

## Notes to the early history of the Knot Theory in Japan.

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The goal of this essay is to give a preliminary description of the growth of research on Knot Theory in Japan and to look at its origins. In particular, the influences of R.H. Fox of Princeton is analyzed<sup>1</sup>.

### 1 Early history of Topology in Japan

The University of Tokyo<sup>2</sup> and the Tokyo Mathematical Society were founded in 1877, the tenth year of the Meiji era (1868-1912). During the period 1897-1942 six more Imperial Universities were founded: Kyoto 1897, Tôhoku (Sendai) 1907<sup>3</sup>, Hokkaido (Sapporo) 1930, Osaka 1931, Kyushu (Fukuoka) 1939, and Nagoya 1942. In addition, two other universities (called Higher Normal Schools<sup>4</sup>), later renamed Bunrika Daigaku, with departments of mathematics were founded in Tokyo and Hiroshima in 1929.

Most likely Takeo Wada (1882-1944) published the first paper in Japan devoted to topology [Wad], 1911/1912. Wada graduated from Kyoto University and became an assistant professor in 1908. He visited the USA, France and Germany from 1917 to 1920.

Kunizô Yoneyama (1877-1968) did research in topology under Wada's influence [Wad]. He wrote (1917-1920) the first Japanese tract on General Topology.

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<sup>1</sup>Ralph Hartzler Fox (1913-1973). We give his short biography in Section 7.

<sup>2</sup>In the period 1886-1947, Tokyo Imperial University. We say concisely Tokyo University.

<sup>3</sup>By 1911, the Tohoku Mathematical Journal was initiated. It was Japan's first western style, research-level journal.

<sup>4</sup>They were professional training schools with the main goal to produce middle school teachers.

Wada's and Yoneyama's work was continued by Hidetaka Terasaka (see Section 2).

In 1929 Kôshiro Nakamura (1901-1985) from Tokyo Bunrika University (Higher Normal School), visited Berlin University and studied algebraic topology under H.Hopf. Then, following Hopf, he visited Zurich (Switzerland). He came back to Japan in 1932 and published two books introducing algebraic topology to Japan. Atuo Komatu (1909-1995) was then a third year student at University of Tokyo, and he was strongly influenced by Nakamura. Komatu graduated from Tokyo University in 1932. He wrote his doctoral thesis under the supervision of S.Nakagawa (see the footnote 11) in 1941, [Kom].

Work on algebraic topology was also done by Makoto Abe (1914-1945) and Kunihiko Kodaira (1915-1997), both of whom were students of Iyanaga<sup>5</sup> at Tokyo University. Abe died in the chaos after the end of World War II<sup>6</sup>. Kodaira received the Fields medal in 1954.

Kinjirô Kunugui (1903-1975) went in 1928 to study in Strasbourg, and then in Paris under Fréchet and he did his PhD in Paris on Dimension Theory.

The fundamental book on Dimension Theory by Hurewicz and Wallman (1941) motivated research of Kiiti Morita (1915-1995), Jun-iti Nagata (1925-), and Keiô Nagami (1925-).

Shizuo Kakutani (1911-) graduated in 1934 from Tôhoku University and became an assistant at the newly founded mathematics department of Osaka University, where he was under the general guidance of T.Shimura. His 1936 paper on Riemannian surfaces caught the attention of H.Weyl who invited Kakutani to IAS (Princeton) in 1940. The war forced him to go back to Japan in 1942.

In next sections we describe people involved in the early study of knot theory in Japan. We follow, in our description, the "generation" approach

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<sup>5</sup>Shôkichi Iyanaga was born in 1906 and graduated from Tokyo University in 1929 (he studied with T.Takagi). He spent 3 years in Europe (1931-34), partially in Germany (Hamburg) where he was a student of E.Artin. In 1937, after his teacher, Nakagawa, reached 60 years of age, the *Chair* in geometry was passed to Iyanaga. Iyanaga was a specialist in number theory and geometry but was also interested in topology, for example he gave a talk *The foundation of general Topology* at the 4th Topology Colloquium at Kyoto University in April 1939. He was also a member of the editorial committee of the bulletin of the Topology Colloquium (from April 1938) [Mim]; compare the entry on Murasugi.

