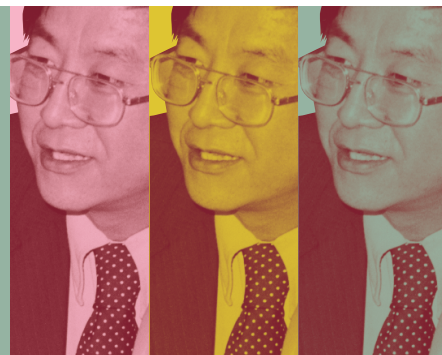
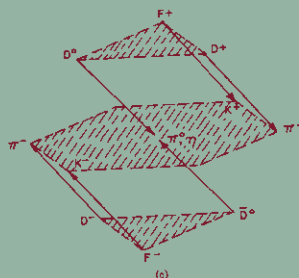
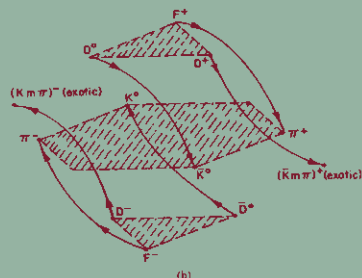
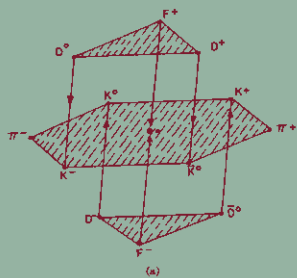




RE-REMEMBERING BENJAMIN WHISOH LEE

PROMOTER OF GAUGE THEORIES

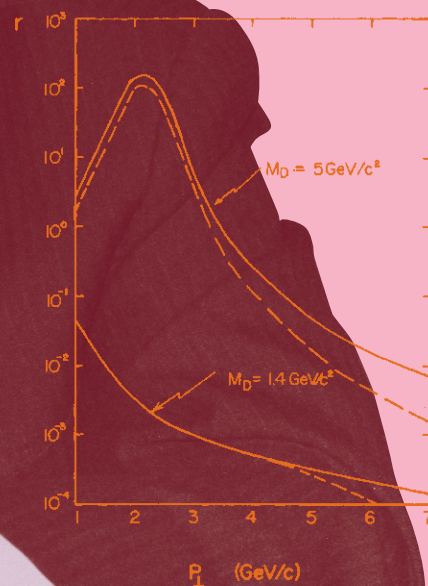
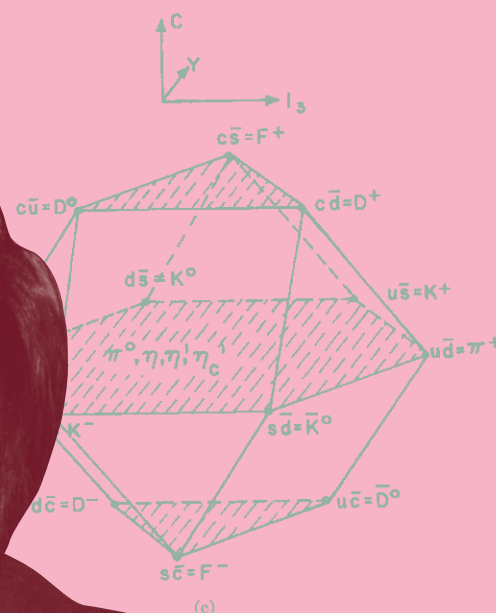
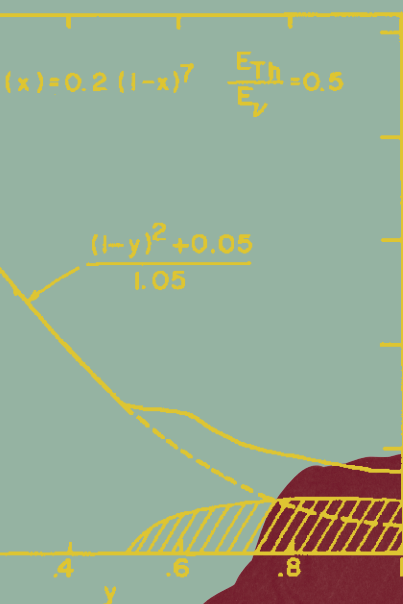


The Korean American physicist made the framework underlying the standard model accessible to a generation of particle physicists.

