Leon Henkin

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Abstract Leon Henkin was born in 1921 in Brooklyn, New York, in the heart of a Jewish family that originally came from Russia. He died at the beginning of November in 2006. He was an extraordinary logician, an excellent teacher, a dedicated professor, and an exceptional person overall. He had a huge heart and he was passionately devoted to his ideas of pacifism and socialism (in the sense of belonging to the left). He not only believed in equality, but also worked actively to see that it was brought about.

Keywords History of logic · Biographical studies of mathematicians · Foundational studies in logic · Henkin

1 Life[1]

Leon Henkin was born in 1921 in Brooklyn, one of the five boroughs of New York City, in the heart of a Jewish family that originally came from Russia. His second name was Albert, but he never used it in publications. In a footnote to one of his biographical papers, *The Discovery of my Completeness Proofs*, Henkin tells the story of his middle name:[2]

> In fact, he (father) had shown his high expectations for me at the time of my birth by choosing my middle name to be “Albert”. He once told me that at that time (April 1921) the *New York Times* had run a series of articles publicizing Einstein’s revolutionary theory of relativity, so my father decided to borrow Einstein’s first name for his newborn son.

Leon’s oldest uncle Abraham was the first in the family to emigrate from Gomel, in White Russia, and became a doctor in the USA. After saving some money, he was able to bring Leon’s father to the States and later he brought Leon’s grandmother and aunts as well.

In 2009, during a short visit to California, I (María Manzano) had the happy opportunity to interview Ginette Henkin, Leon’s wife. Steve Givant and I visited her at her Oakland apartment and she drove us to a restaurant where we had lunch. Ginette told us that Leon belongs to a very close-knit family: in the first place because they belong to a tradition where family relationships were important, but also because they were immigrants and the new families they formed were also related by family links, as two brothers

[1] Information for writing this section was mainly provided by Leon’s family: his wife Ginette, his oldest son Paul, and his youngest son Julian. Unfortunately, Ginette passed away in June 2012. Other sources are [1] and [39].

[2] In [29, p. 150, footnote 30].

© Springer International Publishing Switzerland 2014
M. Manzano et al. (eds.), *The Life and Work of Leon Henkin*, Studies in Universal Logic,
DOI 10.1007/978-3-319-09719-0_1

married three sisters. Leon's oldest uncle married one sister and Leon's father married another sister; when Leon's mother passed away, his father married a third sister. These women were also immigrants from White Russia whose father was a doctor. In Leon's son Paul words [32] *'Perhaps all these doctors explain his lifelong fascination with health and dentistry. Well into his eighties, he would exercise…'.*

He lost his mother shortly after the birth of her daughter Estelle, almost five years younger than him. Leon was very close to his cousins, they lived nearby, and grew up together in Brooklyn. There are several stories in the memorial documents ([32] and [10]) referring to playing in the streets with other kids. His son Paul told us [32], that *'In Brooklyn, he was nearly run over by a milk truck while playing stickball in the street.'* Most of his early education was in the NY public schools; he went to Lincoln High School, which produced a lot of mathematicians that year.

Leon's family was socialist, they were all supporters of Norman Thomas, an American minister who achieved fame as a socialist, pacifist, and six-time presidential candidate for the *Socialist Party of America*. The family was not religious, and even the grandfather (who was a Hebrew scholar) was not very observant, but they strongly kept the Jewish tradition. It seems that the family rigorously observed the Passover Seder, probably because the Seder is conducted in the family home, while other Jewish holidays revolve around the synagogue. On such occasions, it is customary to invite guests, in particular strangers and the needy.

In the aforementioned interview, Ginette gave us a nice headline concerning how she met Leon the first time: *Two couples met at same weekend.* The two couples were Leon and Ginette Henkin and Harold and Estelle Kuhn. The story goes like this: Leon and Estelle travelled to Montreal for the September Labor Day weekend (1948); Leon was driving a friend (Harold Kuhn) from gradschool who wanted a lift and so he introduced Harold to Estelle. The three of them and Maurice L'Abbé went to Montreal; during their stay there Leon met Ginette. Estelle, L'Abbé, Ginette, Leon and several others had dinner together and went dancing afterwards. In December that year, Ginette took a first plane ride to NY (Leon invited her) and she stayed in father's and Estelle's place. Ginette was 25 when they married in 1950; she was a Catholic with a western style education. According to David Gale [10], a colleague and co-student at Princeton University, *'In graduate school he was well known for being "anti-marriage". "I oppose it in all forms" he told me when I asked him about his views on the subject.'* However, after the mentioned trip to Montreal he had a life changing experience. *'One day shortly after returning to Princeton we were talking about this and then to my surprise Leon said "Maybe I'll get married and see what that looks like". As we know, he did and from all indicators it turned out to look pretty good!'* Ginette was a wonderful person and an excellent cook, as we can attest. Ginette and Leon had two adopted sons, Paul and Julian, in 1957 and 1959. Julian said: '*I would characterize my father as the most supportive parents and persons I have known.* […] *My father was a very good driver. He could handle long driving shifts on family trips.*' Julian also said that Leon forced them to learn, as he always was in a teacher role, thus '*It would not surprise me to know that all of his students have that Leon-instilled confidence*' [10].

On several occasions Leon attended his children's school to '*introduce us six-year-olds to negative numbers*' or '*subtraction by addition*'. One classmate of Leon's son Julian told us: *'The first thing Mr. Henkin asked was whether it was difficult for us to remember to carry a number in addition and to borrow a number in subtraction. We second graders, responded, "Yes". Mr. Henkin went on to say that we should not worry about that because* *he was going to teach us a way to do subtraction without borrowing. It was doing subtraction by addition.'* Henkin's enthusiasm and understanding of just how much to challenge younger age groups was a rare gift.

