Thomas Hunt Morgan and the Rise of Genetics

Today we stand just over a hundred years removed from the rediscovery of Mendel's laws, and exactly fifty years on from the elucidation of the structure of DNA by James Watson and Francis Crick in 1953. Looking back on the past fifty years of genetics that have taken us from the double helix to designer genes, it is easy to overlook the stunning advances in our understanding of heredity and variation in the first half of the twentieth century. Yet, it was in those few decades after de Vries, von Tschermak and Correns independently rediscovered the principles of segregation and independent assortment that the science of genetics grew up from infancy to youth. It was also in those decades that the foundations for much subsequent research in genetics were laid. Thomas Hunt Morgan's professional life straddled the decades of the adolescence of genetics. It was in his laboratory that X-linked inheritance was discovered, the first genetic maps made, and the proposition that genes were linearly arranged on chromosomes experimentally verified. Morgan himself was awarded the Nobel Prize in Physiology or Medicine for 1933 for "*his discoveries concerning the role played by the chromosome in heredity*". It was also through its early use as a model system in Morgan's laboratory that the fruit fly *Drosophila* became the First Organism of genetics, a place it still occupies in the face of competition from diverse bacteria, viruses, yeasts, worms, mice and plants. Other geneticists who worked with Morgan as students, research associates or colleagues – most notably Hermann Muller (Nobel Prize 1946), George Beadle (Nobel Prize 1958) and Theodosius Dobzhansky – extended genetics beyond chromosomal mechanics, and the use of *Drosophila* beyond gene mapping.

Thomas Hunt Morgan was born in 1866 into a distinguished southern family in Lexington, Kentucky. His father Charlton Hunt Morgan was a US consul, and one of his uncles, John Hunt Morgan, a well known confederate general in the American civil war. Morgan was interested early on in natural history and after obtaining his bachelors' degree from Kentucky State College in 1886, went on to study the evolutionary relationships and development of pycnogonids (sea spiders) under the supervision of embryologist and morphologist William Keith Brooks at Johns Hopkins University, obtaining his PhD in 1890. Johns Hopkins, at Baltimore in Maryland, was the first research university in the United States and a major research centre. Although Brooks was more of a field zoologist, Morgan was also influenced by H Newell Martin, a physiologist at Johns Hopkins, who was an advocate of rigorous experimental approaches in biology. In 1891, Morgan took up a teaching position at Bryn Mawr College and stayed there till 1904. During these years, he also spent time at the Zoological Station in Naples, Italy, and developed a close friendship with the embryologist Hans Driesch. In 1904, Morgan married a former student, Lillian Sampson, and moved to Columbia University as professor of experimental zoology.

Morgan stayed at Columbia University till 1928, and it was here that the famous genetic work on *Drosophila* was done, with the assistance of a bright group of youngsters like Calvin Bridges and Alfred Sturtevant. Sturtevant was a 19 year old undergraduate when he conceived of the technique of recombinational mapping of genes, an advance which Morgan referred to as "*one of the most amazing developments in the history of* *biology*". X-linked inheritance was discovered at Columbia, and it was the first time a gene (for eye colour in *Drosophila*) had been associated with a particular chromosome. This work gave rise to the idea that genes were linearly arranged along chromosomes, that crossing over could exchange genes between homologous chromosomes, and that the degree of crossing over between genes could be used to map their location along chromosomes. These early findings altered genetics forever, and were summarized in an influential book called *The Mechanism of Mendelian Heredity* by Morgan, Sturtevant, Bridges and Muller, published in 1915. The small 16 × 23 feet fly room – Room 613 in Schermerhorn Hall at Columbia – became well known around the world, both for the quality of the science being done there and the open and friendly, yet intensely critical, working atmosphere.

In 1928, the eminent astronomer G E Hale invited Morgan to set up a biology division at the recently established California Institute of Technology (Caltech) in Pasadena. Morgan moved to Caltech, along with Sturtevant, Bridges, Dobzhansky, and much of the fly group, and established the biology division as a premier centre of experimental biology. Morgan chaired the biology division at Caltech till 1942. Between 1942 and 1946, the division was led by a committee chaired by Sturtevant. Edward B Lewis, who shared a Nobel prize in 1995 for developmental genetics research, was Sturtevant's student, and later joined the division. It was also at Caltech that the outstanding work of Dobzhansky, initially in collaboration with Sturtevant, on the genetics and evolution of wild populations of *Drosophila* was done. In 1946, George W Beadle, who had earlier been a research associate at Caltech, working on inversions and developmental genetics in *Drosophila*, was invited to chair the division of biology, which went on to grow from strength to strength, attracting such leading figures in biological research as N H Horowitz, Max Delbrück, R Dulbecco, S Benzer and R Sperry. During the Caltech years, Morgan was not directly involved in most of the genetics work going on in the group, which was largely directed by Sturtevant. Morgan helped establish a marine laboratory for Caltech at Corona del Mar and increasingly returned to his earlier interest in the developmental biology of marine invertebrates. Other than the Nobel Prize in 1933, Morgan was awarded the Darwin Medal (1924) and the Copley Medal (1939). He served as president of the National Academy of Sciences, the American Association for the Advancement of Science, and the Sixth International Congress of Genetics. He authored several books, including *Evolution and Adaptation* (1903), *A Critique of the Theory of Evolution* (1916), *The Mechanism of Mendelian Heredity* (1915), *The Theory of the Gene* (1926), *Experimental Embryology* (1927), and *Embryology and Genetics* (1934). Morgan remained on the faculty at Caltech till his death in 1945.