Eun-Joo Ahn



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Ben Lee giving a lecture titled "Development of Unified Gauge Theories: Retrospect" at the 1977 American Physical Society meeting held in Chicago. (Photo courtesy of Fermilab; figures adapted from ref. 11.)

RE-REMEMBERING BENJAMIN WHISOH LEE



A FAMILY PHOTO IN SEOUL, KOREA, taken in 1943 shows Benjamin Whiso Lee (right) at age 8. His mother Park Soonhui (left) holds his youngest brother Moo-Un, and his sister Youngja stands beside her. His grandmother holds his brother Chulwoong. (Photo © Korea University Museum.)

Gauge theories use the mathematics of symmetries to explore how subatomic particles behave. The theories have been used to predict the existence of elementary particles, including the Higgs boson, well before they've been observed and to unfurl details about the first few seconds of the universe's existence. To this day, researchers in cosmology and particle physics benefit from Benjamin Whiso Lee's contributions to the development and dissemination of gauge theories.

Well versed in mathematical and theoretical work, Ben Lee (as he was better known to his colleagues) made the demonstration of a renormalizable electroweak theory—the unified description of weak interaction and electromagnetism—accessible to other physicists. (See the article by Steven Weinberg, *PHYSICS TODAY*, April 1977, page 42.) Most physicists of the late 20th century studied his lectures rather than the original papers.¹ Lee's work was crucial, akin to Freeman Dyson's efforts to make quantum electrodynamics accessible to the physics community in the 1950s.² (See the article by Dyson, *PHYSICS TODAY*, September 1952, page 6, and reprinted January 2025, page 18.)

Lee was born in Korea in 1935 and went to the US at age 20 to study physics as an undergraduate transfer student at Miami University in Ohio. Within 10 years, he became a tenured professor at the University of Pennsylvania. Later, he

was a professor at SUNY Stony Brook and then at the University of Chicago, and he also headed the theoretical division of Fermilab. Lee's scientific contributions permeated theoretical and experimental particle physics in the 1960s and 1970s. His untimely death in 1977 in a car accident was met with shock by the international physics community. (See his obituary in *PHYSICS TODAY*, September 1977, page 76.) Though he is still warmly remembered by close friends and colleagues, his early death perhaps contributes to his obscurity today.

We can honor Lee's memory by remembering his scientific contributions in a societal context. At a time of unprecedented expansion in elementary particle physics, Lee enabled a generation of physicists in the field to embrace gauge theories. He also embodied the student immigrant who, during the second half of the 20th century, went to a wealthier and more powerful country to gain knowledge and seek a better life.

Growing up in Korea

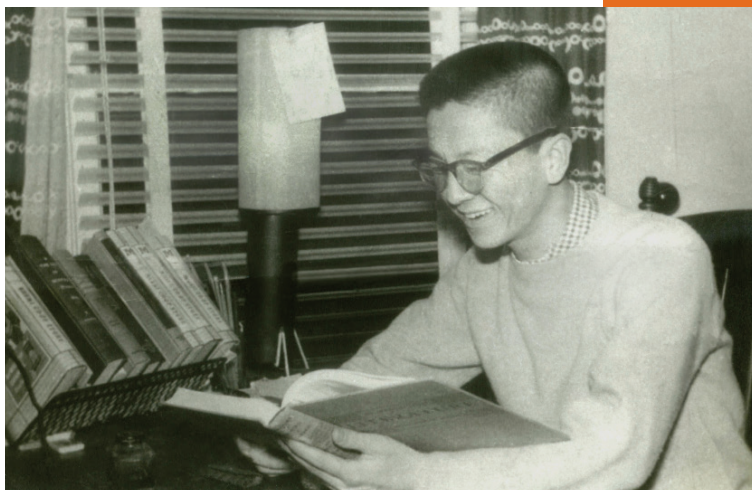
Lee Whisoh (his given name) was born in Seoul during the period when Korea was colonized by Japan, which lasted from 1910 until the end of World War II. His family—Lee, his three younger siblings, his grandmother, and his parents—lived comfortably off the income from the medical practice of his mother, Park Soonhui. Despite an increase in doctors trained in Western medicine after Japan and Western powers forced the opening of the Korean border in the late 1800s, women doctors were still rare. Park, who specialized in pediatrics, obstetrics, and gynecology, worked at a charity hospital and later opened a private practice. The family's financial security was rare among Korean families, who suffered under the repressive and exploitative Japanese occupation.