Paul, in his *Proposed Memorial Oration*, also told us about a terrible experience the family had to face: *'In 1969, I had a brain tumor removed and all sorts of complications, and barely survived, but my parents poured time, resources and energy into my care. Meanwhile, my mother supported my father's career in all sorts of ways, from giving dinners and parties for academics and students alike to working on faculty groups distributing supplies to foreign and minority students.'*[3]

When Leon had his own family, they used to celebrate Passover. Bill Henkin (Jr.), his first cousin once removed said: *'I actually learned a great deal about the purpose of religion from his approach to Pesach because his attention at this holiday was not on a capital G—God—of any sort, his concern was clearly for the people around him at those times, as well as for people who could not be present, and he enrolled us all in his approach and thoughts as he enrolled students in mathematics in his other, better-known roles as an educator.'* According to Cliff Kuhn, Leon's nephew, the eldest son of his sister Estelle, *'He was THE central bridge in our family, reaching across continents and generations to make and strengthen family connections, and serving as custodian of the family's history.'* In Nicholas Kuhn's, the middle son of Estelle, words: *'I own two books given to me by my uncle Leon. The first is "Geometric Algebra" by Emil Artin.* [...] *The second book is "The Apted Book of Country Dances"*.[4]

Leon and Ginette were always happy to invite students and colleagues to their home. Their broad interests in politics, education, and arts, plus good wine and excellent cuisine always made the stay a memorable one. They first lived in an apartment on Virginia Street and later on moved to a house on Maybeck Twin Dr. in Berkeley. As some colleagues attested: '[...] *in 1955, the Henkins were among the first people in the math department to invite us to their home* [...]. *I was much impressed with the all-white décor of their livingroom and diningroom, and with the charm and sophistication of Leon and Ginette.'* I (María Manzano) was invited on two unforgettable occasions to his simple, vanguard, and minimalist home in Berkeley Hills, decorated with exquisite *objects d'art*, among which those from American Indian cultures were outstanding. The view from his living room was breathtaking, with a gorgeous sight of the Golden Gate of San Francisco. Henkin actually died in Oakland, since some years previously he had to move there with his wife Ginette, leaving behind his beautiful home.

I could also appreciate the couple's good taste during the preparation of their visit to Barcelona. The *Hotel Colón* was chosen by me as a venue and the couple agreed to this since Ginette and Leon preferred a local touch: *'Both of us share your preference for a place with distinctive Spanish character, rather than the ugly, commonplace international style that infects big cities'*.

Leon's fondness for dancing, both ballroom and modern, is well known. According to Ginette, Leon was extremely shy when he was young. At that time boys and girls only met on weekends to dance; as there were more girls than boys, he was forced to dance. When he connected music and steps he became a dance lover and remained one all his

[3] See [32]. The *Faculty wives equipment loan center* is a very useful organization. In 1977, when María Manzano was in Berkeley with a Fulbright grant, she was able to loan dishes and sheets from them.

[4] In this paragraph, all the quotes are taken from [10].

life. In some of the anecdotes compiled at his death, *Many views of Leon Henkin*, some people refer to this. His son Paul ended his *Proposed Memorial Oration* with these words: *'In closing, I must make mention of his love of dance. Music too. One of my last memories of him was his feet trying to dance under the covers.'*

Ginette told us *'He used to go solo camping for a week, started this around age 60. But one year he got lost around Mammoth Lakes and he never went solo camping again after that.'*

Henkin was also interested in literature. In 1983, in a personal letter to me, in reply to me praising the novel *Rabbit is Rich* by the newly awarded Pullitzer Prize winner John Updike, Henkin writes: *'I am glad you enjoyed the language of Updike's writing. I took a volume of his stories on my camping trip last summer, and I admired his writing very much. I still have my school-boy dream of becoming a story writer, but I'm aware I could never achieve such a master style as Updike.'* Ginette gave me a short story written by Leon, *A Walk*, in which a fifteen-year old Leon takes a memorable walk for the first time in his life. *'So far as he remembered he had never done such a thing before. Until the age of twelve, he had played in the street, after school, with the other boys.'* During the walk he saw three girls, the blonde hair intrigued him, she and the picture of a certain tree remained in his mind. *'No, he did not sleep. He lay in bed, with his eyes wide open, thinking, staring, far into the night.'*

Leon was always on the chess team in high school and college. He avoided games of chance, preferring to encourage thinking. He liked blindfold chess, go, and scrabble. He had speech trouble with r, so while he was at Columbia the family sent him to speech therapy. The difficulty disappeared, but he had a slow and peculiar pronunciation. Anyway, he was such an eloquent, creative, and persuasive teacher that this slight oddity became unnoticeable as soon as he went on talking.

Henkin was a politically committed person, he was passionately devoted to his ideas of pacifism and socialism (in the sense of belonging to the left). Paul told us that early in the fifties he was participating in political groups: *'Next year, he became a professor of math at USC, and he stayed in California thereafter. There, he also became involved in a political club where he was beaten for president by Jess Unruh, the future Speaker of the Assembly.'*[5]

Henkin did not wish to visit Spain during the Franco era, but after November of 1975 this was fortunately no longer the situation. His first trip was in 1982 and he visited several Spanish Universities, such as Barcelona, Madrid and Seville. He wished to know all about Spain, especially its social and political developments, and in 1982 he commented: *'Yes, we too were very pleased with the clear and strong victory of the Socialist Party in Spain.* [...] *we were worried about the role of the military, and relieved that they did not interfere'*. In turn, I (María) was always informed about the developments in his country: *'Our own election in California was a disaster, with a new Governor and Senator, each more conservative than the other. The State is in a fiscal crisis and I'm afraid the University will be in for a rough time...'*. He bewailed the absence of international news in the American press and in July 1984 he wrote: *'I recall your Spanish election in the week following our visit in 1982. I hope that your new government is working out well...we get little news of Spain in our journals.'* In the same letter, he told me that for the first time in American history a woman

[5] See [32].

had been nominated as Vice-President of the Democratic Party. However, he was saddened by the fact that Reagan might win the election again, as in fact happened. Today he would possibly have been thrilled by the role played by Barack Obama and Hillary Clinton.

According to Ginette, Leon's life was the university, it was his baby. In fact, when he died he left some money to the university. Ginette also said that he wanted to be an academic early in his life, partially because he didn't want to think about money.

He died at the beginning of November in 2006, as we are told by mutual friends, from the same cause as the great mathematician Eratosthenes of Cyrene.