<sup>6</sup>He was of weak health and was overworked when in a charge of an evacuation of Tokyo University. Lung cancer and malnutrition caused his death in 1945.

of Noguchi [No-3]. This period is summarized by M.Mimura as follows [Mim]: “Right after World War II, Terasaka and Kinoshita in Osaka and Noguchi, Homma and Murasugi in Tokyo were working by themselves without good contacts, but their research made good progress when Homma and Noguchi paid a visit to Osaka University. Around 1950 Terasaka, Kinoshita and Homma were studying homeomorphisms of  $R^2$  and of  $R^3$ ... In this research the importance of how to embed a closed curve (knot) and a surface (2-dimensional manifold) in  $R^3$  attracted attention.<sup>7</sup> Homma proved Dehn’s lemma [Hom-2]), i.e. whether a knot ( $S^1 \subset R^3$ ) is truly unknotted is determined by whether the knot group  $\pi_1(R^3 - S^1)$  is isomorphic to  $Z$ , almost at the same time as, and independently of, Papakyriakopoulos. Terasaka, Kinoshita and others also undertook research in knot theory. One of the typical results at that time was the generalization of composition of knots by Kinoshita and Terasaka [K-T]. It can be said that research in knot theory in Japan truly started around this time”. Several influential paper on knot theory were published in Japan in 1957 -1958 period [Has, Ha-Ho, Hom-2, Hos, Kin-4, Kin-5, Kin-6, Kin-7, Kin-8, K-T, Mur-1, Mur-2, Saka, Ya-Ki, Fo-1, Fo-2]. The earliest of these papers [Kin-4] was received by Osaka Mathematical Journal on March 25, 1957<sup>8</sup>. Mimura adds: “Visits to Japan by people like Moise, Fox, Cairns, Bing, Harrold and visits to the USA by Noguchi, Kinoshita, Homma, Murasugi, Hosokawa, Junzo Tao made possible a close research cooperation and the exchange of information between Japan and the USA”<sup>9</sup>. Visits by Fox to Japan<sup>10</sup> and Japanese knot theoretists to Princeton (where Fox worked) were of great importance. Fox was very friendly and encouraging toward young topologists and often invited them to Princeton.

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<sup>7</sup>Another reason for interest in knots by Kinoshita and Terasaka may be their interest in transformations of the Euclidean 3-space and their fixed point sets.

<sup>8</sup>Most likely the first in Japan course on knot theory (based on Reidemeister’s book) was conducted by Gaisi Takeuti at Tokyo University of Education in 1952 or 1953. K.Murasugi attended this course, compare Section 3.

<sup>9</sup>One should add here frequent visits by J.P.Mayberry [Mur-4]; compare the entry on Murasugi.

<sup>10</sup>His first visit to Japan was as an American representative to the World *Go*-game tournament in October 1963. The universities of Tokyo, Osaka, Nagoya, Kyoto and Fukuoka have invited him to lecture on knot theory while he was in Japan [Fo-9]; compare Section 7 .

## 2 First generation.

Hidetaka Terasaka, born 1904 in Tokyo, died April 3, 1996. He graduated from Tokyo University in 1928, as a student of Nakagawa<sup>11</sup>. In 1933 Terasaka went to Germany and Austria (Vienna) as a scholarship fellow of the Ministry of Education of the Japanese Government. In Vienna, where he spent more than a year, he studied mostly with Karl Menger (1902-1985)<sup>12</sup>. He met there also Heinrich Tietze (1880-1964), and Herbert Seifert (1906-1996), who just came from Dresden<sup>13</sup>. Terasaka was supposed to stay in Vienna for 2 years but came back after one year to become an assistant professor (and a year later a full professor) in the newly opened Osaka University. Other full professors, in addition to Terasaka, at Osaka in 1935 were: Kunugi, Shimizu, Shoda and Kôzaku Yoshida. A few years later they were joined by Kakutani, Komatu, Nakamura and Sakata (Shizuma<sup>14</sup>). Terasaka was appointed to the editorial committee of the Bulletin of the Topology Colloquium (April 1938), which was then named Isosugaku (Japanese name for Topology). The first issue was published in October 1938 [Mim].

Terasaka was familiar with the work of the Polish school of topology and in particular he applied to general lattices Kuratowski's method of defining a topological space by using the closure operator. He submitted his paper to the leading Polish mathematical journal *Fundamenta Mathematicae*<sup>15</sup>. It was accepted for publication just before the Second World War. However Poland

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<sup>11</sup>Senkichi Nakagawa, (1876-1942) was born in Kanazawa and graduated from the mathematics department of Tokyo University (1898). He went to Germany where he studied geometry. After returning to Japan, he was appointed assistant professor at his alma mater, and professor (1914). He was a specialist in Non-Euclidean geometry [Ja].

<sup>12</sup>Menger held the chair of geometry at the University of Vienna (after Reidemeister left for Königsberg) from 1927 till 1938 [Sig].

<sup>13</sup>Noguchi wrote in his stories of mathematicians [No-3]: "In the 20'th there were two trends in topology, one represented by Brouwer, Uryson and Menger, second by P.Heegaard, S.B.Kerékjártó and Veblen. Seifert followed the second trend."

<sup>14</sup>Ryozi Sakata (1916-1985) was adopted by the Shizuma family in 1942, after which he used the name Shizuma [Mim].