At age six, Lee entered elementary school. The colonial government's education policy in Korea was aimed at producing useful subservient labor for the Japanese Empire, which led to a segregated education system: a superior one for Japanese citizens that was on par with the education standards in Japan and an inferior one for Koreans that emphasized loyalty to the Japanese emperor. Unlike most Korean children, Lee attended a school intended for Japanese children. There is speculation, but no proof, that Park formed connections through her medical practice that enabled her son to attend the elite school.

Two years after Korea's 1945 liberation from Japanese rule, Lee took the entrance exam for the top academic secondary school in Seoul and was accepted. His academic trajectory straddled privilege and turmoil. After liberation, despite many Koreans' hope for a unified country, Korea was partitioned along the 38th parallel, with the Soviet Union administering the North and the US administering the South. The North established a Communist regime, and the South formed a democratically elected government that quickly became increasingly authoritarian. The clash between the two Koreas culminated in the 1950–53 Korean War.

In 1951, Lee's family evacuated to the Pusan Perimeter in southeast Korea, the area that South Korean, US, and United Nations forces were holding against the advancing North Korean forces. During the war years, the family maintained relative stability. Lee's parents worked as doctors, and Lee resumed attending his secondary school, which had relocated to inside the perimeter. In those times of starvation and devastation, education was a luxury denied to most families. The war took a toll on Lee and his family, especially with the loss of his father. That loss contributed to Lee hastening to finish his secondary school studies and to take the entrance exam for Seoul National University, which also had been moved inside the perimeter. In 1952, he started in the university's most prestigious and popular department: chemical engineering.

Three years of war destroyed Korea's infrastructure and left the country heavily reliant on foreign aid to provide food against famine and to rebuild the country. In South



AFTER GRADUATING FROM MIAMI UNIVERSITY in 1956, Ben Lee went on to study theoretical particle physics in graduate school. He then earned an MS degree from the University of Pittsburgh in 1958 and a PhD from the University of Pennsylvania in 1960. Lee is shown here reading a textbook in the late 1950s. (Photo © Korea University Museum.)

Korea, chemical engineering was prized as a discipline that could accelerate industrialization through development of existing textile factories and agricultural production. Physics, on the other hand, was regarded as less helpful.³

But when he returned to Seoul after the armistice of 1953, Lee became increasingly drawn to physics. Despite being the best university in South Korea, Seoul National University lacked the teachers, textbooks, and lab instruments to properly teach science. Courses in chemical engineering focused on the application side, but Lee found fundamental chemistry and basic principles more interesting. By his third year, Lee was studying quantum mechanics on his own and sought to transfer to the physics department. But he was in the College of Engineering, and the physics department was part of the College of Liberal Arts and Sciences. University regulations did not allow transfer between colleges. Ordinarily, his only option would have been to retake the entrance exam. Yet the war that devastated Korea ironically provided an alternative path for Lee to pursue physics.

That path came in the form of scholarships that were available for students to study abroad. Considered humanitarian aid, the scholarships were made available by private foundations and nongovernmental organizations, mostly in the US, that were affiliated with Christian missionaries or with military personnel. Though the scholarships were privately sponsored, they were nevertheless designed to expand US soft power and to help stop the spread of Communism in South Korea. The scholarships were often merit based and required applicants to take a test. As a student at the nation's premier university, Lee was well positioned to apply for one.