In the obituary in the *San Francisco Chronicle* (Monday, November 20, 2006 [6]), the logician J.W. Addison, at that time an emeritus professor in the same department of the University of California at Berkeley, we read: *'You could say he was an academic triple threat—very strong in teaching, very strong in research, very strong in administration.'*

What kind of effect did Leon Henkin have on the world? That was the main question we asked ourselves. To answer it, we have investigated not only his research, but also his teaching, as well as his contribution to the development of logic in a broader sense. He made great efforts to disseminate mathematics and logic to a wider circle of students. As far as we are beings immersed in history, we have tried to reproduce his mathematical and social environment in order to contextualize his contributions.

In the following sections we discuss Henkin's academic life as well as his social activism.

2 Graduate Studies at Columbia University

Between 1937 and 1941, Henkin pursued his undergraduate studies at Columbia College in New York City obtaining a diploma in mathematics and philosophy. His father then moved uptown because he didn't want Leon to commute. Henkin lived in this new home for four years before going to Princeton, and it was during that time when he became interested in logic. Let us quote the first two paragraphs of his 1962 paper, *Are Logic and Mathematics Identical?*, which won the prestigious Chauvenet Prize in 1964.

> It was 24 years ago that I entered Columbia College as a freshman and discovered the subject of logic. I can recall the particular circumstance which led to this discovery.
> One day I was browsing in the library and came across a little volume by Bertrand Russell entitled *Mysticism and Logic*. At that time, barely 16, I fancied myself something of a mystic.
> [...]
> Having heard that Russell was a logician I inferred from the title of his work that his purpose was to contrast mysticism with logic in order to exalt the latter at the expense of the former, and I determined to read the essay in order to refute it.[6]

While at Columbia, Henkin took a course in logic with Ernest Nagel in the Dept. of Philosophy, and this led him to become interested in the field to the point where he even read Russell's *Principles of Mathematics*. It was in that book that he first have read about the axiom of choice, and he tells us that he was impressed by the amusing and intimate way Russell used to explain it, contrasting how easy is to choose a shoe from an infinite collection of pairs of shoes, with how difficult it is to choose a sock from an

[6]See [21].

infinite collection of pairs of socks. Russell's book inspired him to read the *Principia Mathematica* of Russell and Whitehead [38], and he became infatuated with the theory of types and the axiom of reducibility. He then took another course on logic with Nagel, during which he read an article by Quine, containing a proof of the completeness theorem for propositional logic. Let us quote him:[7] *'As to the concept of completeness which was the focus of Quine's paper, it did not get through to me. I simply noted that the aim of the paper was to show that every tautology had a formal proof* [...] *the result was that I failed to get "the idea of the proof", the essential ingredient needed for discovery.'*

He also had the chance to listen to a lecture by Tarski concerning Gödel's work on undecidable propositions in type theory. (Tarski travelled to America in August of 1939 to attend the Unity of Science Congress being held at Harvard that year. The German invasion of Poland on September 1 prevented him from returning home.) However, Henkin's first deeper contact with the work of Gödel arose from a sort of reading seminar he took with F.J. Murray—a collaborator of von Neumann—to study Gödel's results on the consistency of the continuum hypothesis. Henkin said:[8] *'As far as I can recall, Murray and I had one or two meetings to discuss the scope and the beginning of the work, and then he found himself too busy with other projects and I was left to work through Gödel's monograph on my own.'* At that time, Henkin had still not graduated from Columbia, but he was the only student who seemed to be interested in these issues, and who was prepared to invest time and energy to study them.

Upon finishing his studies at Columbia, he applied for admission to several universities where logic was well established: Harvard (where Quine was), Princeton (where Church was) and Columbia. Nevertheless, as he stated during an interview held much later (on May 18, 1984) in Berkeley.

> Those are the places [Harvard, Princeton, and Columbia] to which I made application. I was accepted at all places, but Harvard did not offer any financial help. Both Princeton and Columbia did. My Columbia professor said, "Well, you've been around here. You know, you've learned from us. Here is this exceptional logician, Alonzo Church, at Princeton. Why don't you go there?" So I did. Happily ever after, as they say.[9]

3 Doctorate Studies with Alonzo Church

The Completeness of Formal Systems[10] is the title of the doctoral dissertation that Henkin wrote at Princeton in 1947 under the direction of Alonzo Church. Chapter "Henkin on Completeness" of this book is devoted to this topic, so we will limit ourselves here to a discussion of his previous training in logic under the supervision of Church.

It was at Princeton University that Henkin followed his master's and doctorate studies, although between the two, he worked on the famous Manhattan project, an initiative of the United States government with the collaboration of Canada and the United Kingdom.

[7] In [29, pp. 129–130].

[8] In [29, p. 131].

[9] See [36].

[10] The thesis was never published, but the results were published in several papers; the more directly related are [11], and [12].

During his initial term at Princeton, he followed a course in logic given by Church in which both propositional and first-order calculi were studied and normal form and completeness theorems were proved for them, and the Löwenheim–Skolem results were analyzed. The completeness proof was that of Gödel (Henkin's, obviously, still did not exist) and the *reductive nature* of the proof was remarked on—namely, that the problem of completeness for first-order logic was reduced to that of completeness for sentential logic using Skolem's normal form. During the second semester, a second-order language was studied and, in particular, Peano Arithmetic was introduced in great detail, and the results of incompleteness were proved, both for arithmetic and second-order logic. To prove incompleteness, recursive functions were introduced, although only the primitive ones. General recursive functions were not studied, but the role they play in the proof of certain results of undecidability was mentioned. Henkin tells the reader in [29] that although the content of the course was not, in the least surprising, what was striking was the style of Church, the way he had of transmitting his conception of logic. It appears that he would make frequent halts in his discourse to clarify the idea that he was following the *"logistic method"*: clearly delimiting what was language and what was metalanguage; stressing how the formal language should be established in a completely effective way, and why the metalanguage (English, in his case) should be limited. One can gain an idea of Church's style by reading his book *Introduction to Mathematical Logic, vol I*.[11]

The Frege theory about the notions of *sense and denotation*[12] were the topic of a seminar that Henkin followed with Church when he (Henkin) returned from his four years of service. Henkin affirms that in that seminar Church convincingly defended the notion that in addition to the formal language and the universe of mathematical objects in which we interpret the formulae of the language, there is a third dimension of abstract objects, namely concepts or senses. A sentence expresses a proposition but also names a truth-value. Henkin writes: *'Under this theory a symbolic expression functioning as a name denotes an object of the universe of discourse, and expresses some sense of that object; a sentence is construed as a name of its truth value, and the sense it expresses is called a proposition.'*[13]

3.1 The Princeton Mathematics Community in the 1930s

In an interview from the series entitled *"The Princeton Mathematics Community in the 1930s"* [36], Henkin recounts an amusing anecdote about his years at Princeton. Professor Alfred Tucker asked him to create a sort of disturbance on the last day of the academic year: *'Like every great teacher he wanted some dramatic incident to imprint the course on the minds of the young students."*

So Henkin started dancing around and contorting himself before his classmates, whose eyes bulged because they were unaware of the theatrical nature of the event and were

[11] The second volume, whose index appears in the first, was never published, although some of its chapters were circulated among his students.