<sup>15</sup>Fundamenta Mathematicae was created by young Polish Mathematicians, Z.Janiszewski (1888-1920), S.Mazurkiewicz (1888-1945) and W.Sierpiński (1882-1969), in 1920, after Poland gained independence in 1918. In a sense, the situation of Poland and Japan was similar at that time with respect to grow of mathematics: several young mathematicians, educated in Germany or France were returning to their native countries and building, almost from scratch, schools of modern mathematics.

was attacked by nazis on the first day of September of 1939 and the journal was burned<sup>16</sup>. Fortunately off-prints (50 copies) safely reached Terasaka in Japan. In the *Fundamenta Mathematicae* issue (with date 1939) published in Poland after the war only the title of the Terasaka paper is included as he thought that after six years his paper was not up to date, and reprints were already sent out [Ter-1]<sup>17</sup>.

Terasaka heard talks on the knot theory by Seifert in Vienna, but he started to work on the topic by himself later, after 1953. Most likely in this he was influenced by his student, Shin'ichi Kinoshita (see the entry on Kinoshita). Some other Terasaka students were Tao and Hosokawa (Section 3). In 1961 Terasaka moved from Osaka to Tokyo Women Christian University (TWCU) invited by Aiko Negishi his former student (she graduated from TWCU but went to Osaka University to study with Terasaka). After 2-3 years he moved to Sophia University to the newly founded mathematics department, invited by his old colleague from Tokyo University, M.Moria (later president of Sophia University). Hisako Kondo was his master degree student at Sophia University (1975)<sup>18</sup>. Junzo Wada<sup>19</sup> was another student of Terasaka specializing in functional analysis. Takaaki Yanagawa and Takeshi Yajima were also students of Terasaka at Osaka University.

Terasaka died April 3, 1996.

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<sup>16</sup>K.Kuratowski writes in [Kur]:“Before the war ‘Fundamenta’ published 32 volumes. Volume XXXIII was in print. The first several pages were printed before the war. Most of the materials and manuscripts were destroyed on order of the director of the printing shop [in old Jagiellonian University in Cracow], who had been nominated to that position by the nazis. However, due to the exceptional efforts of workers of the printing shop, a lot of materials (proofs, manuscripts) were hidden and survived till the end of the war... Volume XXXIII of ‘Fundamenta’, containing to great extend, recovered prewar results and some results obtained in the war period, was published before the end of 1945.”

<sup>17</sup>One can add here that Kinoshita, Terasaka’s student, also published his early papers in *Fundamenta* [Kin-2, Kin-3].

<sup>18</sup>She was born in 1951 and graduated in March of 1973 from Japan Women’s University (Nihon Jyosidaigaku). She wrote an influential paper on the Alexander polynomial of the unknotting number one knots [Kon]

<sup>19</sup>He was a professor at TWCU and later at Waseda University. Now he is retired.

### 3 Second generation

From the Preface to [Su-2]: “The Topology and Computer Science Symposium was held at Akanezaki Hotel in Atami from the 17th to the 20th January, 1986. The Symposium was in honour of Professors Shin’ichi Kinoshita, Hiroshi Noguchi and Tatsuo Homma on their sixtieth birthday. The three professors studied topology at the Osaka University under Professor Hidetaka Terasaka. During the past 35 years their ardor and skills have contributed to Knot Theory, PL Topology and Computer Science, and they educated many students. Most of the participants of the symposium were their former students who owe much to their encouragement and stimulus.”

(K) Shin’ichi Kinoshita, born 1925.

He was a student of Terasaka in Osaka University and the first Japanese to publish research on Knot Theory [Kin-4].

The first subject he studied was the fixed point property. These studies were concluded with the publication of [Kin-1, Kin-3]. After that, he became interested in topological transformations, which were, probably, the main achievements of Terasaka. In April 1953 T.Homma came to Osaka University as a Yukawa Fellow (compare entry on Homma). He stayed one year (till March 1954), and Terasaka and Kinoshita studied topological transformations with him. Homma and Kinoshita wrote three joint papers on this subject [H-K-1, H-K-2, H-K-3]. After finishing their third paper they realized that it would be difficult to advance the research further without studying 3-dimensional topology, and they heard of the progress made by Moise, Bing and Harrold<sup>20</sup> in USA. H.Noguchi, who joined the group, had been interested in the Poincaré Conjecture. He strongly suggested to study knot theory and to contact Professor R.H.Fox at Princeton University. So, Kinoshita wrote a letter to Fox asking for reprints of his papers<sup>21</sup>. In 1955, with Fox’s papers in hand, they (Terasaka, Kinoshita and Yajima) started a seminar on knot theory. In 1956, H.Noguchi came to Osaka University as a Yukawa fellow (April-September). The seminar grew and new participants included Noguchi, Miss. Y.Hashizume, F.Hosokawa and

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<sup>20</sup>Later he wrote a joint paper with Kinoshita [H-K].

<sup>21</sup>New journals from abroad were available only in the library of American Cultural Center [Mim], and there were no copying machines then.