RE-REMEMBERING BENJAMIN WHISOH LEE



BEN LEE BECAME HEAD OF THE THEORY GROUP at the National Accelerator Laboratory (now Fermilab) in 1974. From left are Antonio Pagnamenta, Lee, Mary Gaillard, Shirley Ann Jackson, Robert Savit, Anthony Ichiro Sanda, Satish Joglekar, John Bronzan, and Jochen Bartels. (Photo courtesy of Fermilab.)

Lee received a scholarship sponsored by the spouses of military officers. After getting accepted as a transfer student to major in physics at Miami University, he left South Korea in January 1955 on a student visa. From the devastated grounds of Korea in the 1950s, an education in the US was a privilege only a few could attain. Lee joined other members of the emerging Korean middle class in using education to navigate the turbulent period.

A Korean student in the US

Lee did his best to acclimatize to life in the college town of Oxford, Ohio. It was his first time seeing so many white people and being on a coed campus. In an effort to better fit into US society, he gave himself an English name: Benjamin, after the American polymath and founding father Benjamin Franklin, whom Lee had learned about in Korea and admired for his empirical turn of mind.

For Lee and fellow Korean students, studying abroad generated mixed feelings of homesickness, appreciation of opportunity, and ambition to study hard. Simple chores such as going to the laundromat brought out the contrast with Korea, where laundry was still washed by hand. Regular correspondence between Lee and his family at that time reflects how much he missed them. He wrote to them about the times he got together with other Korean students on campus, visits made by Korean students from nearby cities, and homesick children he helped while working as a summer camp counselor. As the eldest son, he felt the duty to oversee his younger siblings' upbringing, even from far away, and would remind them to mind their mother and not cause trouble.

Lee studied hard and was determined to be at the top of

his class. He had outstanding professors, including George Arfken, who would go on to write the well-known textbook *Mathematical Methods for Physicists*, and took up the challenge of advanced mathematics courses. In his third and last semester, Lee became the top physics student and applied to graduate school. In 1956, Lee graduated summa cum laude and started his physics graduate studies at the University of Pittsburgh, where he had secured a teaching assistantship.

As a graduate student, Lee developed a preference for theoretical work and became interested in quantum field theory. With his adviser, Edward Gerjuoy, he systematically studied scattering processes, which became the basis of his master's thesis. Building on that work, Lee published his first scientific article demonstrating a new dispersion relation for particle scattering.⁴ Gerjuoy recommended that Lee transfer to the University of Pennsylvania to work with Abraham Klein, who was an expert on field theory and had studied under Julian Schwinger. After receiving his MS degree from Pittsburgh in the summer of 1958, Lee moved to Philadelphia. At Penn, Lee continued working on the dispersion relations of particle scattering for his PhD thesis.

Lee and his family regarded his studies in the US as an investment in a better financial and sociocultural future for them all. Though he took on some part-time jobs, especially at the start of his time at Miami University, Lee regularly asked his mother to wire him funds so he could focus on his studies. Her income was not enough to support Lee and his siblings, and the family faced increasing financial difficulties. Lee was sensitive to the hardship he was causing. In graduate school, he would send money home whenever he could spare it from his fellowship stipend or assistantship salary.



Becoming a Korean American physicist

When he first traveled to the US, Lee expected to return to South Korea with a physics degree. As time went by, though, he remained in the US. His rise in the physics community, the availability of jobs, politics in both South Korea and the US, and personal choice all shaped his ultimate decision to stay.