[12] Probably Church explained in class what was to become his paper [5] on that subject.

[13] See [29, p. 142].

unable to understand his lack of respect towards his teacher. He ended up by removing his waistcoat without taking off his jacket!

There are other interesting anecdotes in these interviews ([36] and [37]). Here is one that had to do with a conflict he felt about two different approaches to teaching: presenting the topics clearly to students or forcing them to make an effort: '*That effortless way in which the ideas came made them too easy to slip away. I probably learned more densely packed material from what we called the "baby seminar", in point set topology conducted by Arthur Stone. I learned more because he made us do all the work.*'

In relation to that same seminar, he describes the following exchange with Professor Lefschetz, which reveals how self-confident Henkin was, even as a graduate student:

> I was giving my solution to one of the problems that Arthur Stone has set to me before, and being a logician I wanted to make all the details very clear and Lefschetz became impatient. As I got into some of those details he said, "Well, that's all obvious. Just go on toward the end." I was a very brash young man. I said, "Professor Lefschetz, it may be obvious to you, but I have come from an environment where a proof requires us to give all the details." And I just went ahead.

3.2 The Second World War

In an interview from the above mentioned series, Henkin recounts how the atmosphere of relative calm with respect to WWII changed radically towards the end of 1941, when America entered the conflict after the bombing of Pearl Harbor on December 7, 1941. He tells us that he came upon Mrs Eisenhart in the street, and we learn that in their conversation she said: '*We must all do our duty and get on with it.*'

Henkin says that very soon everybody was expressing similar opinions. He also mentions that his professor, Herman Weyl, decided not to change his work schedule and that he (Henkin) was positively impressed by this:

> I also remember that I had a lecture by Hermann Weyl that same morning, Monday the 8th. It was 9:00. He said, "I know that all of you are very excited and upset and cannot let go of these great world events that have engulfed us". But, he said, "I've learned from my experience that in the most tempestuous of times, there is a great value in giving some of your attention and your energy to your continuing work". Therefore, he said, "I am just going to give the regular lecture now that I planned with you last week." So he did, and I think there is something of real value in those opening remarks.[14]

Like many scientists, Henkin felt that he had to be committed and he worked for four years on the Manhattan project. The project gathered together a large number of eminent scientists—including exiled Jews, pacifists and people on the Left—, many of whom joined the cause against fascism and contributed to the mission of developing an atomic bomb before the Germans. As he tells us: '*During the period May, 1942–March, 1946, I worked as a mathematician, first on radar problems and then, beginning January 1943, on the design of a plan to separate uranium isotopes. Most of my work involved numerical analysis to obtain solutions of certain partial-differential equations.*'[15]

[14] See [36].

[15] In [29, p. 132, footnote 11].

4 Service to the Department and to the University

Tarski arranged for Henkin to be offered a tenured position in the Mathematics Department of the University of California at Berkeley in 1952, but Henkin refused the offer because of the controversial loyalty oath that was required of all professors at the University of California at that time.[16] When the oath was no longer required in 1953, Henkin accepted Tarski's offer and went to Berkeley. He valued the role of Tarski very highly as regards his own decision to come to Berkeley. On 30 October 1983, in a personal communication to María Manzano he wrote: *'I write to tell you that Alfred Tarski, who came to Berkeley in 1942 and founded our great center for the study of logic and foundations, died Wednesday night (Oct. 26), at age 82. All through this year he has been getting weaker; his wife Maria worked heroically to comfort and protect him, but finally he gave up his life* [...] *It was he who brought me to Berkeley in 1953, so I owe much to him personally as well as scientifically.'*

Feferman [7] explains how Tarski's general conception of logic, as the quintessential interdisciplinary subject, urged him to campaign on behalf of it from his base at the University of California in Berkeley.

> The first order of business was to build up a school in logic bridging the university's Mathematics and Philosophy Departments, and the opening wedge in that was the hiring of Leon Henkin as Professor of Mathematics in 1953. From then on, Henkin was Tarski's right-hand man in the logic campaigns, locally, nationally and internationally, but he had other allies, both in Mathematics and in Philosophy. The first goal was to increase the proportion of logicians on the mathematics faculty to 10 % of the whole; that took a number of years, eventually achieved with the appointment of Addison, Vaught, Solovay, Scott, Silver, Harrington and McKenzie. Through his influence in Philosophy, he succeeded in recruiting Myhill, Craig, Chihara and Sluga.[17]

Assembling together a number of logicians, mathematicians, and philosophers from the departments of mathematics and philosophy, Tarski and Henkin created an interdisciplinary group called the *Group in Logic and the Methodology of Science*. In 1957, they initiated a pioneering interdisciplinary graduate program leading to the degree of Ph.D. in *Logic and the Methodology of Science*. They were able to organize several very important meetings on logic in the Bay Area: the conference on *The Axiomatic Method in Mathematics and Physics* at U.C. Berkeley in 1957; the *First International Congress for Logic, Methodology and Philosophy of Science* that Tarski presided over at Stanford University, in 1960; and the very important *Theory of Models* conference at Berkeley in 1963. Henkin was the driving force behind the organization of the Tarski Symposium at Berkeley in 1971, honoring Tarski on the occasion of his 70th birthday. In 1983, a meeting of the Association of Symbolic Logic was held at Berkeley, and Alonzo Church gave an invited talk on intensional logic: *'a subject he was beginning to study as I was finishing my studies with him in Princeton, some 35 years ago'*, Henkin told María Manzano in a private letter. Feferman says: *'In a sense the Logic and Methodology congresses are an intellectual descendant of the Unity of Science movement, but now with logic at the center stage, very much in tune with Tarski's conception of logic as a common basis for the whole of human knowledge'*.

