tale of how we are now physically related, both socially and biologically changed, by the products of synthetic chemistry. Many of the twentieth century’s synthetic chemicals were introduced as mimics: synthetic dyes produced the same colors as plant-derived dyes, nylons appeared like silk stockings, and plastics like glass. In our attempts at mimicry, however, much that is different is smuggled in, and those differences are important. For instance, the substitution of synthetic alternatives to dyes, nylons and glass has transformed environments the world over, replacing colonial agricultural industries with factories dependent on fossil fuels (Travis, 1993). Nowhere has synthetic chemistry been more influential than in the effort to control pests, and control our environment. In these efforts, it appears we have transformed ourselves biologically. Studies of human body fat now indicate that
humans born today are host to hundreds of synthetic chemicals (CDC, 2009; EWG, 2009). As the historian and science studies scholar Michelle Murphy argues, endocrine disruptors link us to our environments and our non-human others; our bodies’ burden of synthetic chemicals shows where we have been and what we have been exposed to, like an environmental history (Murphy, 2006, p. 696). Many of those chemicals are hormone mimics, and, just as we attempted to forestall insect metamorphosis by providing mistimed hormonal signals, so too human development and biology is being transformed by exposure to such errant signals. Recent studies link exposure to endocrine disruptors to decreased sperm counts, increased infertility, obesity and autism (Colborn, 2004; vom Saal et al., 2007; Newbold et al., 2008; Crain et al., 2009).

To answer the first question laid out in the Introduction, mimesis was employed by Wigglesworth and Williams as a social and biological tool to produce second-natures so that we now find ourselves in kinship relationships with the significant others that Wigglesworth and Williams produced on their benches (Haraway, 2003). This mimetic spirit of mischief reveals that we have always had, and will always have, companion species relationships to these organisms that have previously been regarded as insignificant others. Indeed, understanding these biological similarities and their significance to humans changed the perspectives of the researchers described in this story, in Taussig’s rather than Haraway’s use of the term, it made them significantly other.

Understanding this potential of mimesis to produce change calls for renewed attention to the species around us as companion species, with whom we share historical relationships and biological sensibilities and whose transformation equally involves our own unpredictable transformations. To answer the second question of how social science can inform epigenetic research, analyzing the mishaps produced by juvenile hormone mimics reveals what social scientists have foretold about mimicry—that it operates through the human capacity to imagine ourselves as other and that, in imagining ourselves so, we may be transformed. The laboratory regarded as a mimetic space offers us a warning for how we should regard its products. The story of juvenile hormone mimics shows the laboratory is not a place of exception where we can step outside our biological and social histories; it is, rather, one environment among many in which we may transform relationships; but such transformations are not possible without simultaneously and unpredictably transforming ourselves. Thus, one caution this social scientist offers the sciences as we endeavor to understand the relationship between the genome and its environment is to return to a view of science that regards laboratory and field sciences as different but equal: a view that cautions against regarding laboratory studies as more certain and more valuable than correlations found by field sciences and the results of ethnographic and historical inquiry. We require a renewed awareness of the limitations of laboratory studies and fine-grained attention to any product with mimetic aspirations. There is, nevertheless, also promise in this story—the promise that we may yet imagine ourselves and our relationships to be other.
Notes

1 For an excellent review of the policy and scientific controversies in regulating endocrine disrupters see the special issue of *Environmental History* edited by Roberts and Langston entitled: ‘Toxic Bodies/Toxic Environments: An Interdisciplinary Forum’ (2008). In particular the articles by Linda Nash, Barbara Allan, Sarah Vogel, Frederick Rowe Davis and Arthur Daemmrich speak to the regulatory and scientific issues related to endocrine disruption. For more in history of science on the field of endocrine disruption see Krimsky (2000) and Langston (2003, 2010). For a general introduction into the study of endocrine disrupters see Colborn *et al.* (1997). For a general review and history of science perspective on the development and regulation of BPA see Vogel (2008).

2 Landecker, unpublished manuscript.

3 Other important works in social studies of field sciences are those by Kohler (2002), Allen (2003) and Mitman *et al.* (2004).


5 Stefan Helmreich makes a similar argument about the use of mimesis in order to create second nature in artificial life communities (Helmreich, 1998, pp. 132–134, 242–244). There is a long academic history to the use of the term ‘second nature’; for a review see Helmreich (1998, pp. 11–12).


9 The company name ‘life control’ connects the story to the larger theme of life control present in the twentieth century’s turn toward experimentally based biological research. For more on this see: Pauly (1987), Maienschein (1991), Oudshoorn (1994) and Clarke (1998).


References


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