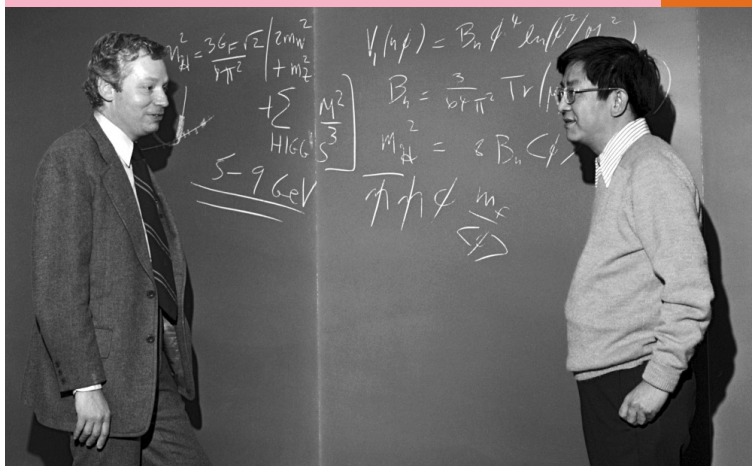
Lee's interest in elementary particles expanded in breadth and depth. Experimental physicists used increasingly powerful accelerators to further probe the nature of subatomic particles. Lee studied with mathematical rigor how particles such as kaons, pions, and nucleons scatter or interact via resonances. At Penn, he worked not only with his adviser but also with other professors, postdocs, and fellow graduate students in the department. Those collaborations led him to write eight articles—an extraordinary number for a graduate student—that were published in several high-profile journals. After filing his PhD thesis in October 1960, Lee was offered an assistant professorship at Penn. Before starting, he took a year of leave at the Institute for Advanced Study in New Jersey. There, Lee widened his pool of collaborators and continued to study dispersion relations and phenomena in strong interactions.

The opening sentence in a 1962 *Review of Modern Physics* article by Lee and colleagues aptly captures his perspective at the time: "One of the most natural questions when one looks at the mass of uncorrelated data on elementary particle interactions is whether a systematic pattern is emerging from this complexity."⁵ Lee used his impressive mathematical skills to search for and explore the consequences of those patterns. Back at Penn, he became increasingly interested in spontaneous symmetry breaking.⁶ In 1966, Nobel laureate Chen Ning Yang recruited Lee to the newly formed Institute for Theoretical Physics at Stony Brook.

Lee's academic brilliance was no doubt essential to his ascendance in the field. The state of physics during that time was also an important factor. In the aftermath of World War II, and with the onset of the Cold War, physics was perceived to hold the key to US security and prosperity.⁷ The sentiment was exacerbated when the Soviets launched the first artificial satellite, *Sputnik I*, in 1957. The scope of physics research expanded: Physicists advised the government, government agencies provided generous research funding, and graduate training in physics was deemed critical.⁸ Fueled by unprecedented funding, physics departments throughout the country expanded, awarded many PhDs, and hired faculty as never before.

Meanwhile, in South Korea, the anti-Communist president Syngman Rhee led an authoritarian and corrupt government. Rhee was ousted in a citizen-led revolution in 1960 that brought hopes of democracy. Such hope was extinguished the following year by a military coup led by Park

STEVEN WEINBERG AND BEN LEE, pictured here at Fermilab, had a fruitful collaboration that produced an early calculation of the lower bound of heavy neutrinos' mass. (Photo courtesy of Fermilab.)



Chung Hee, who established a dictatorship. Yet Korean students in the US were never regarded as political refugees the way Chinese students were when the Communist Party gained control of mainland China in 1949. Despite human rights abuses and crackdowns on democratic movements in South Korea, the US regarded the firmly anti-Communist government as a close ally.

Changes to US immigration laws opened the channel for foreign students, particularly those from Asia, to become US citizens. Legislation from the late 1800s and early 1900s had effectively banned Asian immigration. The 1952 Immigration and Nationality Act restricted global immigration in response to national security concerns fueled by the Cold War. But the legislation also abolished the earlier bans on Asian immigration, although it still retained a stringent quota. Influenced by both the civil rights movement and Cold War geopolitical concerns, the US government passed an act in 1962 that facilitated application for permanent residency by skilled workers, and in 1965, it passed the Immigration and Nationality Act that eliminated racial quotas. Korean students with advanced degrees had a choice of either returning to their home country or applying for US citizenship.