[16] In his contribution to this volume (Chap. "A Fortuitous Year with Leon Henkin"), Solomon Feferman explains a little bit The Loyalty Oath, whose main requirement was to force people to declare they were not members of the Communist Party.

[17] See [7, pp. 5–6].

Henkin was chairman or acting chairman of the Department of Mathematics at the University of California at Berkeley on at least two occasions: during 1966–1968 and during 1983–1985. Although it seems strange, the second period was more complicated than the first, in 1983 he wrote:[18] *'It is much harder now than when I served during 66–68. One big difference is that the University budget has suffered greatly through a combination of political and economic conditions.* [...] *I send a clipping from our student newspaper—on the first day of our academic year—describing some of the problems. (The Dean was unhappy, but the Chancellor gave us $20,000 more to open 2 new courses!).'*

In that clipping from the *The Daily Californian* [35], the situation is explained and the writer tells us that Henkin and the Vice-Dean David Goldschmidt had sent a letter to the Republican Governor George Deukmeijian in which they set forth their demands. The situation deteriorated to the extent that a year and a half later Henkin said he wanted to resign, although he was eventually convinced to carry one for a further year.

5 His Research

Leon Henkin has left behind as his heritage an important collection of papers, filled with exciting results and very original methods. One example is the paper containing his innovative and highly versatile method for proving the completeness theorem—both for the theory of types and for first-order logic—a method that was applied later to many other logics, even non-classical ones. For some of his results we know the process of discovery,[19] what observed facts he was trying to explain, and why he ended up discovering things that were not originally the target of his enquiries. In these cases we do not have to engage in risky business of trying to explain the origins of his ideas merely on the basis of the final scientific papers that presented them. It is well known that the *logic of discovery* is often hidden in the final exposition of our research through their different propositions, lemmas, theorems and corollaries.

5.1 Completeness

If you take a look at the list of publications Leon Henkin left us (Appendix of this book), the first published paper, *The completeness of first order logic* [11], corresponds to his well known result, while the last, *The discovery of my completeness proof* [29], is an extremely interesting autobiographical one, the two papers forming a sort of fascinating loop around his career.

For a countable first-order language the completeness proof proceeds in two steps. First, every consistent set of formulas is extended to a maximal consistent set with witnesses. Second, once we have the maximal consistent set with witnesses, we use it as a guide to build the precise model that the formulas of this set are describing; the universe of the model being the set of witnesses or a set of equivalent classes. According to Monk [33]: *'He also used the above basic idea to a generalization of ω-consistency* [15]

[18] Personal letter to María Manzano.

[19] Explained in his [29].

and ω-completeness [18]*, to results concerning the interpolation theorem* [23]*, and the representation theorems for cylindric algebras* [17]*'.*

Several chapters of this book deal with Henkin's completeness theorems (Chaps. "Henkin's Theorem in Textbooks" and "Henkin on Completeness") and its extensions to different logical systems (Chaps. "Henkin's Completeness Proof and Glivenko's Theorem", "From Classical to Fuzzy Type Theory" and "Henkin and Hybrid Logic"). Henkin's method, as well as an abstract setting of Henkin's proof, are also treated in this book (Chaps. "The Countable Henkin Principle" and "Changing a Semantics: Opportunism or Courage?").

5.2 Algebraic Logic

Henkin devoted a large portion of his research to algebraic logic. Tarski and Henkin believed that logic investigation was interesting in and of itself, since it could provide unifying principles for mathematics, *'In fact we would go so far as to venture a prediction that through logical research there may emerge important unifying principles which will help to give coherence to a mathematics which sometimes seems in danger of becoming infinitely divisible.'*[20] The promotion of research in logic (algebraic logic in particular) also had the aim of attracting the interesting of mathematicians. Let us quote Feferman [7] *'I believe that it was because Tarski thought that formal syntax and metamathematics were principal obstacles to mathematicians' appreciation of, and interest in, logic that he was led to work on the algebraic reformulations of logic in terms of Boolean algebras, relation algebras and, finally and most extensively, cylindric algebras.'* Feferman also cites other interesting quotes *'from a 1955 letter that Tarski wrote, with Leon Henkin, to the committee for summer institutes of the American Mathematical Society urging support of the 1957 Cornell Institute in Symbolic Logic.'*

In particular, Feferman includes the following quote from a letter in which Tarski and Henkin identify the source of mathematicians' disaffection with logic as being its philosophical flavor: '*[many] mathematicians have the feeling that logic is concerned exclusively with those foundation problems which originally gave impetus to the subject; they feel that logic is isolated from the main body of mathematics, perhaps even classify it as principally philosophical in character.*'[21]

Algebraic notions are to be found in logic from the very beginning, starting with the work of Boole. This tendency to establish relationships between certain fields of mathematics and algebra, which increased with time, proved particularly fruitful in the case of propositional logic. We know that every Boolean algebra is isomorphic to a quotient algebra of formulae. By the Stone Representation Theorem we also know that every Boolean algebra is isomorphic to an algebra of sets. The theory of cylindric algebras [31] provides a class of algebras that are to first-order logic what Boolean algebra is to sentential logic. The subject was extensively developed by Leon Henkin, Alfred Tarski and Donald Monk over an extended period. Further research in this area was carried out by Istvan Németi and Hajnal Andréka. Henkin's contributions to this field of cylindric algebras are treated

[20] Feferman in [7, pp. 5–6], cites this 1955 letter that Tarski wrote, with Leon Henkin.

[21] See [7, pp. 5–6].

in this book (Chaps. “Leon Henkin and Cylindric Algebras” and “Changing a Semantics: Opportunism or Courage?”).

5.3 Identity

The search for a system of logic that takes the *identity* relation as the sole primitive constant has an ample historical precedent. Henkin studied this matter in depth in at least two of his contributions, namely, in *“A theory of Propositional Types”* [24] and in *“Identity as a Logical Primitive”* [26]. Two chapters of this book deal with his definition of a theory of propositional types based on identity, and in which all types are finite (Chaps. “A Bit of History Related to Logic Based on Equality” and “Reflections on a Theorem of Henkin”).

