



## Gerald M. Edelman (1929–2014)

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Photograph of Gerald M. Edelman (ca. 1965)—Half-length, head turned to left, arms folded. Courtesy of Images from the History of Medicine, National Library of Medicine, Bethesda, MD, United States of America.

The elusive nature of conscious experience has naturally led to the development of several competing theories of consciousness in contemporary scientific thought. While he first came to prominence with his Nobel Prize-winning contributions to immunology, Gerald Maurice Edelman (1929–2014) subsequently offered his own novel theory related to consciousness in 1978, one which he extensively reworked for the remainder of his career and which refuted a widely held notion that brain anatomy is largely fixed and immutable. His

Theory of Neuronal Group Selection (TNGS)—or *Neural Darwinism* as it came to be known—is not among the currently leading theories of consciousness. Yet a highly notable by-product of his work is now abundantly reflected in the scientific literature—namely, the extent to which the adult human brain possesses *plasticity* [1]. Demonstrating the pervasiveness of brain plasticity was not Edelman’s sole aim, despite it being crucial in his larger theory of brain development, function, and consciousness; but it was ultimately this neuroscientific contribution that was to rival those he made in immunology. The copious literature revealing examples of plasticity is now strongly receptive of his work, though it was not until around the 1990s that the general scientific consensus moved ever closer in line with him on the subject [2].

Gerald Edelman was born in the borough of Queens, New York City, to Edward (d. 1979?), a physician, and Anna (*née* Friedmann 1899–1983) who worked in insurance. Music, literature and the visual arts were among his early interests, a love that remained throughout his life so that he displayed a deep knowledge of them though he opted not to follow his first calling in life to become a concert violinist [3]. Gerald Edelman rather turned his focus toward medicine, obtaining a chemistry undergraduate degree at Ursinus College, Pennsylvania (1950), before gravitating toward biology and obtaining a degree in medicine from the University of Pennsylvania (1954). There, he had the opportunity to study medical biophysics under the esteemed biochemist, Britton Chance (1913–2010), focusing on the enzyme cytochrome *c* peroxidase. And following a year of training under rheumatologist Walter Bauer (1898–1963), chief of medical services at Massachusetts General Hospital, he spent three years in the US Army Medical Corps stationed in France—an experience which brought him into contact with thousands of patients and during which he “delivered a fair number of babies” [4]. Dismissed from his army service, in 1958 he entered the graduate program in the laboratory of immunologist Henry Kunkel (1916–1983) at the Rockefeller Institute for Medical Research, New York—later named Rockefeller University (1965)—where he was to remain for over two decades [5]. Following his doctorate (1960), Edelman

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focused on antibodies, applying the Darwinian principles of variation and selection to the functioning of the human immune system to account for the diverse responses it presented in individuals; principles which were to re-emerge in his subsequent work on brain function.

In 1972, Edelman, along with his colleague Rodney Porter (1917–1986), was awarded the Nobel Prize in Physiology or Medicine, for discoveries relating to the chemical structure of antibodies in the human immune system. His department at the Rockefeller Institute increased in size and stature afterwards, developing several subcomponents, each with their own research specialties. However, Edelman turned his personal attention to the workings of the central nervous system, a change in direction that subsequently led to his founding the Neurosciences Institute (NSI) originally at his host institution from 1981, and then from 1992 it relocated to La Jolla, California [6]. It was intended to be a “monastery of science” allowing high-risk, novel research, but Edelman had to face financial pressures and a changing academic world in his last decades [7]; indeed, the Neurosciences Institute had to close its doors permanently shortly after his death.

If it resulted in many challenges, Edelman’s dramatic change in research and publication direction, beginning in the late 1970s, left a lasting influence on modern neuroscience. Consistent with his belief that the evolutionary principles of British natural historian Charles Darwin (1809–1882) could reveal answers to hitherto unexplained phenomena, Edelman used them as a foundation for his Theory of Neuronal Group Selection, first published in *The Mindful Brain* (1978), co-authored with Johns Hopkins professor Vernon Benjamin Mountcastle (1918–2015). Edelman’s theory originally focused on brain development and function, but within ten years it expanded, becoming the basis of his theory of consciousness [8]. Better known as “Neural Darwinism”, a more persuasive label with a nod to its roots in evolutionary theory, it features variation, selection, and reorganization within neural populations as fundamental principles. The theory was outlined and published in his book *Neural Darwinism: The Theory of Neuronal Group Selection* (1987). Edelman’s Neural Darwinism is selectionist in nature, as opposed to instructionist. It is the selectionist basis of Neural Darwinism that was inspired by Darwinian notions, possessing four features, one of which is “degeneracy”, defined as the ability of structurally different combinations of elements to perform the same function. Edelman’s degeneracy bears more than a vague resemblance to the modern concept of neuroplasticity. Indeed, in supporting his own theory Edelman (with La Jolla’s neuroscientist Joseph A. Gally) cited over twenty instances of degeneracy, one of which is the brain’s ability to shift function after brain damage occurs. While at the time when Edelman conceived Neural Darwinism, much was still

to be discovered of neuroplasticity, his ideas foreshadowed reorganization, presently considered a fundamental feature of plasticity in neural networks in response to a multitude of stimuli [9]. Moreover, Edelman also showed great insight in his references to “experiential selection,” which considers behaviors and experiences capable of strengthening and weakening synapses, events now considered functions of neuroplasticity.

Edelman constantly applied Neural Darwinism to the subject of consciousness in *The Remembered Present* (1989), *Bright Air, Brilliant Fire: On the Matter of the Mind* (1992), and *A Universe of Consciousness* (2000), co-authored with Giulio Tononi, an eminent neuroscientist at the University of Wisconsin, who later conceived the Integrated Information Theory of Consciousness [10]. Edelman continued to publish into the twenty-first century with additional works on consciousness: *Wider Than the Sky: The Phenomenal Gift of Consciousness* (2004) and *Second Nature* (2006), which were his final books. His prescience on the brain’s ability to reorganize itself in response to stimuli reflects the workings of his broad knowledge, creative thinking, and boundless ambition to seek scientific order and explanation for consciousness. Tononi notes that in his later years, Edelman made light of his Nobel Prize-winning work in immunology, commenting that others would have eventually discovered the structure of antibodies, but possibly not Neural Darwinism. Edelman’s break-throughs and contributions across multiple scientific domains are rare for an individual to achieve, especially one who considered that he himself, as many of us, began “as an artist” [1].

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## Compliance with ethical standards

**Conflicts of interest** The corresponding author states that there is no conflict of interest.

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