J.Tao. At first, they were interested in trivial knots (the Smith Conjecture, motivated by [M-S], and Dehn's Lemma). However, Terasaka advised Kinoshita to study non-trivial knots (so to treat knots as the main object of study). Kinoshita received a doctorate in mathematics in 1958 for results published in [Kin-7] and announced in [Kin-5], and in 1958-59 was a Lecturer at Osaka University. In September of 1959 he moved to Princeton. For two years ((1959-61) he was a member of the Institute for Advanced Study and later (1961-62) he was a Research Associate at Princeton University. In these three years he collaborated closely with Professor Fox. For two years (1962-64) he was Assistant Professor at University of Saskatchewan (Canada). In 1964-68 he was an Associate Professor at Florida State University, and 1968 he became a Professor there and stayed at FSU till his retirement in December, 1984. In January 1985 he moved back to Japan to become a professor at Kwansei Gakuin University, where his friend Yajima (also student of Terasaka) was a professor. He retired from Kwansei Gakuin University in April of 1994. Now Kinoshita lives in the suburbs of Atlanta (USA) with his wife Michiko. They have 4 children: 3 girls and a boy.

His students include:

Yaichi Shinohara (b. 1942), PhD in 1969 at Florida State University (now Dean at Kwansei Gakuin University).

At Kwansei Gakuin University, Kinoshita's students include:

Toshio Harikae, Hisanori Naka, Masahiro Nakao and Yasushi Yonezawa.

(N) Hiroshi Noguchi, born December 26, 1925 in Tokyo.

He spent two years attending night courses at Science University of Tokyo<sup>22</sup> (working at daytime) during wartimes. In 1945: "At the age of nineteen I was a freshman in a college and decided to study Topology as my major research field "[Su-2]. He graduated in 1948 from Tôhoku University under Prof. Tadao Tannaka supervision. He read Alexandrov-Hopf *Topology*. He was an instructor at Tôhoku University and later moved to Waseda University (1952) and became an assistant professor. He started teaching from Analytic Geometry and Projective

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<sup>22</sup>At that time it was called Tokyo Science School, one of the professional training schools. After attending such a school for about 3 years (possibly 2 during the war) one was able to apply to a degree awarding University.

Geometry. In 1953 he gave a lecture on topological spaces. In 1956 he got a Yukawa fellowship and went to work with Terasaka in Osaka. In Osaka he met Kinoshita once again<sup>23</sup>. Mr and Ms Tao (Ms Tao formerly Hashizume, known for prime decomposition of links 1958) and Hosokawa. Noguchi spent one year in Osaka and went back for one year to Waseda. There was new (1957) exchange program between Waseda and University of Michigan. Noguchi was one of the first people to use it. He spent a year at University of Michigan at Ann Arbor. In January of 1958, in Michigan, he studied under E.Moise (there were there also R.Bott and H.Samelson). In July of 1958 he went to Princeton (for one week). There he met Fox<sup>24</sup>, Papakyriakopoulos, Stallings and L.P.Neuwirth. Before that July he submitted a paper to the Transactions of the American Mathematical Society but the referee (Moise) suggested that he rewrite and split the paper. One part went to Osaka Journal and one to Annals of Mathematics - the best Mathematical Journal in the world (“Smoothing of combinatorial  $n$ -manifolds in  $n+1$  space”). He got PhD for these two papers in 1960 at Osaka University. In Michigan he met Müller and in 1963/4 they published joint papers in computer science.

Noguchi was a Senior Foreign Scientist Fellow in Mathematics visiting the University of Illinois in 1966-1967. After 1970 Noguchi became interested in Mathematical Education and published a high school text in 1975. He is the president of Japanese branch of the Mathematical Olympiad.

Noguchi dedicates his book [No-3] to Tadao Tannaka (his supervisor at Tôhoku University) and Komatu.

In Section 4 we list the students of Noguchi.

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<sup>23</sup>Noguchi met Kinoshita before, in 1954, at the Meeting of the Japanese Mathematical Society in Osaka. Then Kinoshita introduced Homma to Noguchi. Also in 1954 Homma and Kinoshita published their first joint paper [H-K-1], and it was reviewed by Fox. The first joint paper by Homma and Terasaka was published in 1953 [Hom-Ter].

<sup>24</sup>When Noguchi met Fox he was asked about Murasugi. The reason was that Murasugi had sent his papers, [Mur-1], to Fox. Fox told Noguchi that the results were obtained before by his student R.H.Crowell. Later Fox wrote joint review of the papers by Murasugi and Crowell, and advised Murasugi to come to Princeton.

(H) Tatsuo Homma, born January 1926.