5.4 Nominalism

The work of Henkin that is most directly related to philosophy is an article entitled: *“Some Notes on Nominalism”* [14] which appeared in the *Journal of Symbolic Logic* in 1953 and to which there was to be a sequel, in 1955, in the form of a lecture [16]. As Henkin himself was eager to clarify, this was a reply to two papers that appeared in that journal over a short period of time in 1947. The first, *“On universals”* [34] was written by Quine and the second one, *“Steps toward a constructive nominalism”* [8], by Quine and Nelson Goodman jointly. These works, including that of Henkin, are part of a *foundations sensitive* tradition that is perhaps not as popular today. In this book there are no chapters directly devoted to this topic, but in Chap. “Henkin on Completeness” we highlight that the models he builds in all his completeness proofs are in accordance with a nominalistic position.

5.5 Mathematical Induction

We believe that his work on mathematical induction was the result of his devotion to mathematical education. We will comment later on the film about this subject that was part of the *Mathematics Today series*. He also wrote a paper, *On mathematical induction* [19] that he liked very much: ‘[...] *but my little paper on induction models from 1960, which has always been my favorite among my expository papers’*.[22] In it, the relationship between the induction axiom and recursive definitions was studied in depth. Henkin defined induction models as the ones in which the induction axiom holds, and he was able to prove that not all recursive operations can be defined in these models. For instance, exponentiation fails. Induction models are straightforward mathematical structures; there is the standard model that is isomorphic to the natural numbers, and there are non-standard models. The latter fall into two categories: cycles—namely the integers modulo a natural number n—and what Henkin termed *“spoons”*, having a cycle and a handle. The reason there are two categories of non-standard models is that the induction axiom by itself always implies the validity of either the first or the second of Peano’s axioms for arithmetic.

[22]Personal communication to María Manzano.

5.6 Mathematical Education

Several of his publications, dealing with elementary concepts, fall under mathematical education ([20, 22, 25] and [27]). Between 1957 and 1972, Henkin shared his work in research into mathematics with enquiries into its teaching. As from 1972, he devoted himself mainly to investigating the teaching of the subject. In fact, in 1979, with a Fulbright fellowship, he spent time in Israel devoted to looking into the teaching of mathematics. He was then at the *Department of Education in Science* at *Technion University* in Haifa. On this occasion he also visited two universities in Egypt.

5.7 A Problem Concerning Provability

Henkin was also very good at posing problems.[23] Chapter "The Henkin Sentence" in this book is devoted to the most famous one, *A problem concerning provability*. The problem deals with a formula similar to the one Gödel used in his incompleteness results but this formula is expressing its own provability while Gödel's expressed of its own truth. The question Henkin posed was whether the formula is provable or not. Halbach and Visser analyze *'Henkin's formulation of the question and the early responses by Kreisel and Löb and sketch how this discussion led to the development of Provability Logic.'*

5.8 Language with Only a Finite Number of Variables

To finish this section, let us tell you an interesting story Wilfrid Hodges told María:

> First, if my memory is accurate, Henkin played a role you might not know about in computer science logic. I think it was in 1970 or 1971 that he came to Bedford College London and gave a talk to Kneebone's seminar. He talked about proofs in which only some finite number of variables occur, and reported some results of Don Monk in that area. At the end of the talk I asked him whether there is a first-order sentence with no function symbols and only two variables that has models but no finite ones. He said he didn't know. Alex Wilkie remembered the question and passed it on a year or so later to my student Mike Mortimer, who proved that the answer was no. After he'd proved that, we found that Dana Scott had already published the result; but Scott's proof relied on a dubious theorem of Gödel which is now known to be false. So Mortimer has the theorem, and Mortimer's Theorem is the first in a line of theorems about what can be said using only a fixed number of variables.[24]

6 Henkin the Teacher

The story behind this is that of María Manzano, who during the academic year 1977–1978 attended his classes in *Algebra* for students in the first years of the degree course, and of

[23] The whole reference of these problems is included in the Appendix *Curriculum vitae* of this book.

[24] Personal e-mail to María Manzano.

Metamathematics (225A) for doctorate students. According to her impression during that year, Henkin was an extraordinary insightful professor in the clarity of his expositions and was well loved by his students, who on his last day of class in the academic years would applaud his efforts with great emotion. Indeed, Henkin always wondered whether his classes should be easy to follow or whether they should force his students to make important efforts. In the above-commented interview [37] he stresses that things learned with effort are less easy to forget.

Proof of this internal debate are the following words that formed part of the summary of his course on *Metamathematics*.

> Many bright students find my lectures a little slow, and they consider my concern with the machinery of logic (as distinct from the results) as pedantic. Concerning the first of these judgments, it is valid, but since many of the students are as slow-thinking as I, and the quick-thinking ones can always skip lectures and study the references, the pace as a whole is not bad—and indeed, the poorly-prepared students may find themselves struggling a bit to keep up. Concerning the second charge, however, I think it can be at least partially turned aside by adverting to pedagogical principles—which I am quite willing to explicate and discuss in office hours, or even in class if demand warrants.

Many of us who knew him believe that he reached a perfect balance and that he would never be obscure on purpose.

The textbook used in the algebra course Birkhoff and Mac Lane's, *A Survey of Modern Algebra*, but we did not follow the order of the book. The topics were the usual ones in an algebra course: Rings, Fields, Polynomials, Homomorphisms, Vector Spaces, etc. Before each class Henkin would give us a text of some 4–5 pages that summarized what was to be addressed in the class. The texts were in purple ink, printed with the old multicopiers that we called *"Vietnamese copiers"* and that were so often used to (illegally) print pamphlets in our revolutionary days in Spain. Before starting the sessions, and handing out the printed texts with the topics to be addressed, he would give us a sheet explaining the tasks of the week: revision of class notes and of the corresponding sections of the book (indeed, *exactly* which ones), and some 8 problems to solve. In addition to giving us back the exercises corrected, he would give us a copy with exercises containing problems solved by him. Detailed information of everything about the course that might be of interest to us was announced a long time before strictly necessary: the dates for handing in the various tasks, the dates of our exams (to be done in class with our books and notes), and his tutorial schedule. In the courses given in the first years of the degree, he was always very enthusiastic, even jovial, in class and he transmitted a feeling of confidence. His tutorials were always well attended.