Because of those changes, Lee obtained permanent residency in 1962 and became a US citizen in 1968, the year the 1965 Immigration and Nationality Act took full effect. Lee had both personal and professional reasons to stay in the US. He had become a prominent figure in the US particle-physics community, and he kept up with new theoretical and experimental developments. If he had returned to South Korea, he would have had to build a professional community essentially from scratch. Also, his wife Marianne, a Chinese Malaysian medical student, and their children would have been treated as perpetual foreigners. At the time, those considered foreigners—which included people who were half Korean—faced sociocultural hostility and discrimination upon settling down in South Korea.

RE-REMEMBERING BENJAMIN WHISOH LEE

An impactful career

After the 1956 discovery that the weak force does not operate with mirror symmetry (see the article by Chon-Fai Kam, Cheng-Ning Zhang, and Da Hsuan Feng, *PHYSICS TODAY*, December 2024, page 28), the particle-physics community began investigating the suspected connection between weak and electromagnetic interactions. Working independently, Sheldon Glashow, Abdus Salam, and Steven Weinberg developed a formalism that unified electromagnetism and weak interactions. That work would later earn them the 1979 Nobel Prize in Physics (see *PHYSICS TODAY*, December 1979, page 17). But the model required renormalization—a mathematical redefinition of calculated quantities such as mass—to make the infinities that arise in the calculations become finite.

By the early 1970s, the community started to recognize how the Glashow-Weinberg-Salam theory could be renormalized. Lee had the breadth of knowledge needed to examine mathematical approaches, including his own contributions, that laid the groundwork for unified gauge theories. With Jean Zinn-Justin, he published a series of articles that demonstrated the renormalizability of spontaneously broken gauge theories.⁹

Lee was one of the first physicists to recognize the significance of work by Gerard 't Hooft and Martinus Veltman, who received the 1999 Nobel Prize in Physics for demonstrating the renormalizability of the Yang-Mills theory (see *PHYSICS TODAY*, December 1999, page 17), which describes electroweak and strong interactions. With the depth of knowledge needed to grasp the complexities of the work and to synthesize a coherent explanation of gauge symmetries, Lee gave a series of lectures at Stony Brook on gauge theories. Based on those lectures, Lee and his colleague Ernest Abers compiled a review article that became the authoritative source for the study of gauge theories.¹

The long boom of US physics research in the 1950s and 1960s, enabled by generous funding from government agencies because of the Cold War and the space race, was followed by a bust in the early 1970s. In the face of a costly Vietnam War, détente with the Soviet Union, and economic stagnation, federal funding for defense and education declined, and government agencies rapidly decreased physics funding. Research money dried up, and faculty and post-doctoral job openings disappeared.

Even during those hard times, Lee was in demand. In the suburbs of Chicago, experimental particle physicist Robert Wilson was leading construction of the National Accelerator Laboratory (now Fermilab) in the face of retrenchment. Wilson and deputy director Edwin “Ned” Goldwasser were eager to recruit Lee to head the nascent theory department. Well versed in the theoretical and experimental developments related to gauge theories and weak interactions, Lee considered it an attractive opportunity.

A photograph taken at Fermilab in 1974 (see page 40) shows some of the members of the theory group, which was more diverse than most particle-physics groups at the time. According to colleagues at Fermilab, Lee did not discriminate based on gender or race; he wanted group members of the highest caliber. The small group cannot fully represent a cross section of the demographics of particle physicists in the 1970s, but it does show that the US physics community was far from homogeneous. What cannot be shown is the myriad discriminatory barriers faced by members of marginalized groups who sought to become research physicists.

Fermilab’s theory group thrived. Lee’s extensive knowledge of theoretical and experimental work in particle physics drew many visitors and collaborators. Chris Quigg and William Bardeen joined the department as senior members, which further enriched the research program. A collaboration between Lee and Mary Gaillard formed spontaneously when the latter was a visiting scientist at Fermilab. Together they produced a number of influential works, including an evaluation of the effects of strong interaction on weak decay of mesons and a prediction in 1975 of the charm quark mass.^{10,11}

“One of the most natural questions when one looks at the mass of uncorrelated data on elementary particle interactions is whether a systematic pattern is emerging from this complexity.”