He graduated from Tokyo Institute of Technology<sup>25</sup> under Minagawa<sup>26</sup>. He got a Yukawa fellowship in 1953<sup>27</sup> and went to work with Terasaka in Osaka (compare entry on Kinoshita). He attacked Dehn's Lemma in 1950's, first proved it partially [Hom-1], and later in full generality (for  $S^3$ ) [Hom-2], independently from Papakyriakopoulos. Homma was a professor at Yokohama City University, then at Tokyo Institute of Technology, and later at Aoyama Gakuin University (Tokyo). He was a member at the Institute for Advanced Study in Princeton (1960-62). He was also a visiting associate professor at Florida State University (1965), where he wrote Lecture Notes [Hom-3] and at Michigan State University (1967). He gave an invited (1 hour) talk at the AMS meeting in Arkansas. In 1973 he was on the organizing committee of the International Conference on Manifolds and related topic (the major topological conference). He was the chief organizer (from Japanese side) of a joint Japan-US conference held at Hawaii in 1982.

His students include Yasuyuki Tsukui, Mitsuyuki Ochiai, Teruo Nagase and Seiya Negami.

(M) Kunio Murasugi, born March 25, 1929 in Tokyo.

Murasugi attended the Tokyo Higher Normal School from 1945, graduating in 1949 (compare the footnote 5). Then he entered the Tokyo Bunrika University<sup>28</sup> and graduated in 1952 with B.Sc. under Takeuti<sup>29</sup>

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<sup>25</sup>Then called Tokyo Higher Technical School, one of the professional training schools.

<sup>26</sup>Takizo Minagawa was a student of Terasaka specializing in differential geometry; compare [Hom-Mi].

<sup>27</sup>Hideki Yukawa (Ogawa), 1907-81, was the first Japanese Nobel prize winner, 1949, for his work on elementary particles (prediction of mezsos). Hideki Yukawa contributed a portion of the prize to Osaka University, where he once held a position. With this contribution, the university established the Yukawa Fellowship. Ogawa assumed his wife's family name upon his marriage (1932) [Yuk].

<sup>28</sup>Tokyo Bunrika University was absorbed into the Tokyo University of Education in 1949 (Nobel Prize winner in physics, 1965, Sin-Itiro Tomonaga was its president, 1956-1962). In 1973 it changed the official name to the University of Tsukuba.

<sup>29</sup>Gaisi Takeuti was born in 1926 and graduated from Tokyo University under the supervision of Shōkichi Iyanaga who specialized in number theory, but had among his students also Kodaira. Takeuti's main specialization was mathematical logic, however he was interested in topology and about 1950 he worked on homotopy theory. He proved a nice result, accepted for publication in J.of Math. Society of Japan, but to his disappointment

supervision. As a university student Murasugi wanted to study algebraic topology, in particular, homotopy theory, and to determine the  $m$ -th homotopy group of an  $n$ -sphere. This was a fashionable problem in early 1950's. But the famous J.P. Serre's paper (about fiber spaces) appeared in *Annals of Mathematics* in 1951 [Ser]. Murasugi was discouraged by this paper and almost had lost his interest in the problem. Takeuti was then interested in algebraic topology, so Murasugi joined his weekly seminar on topology (he was the only student in the seminar). After Murasugi graduated, Takeuti suggested to him that in order to study homotopy theory he should join some active group in the topic. He should go to Osaka and join the Toda group. Otherwise, Takeuti continued, Murasugi would better study "knot theory". This was the first time Murasugi have heard on knot theory [Mur-4]. In 1952 (or 1953), just after Murasugi's graduation in 1952, Takeuti gave a semester long course in knot theory. It was based mostly on Reidemeister's book [Re] but also on his own thoughts (he was then unaware of the work of Fox and his students<sup>30</sup>). Soon, Takeuti went back to his research in logic, but Murasugi continued working in knot theory. First he wanted to prove the asphericity of the knot complement, using group theoretical methods. He found that the alternating knot group had some regularity, and so he tried to solve the above problem for alternating knots. However the problem was solved by Aumann [Au] for alternating knots, and later by Papakyriakopoulos, for general knots [Pap]. Nevertheless, Murasugi was able to find interesting facts on alternating knots resulting in his first three publications<sup>31</sup> in 1958 [Mur-1, Mur-2], which later become basis of his doctorate<sup>32</sup>.

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the result just has been proven by G.W.Whitehead. Then he moved his attention to knot theory.

<sup>30</sup>Later, in Princeton, Takeuti played *Go* with Fox but never mentioned his knot theory course [Tak].

<sup>31</sup>Murasugi sent a reprint of his first publication to Fox, who noticed that the similar result was obtained by his student Crowell. The work of Crowell was then unknown in Japan, even to Kinoshita who was a referee of Murasugi's paper.

<sup>32</sup>The person with several published and well-received papers could submit them as his doctoral thesis to his (or any other) university. There was no need for a formal supervisor or formal course credits. However Murasugi always considered Takeuti as his supervisor.

