= Barbara McClintock =

Barbara McClintock (June 16 , 1902 ? September 2 , 1992) was an American scientist and cytogeneticist who was awarded the 1983 Nobel Prize in Physiology or Medicine . McClintock received her PhD in botany from Cornell University in 1927 . There she started her career as the leader in the development of maize cytogenetics , the focus of her research for the rest of her life . From the late 1920s , McClintock studied chromosomes and how they change during reproduction in maize . She developed the technique for visualizing maize chromosomes and used microscopic analysis to demonstrate many fundamental genetic ideas . One of those ideas was the notion of genetic recombination by crossing @-@ over during meiosis ? a mechanism by which chromosomes exchange information . She produced the first genetic map for maize , linking regions of the chromosome to physical traits . She demonstrated the role of the telomere and centromere , regions of the chromosome that are important in the conservation of genetic information . She was recognized among the best in the field , awarded prestigious fellowships , and elected a member of the National Academy of Sciences in 1944 .

During the 1940s and 1950s , McClintock discovered transposition and used it to demonstrate that genes are responsible for turning physical characteristics on and off . She developed theories to explain the suppression and expression of genetic information from one generation of maize plants to the next . Due to skepticism of her research and its implications , she stopped publishing her data in 1953 .

Later , she made an extensive study of the cytogenetics and ethnobotany of maize races from South America . McClintock 's research became well understood in the 1960s and 1970s , as other scientists confirmed the mechanisms of genetic change and genetic regulation that she had demonstrated in her maize research in the 1940s and 1950s . Awards and recognition for her contributions to the field followed , including the Nobel Prize in Physiology or Medicine , awarded to her in 1983 for the discovery of genetic transposition ; she is the only woman to receive an unshared Nobel Prize in that category .

= = Early life = =

Barbara McClintock was born Eleanor McClintock on June 16 , 1902 in Hartford , Connecticut , the third of four children born to physician Thomas Henry McClintock and Sara Handy McClintock . Thomas McClintock was the child of British immigrants , and Sara Handy , born Grace , descended from an old American Mayflower family . Marjorie , the oldest child , was born in October 1898 ; Mignon , the second daughter , was born in November 1900 . The youngest , Malcolm Rider (called Tom) , was born 18 months after Barbara . As a young girl , her parents determined that Eleanor , a " feminine " and " delicate " name , was not appropriate for her , and chose Barbara instead . McClintock was an independent child beginning at a very young age , a trait she later identified as her " capacity to be alone " . From the age of three until she began school , McClintock lived with an aunt and uncle in Brooklyn , New York in order to reduce the financial burden on her parents while her father established his medical practice . She was described as a solitary and independent child , and a tomboy . She was close to her father , but had a difficult relationship with her mother , tension that began when she was young .

The McClintock family moved to Brooklyn in 1908 and McClintock completed her secondary education there at Erasmus Hall High School ; she graduated early in 1919 . She discovered her love of science and reaffirmed her solitary personality during high school . She wanted to continue her studies at Cornell University 's College of Agriculture . Her mother resisted sending McClintock to college , for fear that she would be unmarriageable . McClintock was almost prevented from starting college , but her father intervened just before registration began , and she matriculated at Cornell in 1919 .

= = Education and research at Cornell = =

McClintock began her studies at Cornell 's College of Agriculture in 1919 . There , she participated in student government and was invited to join a sorority , though she soon realized that she preferred not to join formal organizations . Instead , McClintock took up music , specifically jazz . She studied botany , receiving a BSc in 1923 . Her interest in genetics began when she took her first course in that field in 1921 . The course was based on a similar one offered at Harvard University , and was taught by C. B. Hutchison , a plant breeder and geneticist . Hutchison was impressed by McClintock 's interest , and telephoned to invite her to participate in the graduate genetics course at Cornell in 1922 . McClintock pointed to Hutchison 's invitation as the reason she continued in genetics : " Obviously , this telephone call cast the die for my future . I remained with genetics thereafter . " Although it has been reported that women could not major in genetics at Cornell , and therefore her MA and PhD ? earned in 1925 and 1927 , respectively ? were officially awarded in botany , recent research has revealed that women did earn graduate degrees in Cornell 's Plant Breeding Department during the time that McClintock was a student at Cornell .

During her graduate studies and postgraduate appointment as a botany instructor , McClintock was instrumental in assembling a group that studied the new field of cytogenetics in maize . This group brought together plant breeders and cytologists , and included Marcus Rhoades , future Nobel laureate George Beadle , and Harriet Creighton . Rollins A. Emerson , head of the Plant Breeding Department , supported these efforts , although he was not a cytologist himself .