In the summary of the metamathematics course Henkin defined metamathematics as the mathematical theory of mathematical theories, and he introduces the latter as the study of structures and their interrelations. *'In metamathematics, we study three classes of structures and their close interrelations: formal grammars, deductive calculus, and interpreted languages.'* The languages of sentential logic, of first-order and equational logic, and of many-sorted logic and higher-order logic were dealt with in a unified way in the course. In Henkin's words, *'we may attempt to deal comprehensively with all of these classes through the study of many-sorted grammars.'* In each case, we studied the relationship between the semantic notion of consequence and the syntactical notion of derivability, with proofs of the soundness and completeness theorems.

It is surprising that the first-order completeness proof that Henkin explained in class was not his own, but was developed by using Herbrand's theorem and the completeness of propositional logic. Another completeness proof he also developed in class was his result based on Craig's interpolation theorem.[25]

The issue of implicit and explicit definability was addressed in detail and the Beth/Padoa theorems relating them, as well as the interpolation theorems of Craig and Lyndon were proved. The Löwenheim–Skolem and compactness theorems were proved and commented upon. Naturally, the notions of universal algebra were introduced to relate structures: substructures, homomorphisms, direct products and also ultraproducts. In particular, the ultraproduct construction was used to prove compactness. Henkin did not forget classic themes such as quantifier elimination and categoricity. The theory of types and Gödel's incompleteness theorem were important parts of the course; indeed, they accounted for 2/5th of the whole. The language of the theory of types introduced by Henkin was that based on identity, very similar to that in his works ([24] and [26]), which contained a selector operator that allows the axiom of choice to be expressed. The recursive functions, the arithmetization of formal language, the Gödelization and self-reference inevitably led to Gödel's theorems of incompleteness. The last topic was that of general recursive functions and relations.

Even though the topics of this course were more or less standard, the whole organization of the material and the presentation of each were highly original. We agree with Steve Givant statement that:[26] *'Henkin never seemed to teach a "standard" course, but rather he presented what one can only describe as his own creations.'*

7 The Roles of Action and Thought in Mathematics Education

Henkin was often described as a social activist. He labored much of his career to boost the number of women and underrepresented minorities in the upper echelons of mathematics. He was also very aware that we are beings immersed in the crucible of history from which we find it hard to escape. This is in fact reflected in what he wrote in the beginning of his interesting article about the teaching of mathematics [28]:

> Waves of history wash over our nation, stirring up our society and our institutions. Soon we see changes in the way that all of us do things, including our mathematics and our teaching. These changes form themselves into rivulets and streams that merge at various angles with those arising in parts of our society quite different from education, mathematics, or science. Rivers are formed, contributing powerful currents that will produce future waves of history.
> The Great Depression and World War II formed the background of my years of study; the Cold War and the Civil Rights Movement were the backdrop against which I began my career as a research mathematicians, and later began to involve myself with mathematics education.[27]

In that paper, Henkin explains how during the first 15 years of his career the path of his research trajectory and his mathematics education path *'had only trivial points of contact (i.e. in my teaching).* [...] *Then, around 1972/73, there was a change. Something new entered my educational work: First, I began to incorporate a few basic elements*

[25] In this book we have devoted the chapter *Henkin on Completeness* to this issue. Therein, we include a section on the completeness proofs Henkin told us in class.

[26] Personal communication to María Manzano.

[27] See [28, p. 3].

of the methodology I employed in doing mathematics; second, I even found that I could employ results! [...] *Best of all, it has allowed me to integrate somehow two streams of my mathematical experience, deepening the satisfaction I derive from both.* [...] *Now another wave of history is welling up in the tide of our country's mathematicians, leading many of them to consider taking some work in mathematics education beyond the teaching of courses* [...].

In this paper he gave both a short outline of the variety of educational programs he created and/or participated in, and very interesting details of some of them; in particular, of the following six:

1. 1957–1959, *NSF* SUMMER INSTITUTES. Henkin relates this initiative to historical facts: *'The launching of Sputnik demonstrated superiority in space travel, and our country responded in a variety of ways to improve capacity for scientific and technical developments'*. These programs were directed at improving high school and college mathematics instruction and addressed math teachers. As a result of his teaching on the axiomatic foundations of number systems, he collaborated at a book, *Retracing elementary mathematics* [20].
2. 1959–1963, *MAA* MATH FILMS. At that time internet resources were not available, so movies were produced. *'Sensing a potential infusion of technology into mathematics instruction, MAA set up a committee to make a few experimental films.* [...] *the committee approached me in 1959–1960 with a request to make a filmed lecture on mathematical induction which could be shown at the high-school-senior/college-freshman level. I readily agreed.'* The film was part of the Mathematics Today series, and was shown on public television in New York City and in high schools. A 20 page manual to supplement the film was also published, containing two parts, one appendix, and some problems. Therein Henkin asks: *'Of what good is this principle anyhow? you may ask.* [...] *there are very few direct applications of mathematical induction* [...] *And yet, to me, the true significance of mathematical induction does not lie in its importance for practical applications. Rather I see it as a creation of man's intellect which symbolizes his ability to transcend the confines of his environment.'*
3. 1961–1964 CUPM. The *Committee on the Undergraduate Program in Mathematics* proposed courses to be taken by elementary teachers. *'Some of my colleagues and I began, for the first time, to have classroom contact with prospective elementary teachers, and that led, in turn, to in-service programs for current teachers. I learned a great deal from teaching teachers-students; I hope they learned at least half as much as I!'*
4. 1964–. ACTIVITIES TO BROADEN OPPORTUNITY. In the sixties, Berkeley students were taken energic actions against segregation in Southeastern USA as well as against military actions in Vietnam. *'In the midst of this turmoil I joined in forming two committees at Berkeley which enlarged the opportunity of minority ethnic groups for studying mathematics and related subjects.* [...] *We noted that while there was a substantial black population in Berkeley and the surrounding Bay Area, our own university student body was almost "lily white" and the plan to undertake action through the Senate was initiated'*. The committee recruited promising student and offered them summer programs to study math and English. If they persisted in the program, they were offered special scholarships. Henkin also collaborated with Bill Johntz, a very engaging and efficient Berkeley High School math teacher, *'He asked if I could steer university math students to him who might be interested in working in parallel classes of elementary students'*. Over the years, many graduated students participated, together with faculty