Murasugi became an assistant at Husei University in 1954, Lecturer<sup>33</sup> in 1956, and Assistant Professor in 1960. Around 1958, Homma was working at the Tokyo Institute of Technology and Noguchi was at Waseda University, also in Tokyo. They used to have a weekly seminar at Homma's office at TIT. Since Noguchi lived near Murasugi's home, (most likely) he introduced Murasugi to Homma some time in 1958, after Murasugi published his first paper. Murasugi first met Terasaka and Kinoshita at the Topology Conference in early summer of 1958. Kinoshita left Japan to Princeton in the summer of 1959 and Homma went to Princeton in 1960.

Murasugi met Moise and Bing in Japan<sup>34</sup> before he left in 1960 to America, but he met Fox for the first time only in Princeton in 1961. One should add that J.P.Mayberry<sup>35</sup> often visited Japan in late 1950's being involved with military duties in Korea. In particular he gave a colloquium at Waseda University (invited by Noguchi), attended, in particular, by Murasugi<sup>36</sup>, Tao and Hashizume. In 1957 Coxeter and Moser published a book on infinite group theory [C-M]. Murasugi studied the book and found it very useful in his research in knot groups. His idea was to first study infinite group theory with Coxeter<sup>37</sup> in Toronto and then study knot theory with Fox in Princeton. He obtained a graduate scholarship as an MA student at the University of Toronto. In 1960 Murasugi went to Canada<sup>38</sup>. In December, 1960, he was told that his doctoral thesis submitted to Tokyo University of Education before he flew to Toronto was accepted and in March, 1961, Murasugi received the doctoral degree from the Tokyo U.E. After getting a doctoral degree from Japan, Murasugi's status in Toronto changed. He was no longer a graduate student but became, in April of 1961,

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<sup>33</sup>In the Japanese system there are three tenured positions: Lecturer, Assistant Professor and Professor. They roughly correspond to American: Assistant Professor, Associate Professor and (full) Professor.

<sup>34</sup>Murasugi remembers that he, Homma and Noguchi met Moise and Bing at the Tokyo (Haneda) airport.

<sup>35</sup>PhD thesis, Princeton Univ., 1955. Now he is a Professor Emeritus of Mathematics at Brock University in St. Catherines, Ontario, Canada.

<sup>36</sup>Later they wrote a joint paper [M-M].

<sup>37</sup>Harold Scott MacDonalld Coxeter (b.1907).

<sup>38</sup>Murasugi arrived at Toronto September 15, after 2 days flight from Japan. He didn't take a ship as stated in [No-3].

a research assistant of William Thomas Tutte (b.1917), a specialist in graph theory. In November, 1960 (2 months after Murasugi left Japan), R.Fox wrote him a letter in which he suggested Murasugi to apply for a visiting membership at the Institute for Advanced Study in Princeton (and enclosed an application form)<sup>39</sup>. He consulted Professor Gilbert de Beauregard Robinson (1906–1992) (representation theory) and was strongly suggested to stay in Toronto. Murasugi agreed with him, and it was one of the reasons that after 2 years at Princeton he returned to Toronto not to Japan. Murasugi was a research assistant of Tutte from April, 1961 to June, 1962. In August, 1962, he (and his family) went to Princeton University as a research associate, and stayed there until August 1964. He got an Assistant Professor position (in Toronto), in July 1964, became an associate professor in July 1966, and professor in July 1969. Toronto became the place for young Japanese mathematicians<sup>40</sup> to learn Knot Theory and to establish relations with American topologists.

Murasugi's students include:

Richard T.Hartley University of Toronto 1976 [Har],  
 Toru Maeda<sup>41</sup>, University of Toronto, 1983 [Ma],  
 Bohdan I. Kurpita, University of Toronto 1992,  
 Peter Clifford Hill, University of Toronto, 1998,  
 John Mighton, University of Toronto, 1999.

In July of 1999, there was a conference on Knot Theory in Toronto to celebrate Prof. Kunio Murasugi's 70th birthday [Mur-3].

- (H) Fujitsugu Hosokawa (b.1930), graduated at Osaka University under the supervision of Terasaka. He moved to Kobe University. Hosokawa is well known for his paper on "Hosokawa polynomial" ([Hos], 1957). His father was also a mathematician. He wrote the first textbook about geometry (university Textbook) [Tôhoku University]. Terasaka read his book. Hosokawa senior moved to Hiroshima University and was killed in Hiroshima by the atomic bomb (at the time he was then conducting

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<sup>39</sup>Next year, in November 1961, Murasugi drove to Princeton to meet Fox for the first time and the whole his family stayed at Kinoshita's home for one week. He also met Crowell there.

<sup>40</sup>And not only Japanese: I also was a postdoc of Murasugi in Toronto 13 years ago.

<sup>41</sup>He is now working at Kansai University in Osaka.

a seminar and some of the young students survived when the building collapsed). F.Hosokawa is a creator of the Kansai school of knot theory. His students at Kobe University include:

Akio Kawauchi (master degree student<sup>42</sup>), Masakazu Teragaito (1986), Yoko Nakagawa (master)<sup>43</sup>, Tetsuo Shibuya, Kazuo Yokoyama, Yasutaka Nakanishi (he was one of the first doctoral students at Kobe University), Makoto Sakuma, Taizo Kanenobu, Yoshiaki Uchida, Yoshihiko Marumoto and Kanji Morimoto (doctorate).