She also worked as a research assistant for Lowell Fitz Randolph and then for Lester W. Sharp , both Cornell Botanists .

McClintock 's cytogenetic research focused on developing ways to visualize and characterize maize chromosomes . This particular part of her work influenced a generation of students , as it was included in most textbooks . She also developed a technique using carmine staining to visualize maize chromosomes , and showed for the first time the morphology of the 10 maize chromosomes . This discovery was made because she observed cells from the microspore as opposed to the root tip . By studying the morphology of the chromosomes , McClintock was able to link specific chromosome groups of traits that were inherited together . Marcus Rhoades noted that McClintock 's 1929 Genetics paper on the characterization of triploid maize chromosomes triggered scientific interest in maize cytogenetics , and attributed to her 10 of the 17 significant advances in the field that were made by Cornell scientists between 1929 and 1935 .

In 1930 , McClintock was the first person to describe the cross @-@ shaped interaction of homologous chromosomes during meiosis . The following year , McClintock and Creighton proved the link between chromosomal crossover during meiosis and the recombination of genetic traits . They observed how the recombination of chromosomes seen under a microscope correlated with new traits . Until this point , it had only been hypothesized that genetic recombination could occur during meiosis , although it had been shown genetically . McClintock published the first genetic map for maize in 1931 , showing the order of three genes on maize chromosome 9 . This information provided necessary data for the crossing @-@ over study she published with Creighton ; they also showed that crossing @-@ over occurs in sister chromatids as well as homologous chromosomes . In 1938 , she produced a cytogenetic analysis of the centromere , describing the organization and function of the centromere , as well as the fact that it can divide .

McClintock 's breakthrough publications , and support from her colleagues , led to her being awarded several postdoctoral fellowships from the National Research Council . This funding allowed her to continue to study genetics at Cornell , the University of Missouri , and the California Institute of Technology , where she worked with E. G. Anderson . During the summers of 1931 and 1932 , she worked at Missouri with geneticist Lewis Stadler , who introduced her to the use of X @-@ rays as a mutagen . Exposure to X @-@ rays can increase the rate of mutation above the natural background level , making it a powerful research tool for genetics . Through her work with X @-@ ray @-@ mutagenized maize , she identified ring chromosomes , which form when the ends of a single chromosome fuse together after radiation damage . From this evidence , McClintock hypothesized that there must be a structure on the chromosome tip that would normally ensure stability . She showed that the loss of ring @-@ chromosomes at meiosis caused variegation in maize foliage in generations subsequent to irradiation resulting from chromosomal deletion . During

this period , she demonstrated the presence of the nucleolus organizer region on a region on maize chromosome 6 , which is required for the assembly of the nucleolus . In 1933 , she established that cells can be damaged when nonhomologous recombination occurs . During this same period , McClintock hypothesized that the tips of chromosomes are protected by telomeres .

McClintock received a fellowship from the Guggenheim Foundation that made possible six months of training in Germany during 1933 and 1934 . She had planned to work with Curt Stern , who had demonstrated crossing @-@ over in Drosophila just weeks after McClintock and Creighton had done so ; however , Stern emigrated to the United States . Instead , she worked with geneticist Richard B. Goldschmidt , who was the head of the Kaiser Wilhelm Institute . She left Germany early amidst mounting political tension in Europe , and returned to Cornell , remaining there until 1936 , when she accepted an Assistant Professorship offered to her by Lewis Stadler in the Department of Botany at the University of Missouri @-@ Columbia . While still at Cornell , she was supported by a two @-@ year Rockefeller Foundation grant obtained for her through Emerson 's efforts .

= = University of Missouri = =

During her time at Missouri , McClintock expanded her research on the effect of X @-@ rays on maize cytogenetics . McClintock observed the breakage and fusion of chromosomes in irradiated maize cells . She was also able to show that , in some plants , spontaneous chromosome breakage occurred in the cells of the endosperm . Over the course of mitosis , she observed that the ends of broken chromatids were rejoined after the chromosome replication . In the anaphase of mitosis , the broken chromosomes formed a chromatid bridge , which was broken when the chromatids moved towards the cell poles . The broken ends were rejoined in the interphase of the next mitosis , and the cycle was repeated , causing massive mutation , which she could detect as variegation in the endosperm . This breakage ? rejoining ? bridge cycle was a key cytogenetic discovery for several reasons . First , it showed that the rejoining of chromosomes was not a random event , and second , it demonstrated a source of large @-@ scale mutation . For this reason , it remains an area of interest in cancer research today .