Apart from his work, there are several things about Morgan's life that are worth highlighting. When Morgan began his professional life, biology tended to be a largely descriptive subject, although things were beginning to change. Morgan himself was convinced of the importance of an experimental rather than a descriptive approach. At the same time, he was not comfortable with too much abstraction; in philosophical terms, he was very much a materialist. In the very early days after the rediscovery of Mendel's laws, the physical basis of heredity was not known. Consequently, as more and more genes were discovered, the explanations for how they interacted became more and more convoluted and abstract. Morgan was not happy with this kind of abstraction, wherever more elaborate theories needed to be developed to accommodate every advance in factual knowledge. Initially he was also skeptical about the view that the chromosomes may be the carriers of hereditary factors, a view that was based on the parallels between the behaviour of Mendel's postulated genes and that of chromosomes during meiosis. He was, similarly, not too convinced early on by the Darwinian view of evolution, which he also regarded as too speculative. Indeed, Morgan's early work with *Drosophila* was begun in an attempt to do some kind of experimental evolutionary studies to assess the role of mutation in evolution in a rigorous and quantitative manner. Whatever his skepticism about Darwinism and Mendelism, however, Morgan had an open mind, and was willing to revise his thinking in the light of new experimental evidence. Eventually, his work along with that of his students and collaborators, led to the experimental verification of the chromosome theory of inheritance, and also contributed to the welding together of Mendelian genetics and Darwinian evolution in what has become known as the Neo-Darwinian synthesis. Morgan's broader interest in development also directly led to the work of Beadle and others, which showed that genes acted largely by specifying enzymes responsible for catalyzing particular steps in metabolic pathways. Thus, the combination of an open mind – skeptical towards dogma but not unwilling to revise its views – and a broad outlook on biology, led Morgan and his group to reorient biology with the gene at its centre, uniting the hitherto disparate realms of evolution, heredity and development into one grand scheme in which genes, physically locatable on chromosomes, were the units of heredity and of evolution, and functioned as controlling switches for metabolic and developmental pathways. This is essentially the view of biology that still persists today; all of us biologists are, in this sense, inheritors of the vision of Morgan.

Morgan also introduced at Columbia an atmosphere for doing science which was different from the norm in those days. American universities at the turn of the twentieth century looked to Europe for inspiration and were, consequently, organized in a hierarchical manner, with the professor at the top of a clearly delineated pecking order. While Morgan was also clearly the 'boss' of the fly group, and kept a tight grip especially on finances, he allowed his students and young colleagues considerable latitude and freedom in defining their research. The whole mapping project, which contributed greatly to Morgan's own fame, was largely conceived of and carried out by Sturtevant and Bridges and was something of a tangential offshoot of Morgan's planned experimental evolution studies. Yet, Morgan was quick to see the potential of gene mapping, and allowed Sturtevant and Bridges a free hand. The fundamentally cooperative nature of research in the fly group, with an emphasis on friendly but critical discussion of everyone's work by everybody was largely due to Morgan's approach to science. In time, this kind of open and free-wheeling approach to science became more common in American universities, and was often favourably compared to the somewhat stifling hierarchical structure of their more distinguished European counterparts. Sturtevant has described the atmosphere of the fly group as: "*Each carried on his own experiments, but each knew exactly what the others were doing, and each new result was freely discussed. There was little attention paid to priority or to the source of new ideas or* *new interpretations*." Indeed, when Beadle left the fly group and started serious work in biochemical genetics, he was quite shocked at the cut-throat competitive nature of the biochemistry community, compared to the much more cooperative attitude of *Drosophila* geneticists, who readily shared ideas, data and biological materials amongst themselves (to some extent this is still true of fly workers, especially in evolutionary genetics). In the present time of secrecy, proprietary rights and patents in much of biology, this is perhaps an important legacy of Morgan that we should try hard not to lose track of. Science is ultimately a collective endeavour and knowledge is a gift to be shared freely, not a resource to be hoarded or an investment to be protected.

Amitabh Joshi
Animal Behaviour Unit, Jawaharlal Nehru
Centre for Advanced Scientific Research,
Bangalore 560 064, India.

Thomas Hunt Morgan and Developmental Biology

Thomas Hunt Morgan was in the unique position of being able to combine genetics and developmental biology and create the discipline of developmental genetics. Yet, the latter field came of its own much later, in the 1970s, over 40 years after Morgan won the Nobel Prize. What took it so long? Morgan's training and the science of his times give us one perspective, which only adds to the puzzle.

We know rather little about how complex functions of organisms – such as processing visual information or the ability for abstract thought – are related to the physiology of the brain. We know even less about how these functions emerge during development. And, we know the least about the roles of genes in either of these two processes. Of course, genes play an all-encompassing role at a rather obvious and trivial level. Organisms are the consequences of the function of their cells and cellular-constituents; and since genes encode proteins, and the function of proteins affects the function of cells, ergo, genes determine everything, including how one reacts to the environment. Looked at in this apparently 'trivial' way, developmental genetics is merely the use of the scalpel of genetics to study developmental biology. However, in practice, it has been an intellectually stimulating discipline in its own right, in addition to being of practical value in understanding developmental mechanisms.

The golden period of embryology was in the 19th and early 20th century with much of the action centered in Europe, principally in Germany. Many American researchers went to Europe and interacted closely with colleagues there and experimental embryology developed rapidly in the USA. Morgan got his PhD on the evolutionary relationships of pycnogonids (sea spiders) at Johns Hopkins University and was an expert in zoology. This choice of career developed from an early interest in wildlife. As a young child of ten, he collected birds, birds' eggs, and fossils and after his undergraduate studies spent some time in a marine laboratory. He succeeded the famous cell biologist E B Wilson, who influenced him greatly, at Bryn Mawr College in 1891, a well-known women's college where Morgan met his future wife (Lilian Sampson, a student, embryologist and his collaborator for some years).