- (Has) Youko Hashizume, later Ms. Tao (b.1930)<sup>44</sup>, graduated at Osaka University under the supervision of Terasaka. She got a position at Kansai University. Her best known result concerns the uniqueness of the connected sum decomposition of links [Has].<sup>45</sup>
- (Ta) Junzo Tao (b.1929), graduated at Osaka University under the supervision of Terasaka. His major field is differential topology. In 1950's Tao and H.Yamasuge shared office at Osaka University. Yamasuge tried to solve the Poincaré Conjecture, and presented his prove of 5-dimensional case [Yam], but died young, in November 1960. Tamura, Kudo, Tao and Saito published his remaining papers. Smale sent a dedicated letter about Yamasuge's work to Tao and Yoshihiro Saito (1930-1997). K.Kobayashi, Kawauchi, Nakanishi, and Hitoshi Murakami were Tao's doctoral students. Tao was an early member of Osaka City knot theory

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<sup>42</sup>Kawauchi was a student of Taniguchi and Terasaka at Sophia University (Terasaka introduced Kawauchi to knot theory and Taniguchi supervised seminar based on the Spanier's book). He did Master degree at Kobe University under Hosokawa and Suzuki supervision. He did his doctoral degree under Junzo Tao at Osaka City University. He spent 2 years at the Institute for Advanced Study in Princeton (1978-1980). He is a professor at Osaka City University. In 1983 he co-organized the KOOK (acronym for the main participating Universities in Kansai district: Kobe University, Osaka University, Osaka City University, and Kwansai Gakuin University), geometric topology monthly seminar, which educated several young mathematicians (see entry on J.Tao). His students include: Makoto Sakuma (Doctorate), Hitoshi Murakami (Master, Dr), Adrian Pizer (Ms, Dr), (She) Masako Kobayashi (Dr), Seiichi Kamada (Ms, Dr), Yasuyuki Miyazawa (Dr), Teruhisa Kadokami (Dr), Shin Satoh (Ms, Dr), and Ikuo Tayama (Dr).

<sup>43</sup>She did her PhD. under Fox at Princeton University and was his last doctorate student. She is now working at Yamaguchi Women's University.

<sup>44</sup>Several papers in Kobe Journal of Mathematics 6(1), 1989 are dedicated to her on her 60th birthday.

<sup>45</sup>I had been generalizing her result on free action on  $S^1 \times S^2$ , [Tao, Pr].

seminar (from 1956), he never wrote a paper on knots but his broad knowledge of topology (including algebraic and geometric topology) was appreciated by participants of the seminar.

KOOK Seminar was established in 1983 by Tao and Kawauchi of Osaka City University with strong support from F.Hosokawa of Kobe University and S.Kinoshita (from January 1985 at Kwansei Gakuin University). The impulse of this creation was the fact that a small conference hall of Osaka City University was opened in a convenient place in Osaka City. It was felt that it would be fruitful to have regular meetings for scholars in knot theory (mostly students and friend of H.Terasaka). KOOK Seminar was organized by geometric topologists from Kobe University, Osaka University, Osaka City University and Kwansei Gakuin University, and was attended by many topologists, mostly from Kwansai area. The naming of KOOK Seminar is due to Adrian Pizer who was a student of Kawauchi [Ka]. From 1994, geometric topologists of Nara Women's University joined the seminar as organizers (and since then it is called often the N-KOOK Seminar).

- (Ya) Takeshi Yajima (1914-1998) was a pioneer of 4-dimensional knot theory [Yaj]. Yajima was a student of Terasaka at Osaka University. Later he was a professor at Kwansei Gakuin University. His students at Kwansei Gakuin University include:  
Kouhei Asano(MS, PhD), Toru Maeda(MS), Katsuyuki Yoshikawa(MS 1980, PhD 1985).
- (Yan) Takaaki Yanagawa (b.1935), [Yan]. He was the last student of Terasaka at Osaka University. He joined Osaka University knot theory seminar in April, 1959 (compare entry on Kinoshita). He worked at Kobe University and now he is a professor at Kansai University in Osaka (invited by Hashizume (Tao), to fill her position after she retired).

## 4 Third generation

Students of Hiroshi Noguchi:

- (Ku) Keiko Kudo (later Kamae); born 1939. She studied at Waseda University under the supervision of Noguchi, and left (even before finishing

her master program) to become an Instructor at Kyushu University, invited by J.Tao. She went to the USA and was an instructor at the University of Illinois. Later she became an assistant professor at Nihon University. She wrote a joint paper with Noguchi in 1963 [Ku-No].