Although her research was progressing at Missouri , McClintock was not satisfied with her position at the University . She recalled being excluded from faculty meetings , and was not made aware of positions available at other institutions . In 1940 , she wrote to Charles Burnham , " I have decided that I must look for another job . As far as I can make out , there is nothing more for me here . I am an assistant professor at $ 3 @,@ 000 and I feel sure that that is the limit for me . " Initially , McClintock 's position was created especially for her by Stadler , and might have depended on his presence at the university . McClintock believed she would not gain tenure at Missouri , even though according to some accounts , she knew she would be offered a promotion from Missouri in the spring of 1942 . Recent evidence reveals that McClintock more likely decided to leave Missouri because she had lost trust in her employer and in the University administration , after discovering that her job would be in jeopardy if Stadler were to leave for Caltech , as he had considered doing . The university 's retaliation against Stadler amplified her sentiments .

In early 1941 , she took a leave of absence from Missouri in hopes of finding a position elsewhere . She accepted a visiting Professorship at Columbia University , where her former Cornell colleague Marcus Rhoades was a professor . Rhoades also offered to share his research field at Cold Spring Harbor on Long Island . In December 1941 , she was offered a research position by Milislav Demerec , the newly appointed acting director of the Carnegie Institution of Washington 's Department of Genetics Cold Spring Harbor Laboratory ; McClintock accepted his invitation despite her qualms and became a permanent member of the faculty .

= = Cold Spring Harbor = =

After her year @-@ long temporary appointment , McClintock accepted a full @-@ time research position at Cold Spring Harbor Laboratory . There , she was highly productive and continued her work with the breakage @-@ fusion @-@ bridge cycle , using it to substitute for X @-@ rays as a

tool for mapping new genes . In 1944 , in recognition of her prominence in the field of genetics during this period , McClintock was elected to the National Academy of Sciences ? only the third woman to be elected . That same year , she became the first female president of the Genetics Society of America ; she was elected its vice @-@ president in 1939 . In 1944 she undertook a cytogenetic analysis of Neurospora crassa at the suggestion of George Beadle , who used the fungus to demonstrate the one gene ? one enzyme relationship . He invited her to Stanford to undertake the study . She successfully described the number of chromosomes , or karyotype , of N. crassa and described the entire life cycle of the species . Beadle said " Barbara , in two months at Stanford , did more to clean up the cytology of Neurospora than all other cytological geneticists had done in all previous time on all forms of mold . " N. crassa has since become a model species for classical genetic analysis .

= = = Discovery of controlling elements = = =

In the summer of 1944 at Cold Spring Harbor Laboratory , McClintock began systematic studies on the mechanisms of the mosaic color patterns of maize seed and the unstable inheritance of this mosaicism . She identified two new dominant and interacting genetic loci that she named Dissociator (Ds) and Activator (Ac) . She found that the Dissociator did not just dissociate or cause the chromosome to break , it also had a variety of effects on neighboring genes when the Activator was also present , which included making certain stable mutations unstable . In early 1948 , she made the surprising discovery that both Dissociator and Activator could transpose , or change position , on the chromosome .

She observed the effects of the transposition of Ac and Ds by the changing patterns of coloration in maize kernels over generations of controlled crosses , and described the relationship between the two loci through intricate microscopic analysis . She concluded that Ac controls the transposition of the Ds from chromosome 9 , and that the movement of Ds is accompanied by the breakage of the chromosome . When Ds moves , the aleurone @-@ color gene is released from the suppressing effect of the Ds and transformed into the active form , which initiates the pigment synthesis in cells . The transposition of Ds in different cells is random , it may move in some but not others , which causes color mosaicism . The size of the colored spot on the seed is determined by stage of the seed development during dissociation . McClintock also found that the transposition of Ds is determined by the number of Ac copies in the cell .

Between 1948 and 1950 , she developed a theory by which these mobile elements regulated the genes by inhibiting or modulating their action . She referred to Dissociator and Activator as " controlling units " ? later , as " controlling elements " ? to distinguish them from genes . She hypothesized that gene regulation could explain how complex multicellular organisms made of cells with identical genomes have cells of different function . McClintock 's discovery challenged the concept of the genome as a static set of instructions passed between generations . In 1950 , she reported her work on Ac / Ds and her ideas about gene regulation in a paper entitled " The origin and behavior of mutable loci in maize " published in the journal Proceedings of the National Academy of Sciences . In summer 1951 , when she reported her work on the origin and behavior of mutable loci in maize at the annual symposium at Cold Spring Harbor Laboratory , presenting a paper of the same name . The paper delved into the instability caused by Dc and As or just As in four genes , along with the tendency of those genes to unpredictably revert to the wild phenotype . She also identified " families " of transposons , which did not interact with one another .