spouses who had studied mathematics in college, and also some engineers, for several hours a week. The program was called Project *SEED*—Special Elementary Education for the Disadvantaged.
5. 1960–1968. TEACHING TEACHERS, TEACHING KIDS. Therein Henkin described several Conferences on School Mathematics as well as several projects and courses he was involved in. The following paragraph caught my eye: *'After I began visiting elementary school classes in connection with CTFO, I came to believe that the emotional response of the teachers to mathematics was of more importance to the learning process of the students than the teacher's ability to relate the algorithms of arithmetic to the axioms of ring theory'*. The National Council of Teachers of Mathematics (NCTM) invited Henkin to participate in the elaboration of several films, and accompanying text, dealing with Whole-Number Systems as well as Rational-Number Systems.
6. 1968–1970. OPEN SESAME: THE LAWRENCE HALL OF SCIENCE. The Lawrence Hall of Science, created in honor of and named after the Nobel prize winner, was originally a science museum in Berkeley. In 1968 Alan Portis transformed the museum into a live center of science and mathematics education when he was appointed as new director. He gathered a group of faculty members from a variety of science departments interested in science education. *'These faculty members proposed a new, interdisciplinary Ph.D program under the acronym SESAME—Special Excellence in Science and Mathematics Education. Entering students were required to have a masters degree in mathematics or in one of the sciences. Courses and seminars in theories of learning, cognitive science, and experimental design were either identified in various departments, or created'*. Nitsa Hadar, a student from the Technion in Israel, was admitted in the SESAME program; she has contributed for this volume Chaps. "Tracing Back "Logic in Wonderland" to My Work with Leon Henkin" and "Pairing Logical and Pedagogical Foundations for the Theory of Positive Rational Numbers—Henkin's Unfinished Work".

8 The Never Ending Story

Leon Henkin has been one of the most original and brilliant minds in the history of Logic. One of those that beyond solving problems posed by others, open new ways to keep looking for the truth. What better way to finish than to talk about some hot historical issues concerning *The Life and Work of Leon Henkin*?

8.1 Bertrand Russell's Request

On April 1, 1963, Henkin received a very interesting letter from Bertrand Russell. In it, Russell thanks Henkin for *'your letter of March 26 and for the very interesting paper which you enclosed.'* He is talking about Henkin's paper entitled *Are Logic and Mathematics Identical?*

Right at the beginning Russell declares *'It is fifty years since I worked seriously at mathematical logic and almost the only work that I have read since that date is Gödel's. I realized, of course, that Gödel's work is of fundamental importance, but I was puzzled* *by it. It made me glad that I was no longer working at mathematical logic.'* It seems that Russell understood Gödel's theorem as implying the inconsistency of Principia: '*If a given set of axioms leads to a contradiction, it is clear that at least one of the axioms must be false. Does this apply to school-boys*' arithmetic, and, if so, can we believe anything that we are taught in youth? Are we to think that $2+2$ is not 4, but 4.001?'[28] He then goes on explaining his *'state of mind'* while Whitehead and him were writing the Principia.

> What I was attempting to prove was, not the truth of the propositions demonstrated, but their deducibility from the axioms. And, apart from proofs, what struck us as important was the definitions.
> You note that we were indifferent to attempts to prove that our axioms could not lead to contradictions. In this Gödel showed that we had been mistaken.
> [. . .]
> Both Whitehead and I were dissapointed that the Principia was almost wholly considered in connection with the question whether mathematics is logic.[29]

Russell ended the letter with a request: *'If you can spare the time, I should like to know, roughly, how, in your opinion, ordinary mathematics—or, indeed, any deductive system—is affected by Gödel's work.'*[30]

Unfortunately, Leon's answer did not freed Russell of his misunderstanding, as Grattan-Guinness affirms that *'Russell was still struggling with the theorem at the end of his life.'*[31]

According to Annellis: *'Henkin replied to Russell at length with an explanation of Gödel's incompleteness results, in a letter of 17 July 1963, specifically explaining that Gödel showed, not the inconsistency, but the incompleteness, of the [Principia] system.'*[32]

8.2 Henkin's Boolean Models: Peter Andrews' Proposed Homework

In 1975 Henkin published a paper with the title *Identity as a logical primitive* [26]. This paper is included in a volume of *Philosophia. Philosophical Quarterly of Israel*, completely devoted to identity. As Peter Andrews pointed out to us by e-mail: *'This expository paper concludes with a brief discussion of Boolean-valued (B-valued) models for type theory, and ends with a footnote which says, "Proofs for the results on B-models will be given in a forthcoming paper.* [. . .] *Boolean models of type theory were described in my paper 'Models of Type Theory' at the Symposium on Theory of Models held in Berkeley in 1963, but the paper was not published. (Cf. The Theory of Models, North-Holland, 1965, p. vii)."'* In his e-mail Peter asked: *'Did Henkin ever publish his paper on Boolean-valued Models of Type Theory? If so, it should be added to the bibliography page. If not, I wonder if his heirs have a manuscript which would be worth publishing even if it does not contain everything that Henkin wanted to include in it. If this were the case, perhaps it would be appropriate to publish it in the volume you are preparing.'*

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[28] See [9, p. 592].

[29] See [9, pp. 592–593].

[30] See [9, p. 593].

[31] See [9, p. 593].

[32] See [2, p. 89, footnote 3]. See also Anellis [3].

Knowing that The Bancroft Library, UC Berkeley, contains important documents of Leon Henkin, we contacted them.[33] The reply was that the collection record is unarranged and therefore unavailable for use.

Acknowledgements The authors wish to thank several colleagues and staff, including Steve Givant, Peter Andrews, Wilfrid Hodges, John Addison, Antonia Huertas and David Kessler. Special thanks to Henkin's family: Ginette Henkin, Paul Henkin and Julian Henkin.

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[33] We interchanged several e-mails.

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