Robert Shrock found the ambience of the Fermilab theory group exhilarating, and he was greatly inspired by Lee in the collaborative research they did together. Their work included examining the interaction of charged and neutral leptons. They showed that the electroweak theory naturally suppresses flavor mixing, and that condition extends to cases for neutrinos with nonzero mass.¹² In another area, Bardeen, Lee, and Shrock obtained nonperturbative results for the nonlinear sigma model.¹³ Such work expanded the understanding of the standard model of particle physics.

Weinberg, who typically preferred working alone, recalled that he made an exception for Lee, with whom he enjoyed collaborating.¹⁴ One of Lee’s last projects was with Weinberg; they derived a lower bound for the mass of stable cosmological leptons, which include neutrinos and other neutral particles that may constitute dark matter. Known as the Lee-Weinberg bound, it informs today’s dark-matter searches.¹⁵

Lee was at the top of the world in particle physics. Gaillard cited Lee’s “rare combination of a familiarity with formal



A FEW MONTHS AFTER BEN LEE'S UNTIMELY DEATH, the particle-physics community celebrated his memory and accomplishments at the Ben Lee Memorial International Conference on Parity Nonconservation, Weak Neutral Currents and Gauge Theories on 22 October 1977 at Fermilab, outside Chicago. (Photo courtesy of Fermilab.)

mathematical techniques and a close touch with experimenters and experimental results" as attributes that enabled him to stay at the forefront of a wide range of research topics.¹⁶

As his career advanced, Lee remained ambivalent about his relationship with South Korea. Disapproving of Park Chung Hee's dictatorship, he kept few to no professional contacts in the country. Even so, in 1974, he helped with an evaluation conducted by the US Agency for International Development that explored strategies to help Seoul National University develop graduate education. Self-described in that report as "Korean—by birth, and an American—by choice and citizenship," Lee combined his insights about the Korean university environment and US higher education. He offered recommendations that spanned issues like faculty salaries, graduate coursework, and library resources.¹⁷

Lee's legacy

On 16 June 1977, Lee died in a car accident on his way to the Fermilab Program Advisory Committee meeting in Aspen, Colorado. He was one of the organizers of a meeting on weak interactions and gauge theories that was going to be held at Fermilab in October of that year. The conference name was changed to the Ben Lee Memorial International Conference on Parity Nonconservation, Weak Neutral Currents and Gauge Theories. His family and colleagues established the Dr. Benjamin Lee Memorial Scholarship at Miami University in his memory. Electroweak theory became an accepted component of the standard model of particle physics, greatly aided by Lee's promotion and teaching of it to his colleagues. Yet Lee's name nevertheless slowly faded away in the physics community.

Lee's remembrance took an unusual turn in South Korea decades after his death. Sometimes exaggerating his achievements and sometimes conflating the field of theoretical particle physics with nuclear physics or engineering, scientists and media portrayed him as a genius patriot whose untimely death tragically precluded him from receiving the Nobel Prize in Physics and helping with the development South Korea's science and engineering programs. Scholars have pointed out that Lee's life was mythologized into a Korean success story, in which he overcame his home country's impoverished circumstances to become a world-leading authority in an impossibly difficult field.¹⁸

Calling Lee a genius who missed out on the Nobel Prize captures only a narrow slice of who Lee was. Even the description of him as the promoter of gauge theories acknowledges just one of his facets. He was eager to advance the field and treated his colleagues equally regardless of gender, race, or position. Weaving together his numerous contributions to the development of today's standard model of particle physics with his navigation of the geopolitical and sociocultural landscape offers a richer understanding of how physics knowledge is made.

I am grateful to Robert Shrock, Liz Quigg and Chris Quigg, and Marge Bardeen and Bill Bardeen for sharing their memories of Ben Lee. I am also grateful to Ned Goldwasser and Lizie Goldwasser who, before their passing, shared their recollections of recruiting Lee to Fermilab. I thank the anonymous reviewer and Valerie Higgins at Fermilab Archives.

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