Her work on controlling elements and gene regulation was conceptually difficult and was not immediately understood or accepted by her contemporaries ; she described the reception of her research as " puzzlement , even hostility " . Nevertheless , McClintock continued to develop her ideas on controlling elements . She published a paper in Genetics in 1953 , where she presented all her statistical data , and undertook lecture tours to universities throughout the 1950s to speak about her work . She continued to investigate the problem and identified a new element that she called Suppressor @-@ mutator (Spm) , which , although similar to Ac / Ds , acts in a more complex manner . Like Ac / Ds , some versions could transpose on their own and some could not ; unlike Ac /

Ds , when present , it fully suppressed the expression of mutant genes when they normally would not be entirely suppressed . Based on the reactions of other scientists to her work , McClintock felt she risked alienating the scientific mainstream , and from 1953 stopped publishing accounts of her research on controlling elements .

= = = The origins of maize = = =

In 1957 , McClintock received funding from the National Academy of Sciences to start research on indigenous strains of maize in Central America and South America . She was interested in studying the evolution of maize through chromosomal changes , and being in South America would allow her to work on a larger scale . McClintock explored the chromosomal , morphological , and evolutionary characteristics of various races of maize . After extensive work in the 1960s and 1970s , McClintock and her collaborators published the seminal study The Chromosomal Constitution of Races of Maize , leaving their mark on paleobotany , ethnobotany , and evolutionary biology .

= = = Rediscovery of McClintock 's controlling elements = = =

McClintock officially retired from her position at the Carnegie Institution in 1967 , and was made a Distinguished Service Member of the Carnegie Institution of Washington . This honor allowed her to continue working with graduate students and colleagues in the Cold Spring Harbor Laboratory as scientist emerita ; she lived in the town . In reference to her decision 20 years earlier to stop publishing detailed accounts of her work on controlling elements , she wrote in 1973 :

Over the years I have found that it is difficult if not impossible to bring to consciousness of another person the nature of his tacit assumptions when , by some special experiences , I have been made aware of them . This became painfully evident to me in my attempts during the 1950s to convince geneticists that the action of genes had to be and was controlled . It is now equally painful to recognize the fixity of assumptions that many persons hold on the nature of controlling elements in maize and the manners of their operation . One must await the right time for conceptual change .

The importance of McClintock 's contributions was revealed in the 1960s , when the work of French geneticists Francois Jacob and Jacques Monod described the genetic regulation of the lac operon , a concept she had demonstrated with Ac / Ds in 1951 . Following Jacob and Monod 's 1961 Journal of Molecular Biology paper " Genetic regulatory mechanisms in the synthesis of proteins " , McClintock wrote an article for American Naturalist comparing the lac operon and her work on controlling elements in maize . McClintock 's contribution to biology is still not widely acknowledged as amounting to the discovery of genetic regulation .

McClintock was widely credited for discovering transposition after other researchers finally discovered the process in bacteria , yeast , and bacteriophages in the late 1960s and early 1970s . During this period , molecular biology had developed significant new technology , and scientists were able to show the molecular basis for transposition . In the 1970s , Ac and Ds were cloned by other scientists and were shown to be Class II transposons . Ac is a complete transposon that can produce a functional transposase , which is required for the element to move within the genome . Ds has a mutation in its transposase gene , which means that it cannot move without another source of transposase . Thus , as McClintock observed , Ds cannot move in the absence of Ac . Spm has also been characterized as a transposon . Subsequent research has shown that transposons typically do not move unless the cell is placed under stress , such as by irradiation or the breakage @-@ fusion @-@ bridge cycle , and thus their activation during stress can serve as a source of genetic variation for evolution . McClintock understood the role of transposons in evolution and genome change well before other researchers grasped the concept . Nowadays , Ac / Ds is used as a tool in plant biology to generate mutant plants used for the characterization of gene function .

= = Honors and recognition = =

In 1947 , McClintock received the Achievement Award from the American Association of University

Women . She was elected a Fellow of the American Academy of Arts and Sciences in 1959 . In 1967 , McClintock was awarded the Kimber Genetics Award ; three years later , she was given the National Medal of Science by Richard Nixon in 1970 . She was the first woman to be awarded the National Medal of Science . Cold Spring Harbor named a building in her honor in 1973 . She received the Louis and Bert Freedman Foundation Award and the Lewis S. Rosensteil Award in 1978 . In 1981 , she became the first recipient of the MacArthur Foundation Grant , and was awarded the Albert Lasker Award for Basic Medical Research , the Wolf Prize in Medicine and the Thomas Hunt Morgan Medal by the Genetics Society of America . In 1982 , she was awarded the Louisa Gross Horwitz Prize from Columbia University for her research in the " evolution of genetic information and the control of its expression . "

Most notably , she received the Nobel Prize for Physiology or Medicine in 1983 , the first woman to win that prize unshared , credited by the Nobel Foundation for discovering " mobile genetic elements " ; it was more than 30 years after she initially described the phenomenon of controlling elements . She was compared to Gregor Mendel in terms of her scientific career by the Swedish Academy of Sciences when she was awarded the Prize .

She was elected a Foreign Member of the Royal Society (ForMemRS) in 1989 . McClintock received the Benjamin Franklin Medal for Distinguished Achievement in the Sciences of the American Philosophical Society in 1993 . She was awarded 14 Honorary Doctor of Science degrees and an Honorary Doctor of Humane Letters . In 1986 she was inducted into the National Women 's Hall of Fame . During her final years , McClintock led a more public life , especially after Evelyn Fox Keller 's 1983 biography of her , A Feeling for the Organism , brought McClintock 's story to the public . She remained a regular presence in the Cold Spring Harbor community , and gave talks on mobile genetic elements and the history of genetics research for the benefit of junior scientists . An anthology of her 43 publications The Discovery and Characterization of Transposable Elements : The Collected Papers of Barbara McClintock was published in 1987 .

= = Later years = =

McClintock spent her later years , post Nobel Prize , as a key leader and researcher in the field at Cold Spring Harbor Laboratory on Long Island , New York . McClintock died of natural causes in Huntington , New York , on September 2 , 1992 at the age of 90 ; she never married or had children .

= = Legacy = =

Since her death , McClintock has been the subject of a biography by the science historian Nathaniel C. Comfort 's The Tangled Field : Barbara McClintock 's Search for the Patterns of Genetic Control . Comfort 's biography contests some claims about McClintock , described as the " McClintock Myth " , which he claims was perpetuated by the earlier biography by Keller . Keller 's thesis was that McClintock was long ignored or met with derision because she was a woman working in the sciences . For example , when McClintock presented her findings that the genetics of maize did not conform to Mendelian distributions , geneticist Sewall Wright expressed the belief that she did not understand the underlying mathematics of her work , a belief he had expressed towards other women at the time . In addition , geneticist Lotte Auerbach recounted that Joshua Lederberg returned from a visit to McClintock 's lab with the remark : ' By God , that woman is either crazy or a genius . ' " As Auerbach tells it , McClintock had thrown Lederberg and his colleagues out after half an hour ' because of their arrogance . She was intolerant of arrogance ... She felt she had crossed a desert alone and no one had followed her . ' "

Comfort , however , asserts that McClintock was well regarded by her professional peers , even in the early years of her career . Although Comfort argues that McClintock was not a victim of gender discrimination , she has been widely written about in the context of women 's studies . Most recent biographical works on women in science feature accounts of her experience . She is held up as a role model for girls in such works of children 's literature as Edith Hope Fine 's Barbara McClintock ,

Nobel Prize Geneticist , Deborah Heiligman 's Barbara McClintock : Alone in Her Field and Mary Kittredge 's Barbara McClintock . A recent biography for young adults by Naomi Pasachoff , Barbara McClintock , Genius of Genetics , provides a new perspective , based on the current literature .

On 4 May 2005 , the United States Postal Service issued the " American Scientists " commemorative postage stamp series , a set of four 37 @-@ cent self @-@ adhesive stamps in several configurations . The scientists depicted were Barbara McClintock , John von Neumann , Josiah Willard Gibbs , and Richard Feynman . McClintock was also featured in a 1989 four @-@ stamp issue from Sweden which illustrated the work of eight Nobel Prize @-@ winning geneticists . A small building at Cornell University and a laboratory building at Cold Spring Harbor Laboratory were named for her . A street has been named after her in the new " Adlershof Development Society " science park in Berlin .

Some of McClintock 's personality and scientific achievements were referred to in Jeffrey Eugenides 's 2011 novel The Marriage Plot , which tells the story of a yeast geneticist named Leonard who suffers from bipolar disorder . He works at a laboratory loosely based on Cold Spring Harbor . The character reminiscent of McClintock is a reclusive geneticist at the fictional laboratory , who makes the same discoveries as her factual counterpart .

= = Key publications = =

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= = = Archives and research collections = = =

The Barbara McClintock Papers ? Profiles in Science , National Library of Medicine .

Barbara McClintock Papers , 1927 ? 1991 at the American Philosophical Society