- (Ko) Kazuaki Kobayashi (b. December 17, 1940), graduated from Waseda University in March 1964. Master degree from Waseda 1966 under Noguchi supervision. Doctorate: Osaka City University under the supervision of J.Tao, 1972; [Ko]. He went in April 1966 to Kobe University (Math. Dept. in Science Faculty) in 1968 moved to Math. Dept. in Art Faculty, and to Hokkaido in 1971. He is now a professor at the Tokyo Women Christian University. His students include: Masaharu Kouno, Ken Sakai, Yoshiyuki Yokota, Yuko Yoshimatsu, Takako Kodate, Chikako Toba, Kumiko Endo, Makiko Ishiwata, Noriko Imi, Kaneko Masuda, and Shizuka Mitaki.
- (S) Shin'ichi Suzuki (b. April 20, 1941), graduated from Waseda University in March 1965. MS, Waseda Univ. Mar. 1967 (with Noguchi). Ph.D. Waseda Univ. March 1974. Terasaka invited Suzuki to Sophia University as an instructor in 1967. Suzuki moved to Kobe University after 2-3 years. Later he created a school of Knot Theory at the Waseda University in Tokyo.

There is the conference this year (October 2001) to celebrate 60th birthday of Kobayashi and Suzuki.

Suzuki's students include:

In Kobe: Akio Kawauchi (MS), Shuji Yamada<sup>46</sup>, Yasutaka Nakanishi, Kanji Morimoto (master and doctorate), Makoto Sakuma, and Taizo Kanenobu.

In Waseda: Teruhiko Soma (PhD), Yoshiyuki Ohyama (PhD), Masao Hara (PhD), Kazuo Yokoyama (MS at Kobe, doctorate at Waseda) (She) Miki Shimabara (now Miyauchi) (master), Kouki Taniyama (doctorate), (She) Yasuko Ogushi (now Ohyama) (MS) Yoshiyuki Yokota (doctorate), Satoshi Yamashita (doctorate) Akira Yasuhara (doctorate), Toshiki Endo (MS), Keigo Makino (MS), (She) Tomoe Motohashi

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<sup>46</sup>He did his master and doctoral degree at Osaka University under supervision of Minoru Nakaoka.

(doctorate), (She) Miyuki Okamoto (doctorate) [graduate of Tsuda College], Eishin Kawamoto (MS), Makoto Ozawa (doctorate), and Tatsuya Tsukamoto (doctorate)<sup>47</sup>.

- (Ka) Mitsuyoshi Kato (b. October 10, 1942), graduated Waseda Univ. Mar. 1964. PhD. 1970<sup>48</sup>. He was a student of Noguchi at Waseda University. He visited the Institute for Advanced Study in Princeton (1968-70). He is now a Professor at Kyushu University. Kato's students include: Sadayoshi Kojima (Master March 1978)<sup>49</sup>, Toshitake Kohno (master 1980)<sup>50</sup>, Masayuki Yamasaki (Master 1978)<sup>51</sup>, Kimihiko Motegi, (She) Haruko Nishi, and Yoshihisa Sato.
- (Fuk) Masako Fukuda (b. March 27, 1942), graduated Waseda Univ. Mar. 1964. PhD. 1974. Her husband Takuo Fukuda wrote with Noguchi a textbook on elementary catastrophe theory, 1976.
- (Fuj) Kiichi Fujino (b. Feb. 15, 1931), graduated Waseda Univ. Mar. 1955. PhD. 1972. Computer Science.
- (Hat) Mitsuhiro Hattori (b. Feb 18, 1941), graduated Waseda Univ. Mar. 1964. PhD. 1974. Computer Science (asynchronous circuits).
- (Hon) Masaru Honda (b. Dec 15, 1941), graduated Waseda Univ. Mar. 1965. Applied statistics.
- (Ik) Hiroshi Ikeda (b. April 18, 1944), graduated Waseda Univ. Mar. 1965. PhD. 1974. Combinatorial topology and graph theory.

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<sup>47</sup>He also has been my PhD student at GWU, graduating in May 2000.

<sup>48</sup>All graduate work of Kato was done at Waseda University; his doctoral theses were submitted to Tokyo University and doctorate was awarded it in 1970.

<sup>49</sup>Kojima went to study for PhD at Columbia University (New York), where he spent two years 1979-1981, and wrote his Ph.D. thesis under the supervision of John Morgan. Kojima is now a professor at Tokyo Institute of Technology. His students include: Shigeru Kitakubo (Ph.D 1992, Graph Theory), Yosuke Miyamoto (Master 1990, Hyperbolic Geometry), Yasushi Yamashita (Master 1991, Ph.D 1996, Hyperbolic Geometry), Mitsuhiko Takasawa (Ph.D 2000, Surface Automorphism), and Kazuhiro Ichihara (Ph.D 2000, 3-Manifolds).

<sup>50</sup>Kohno graduated in 1979 at Tokyo University. He went to Nagoya, later to Kyushu University, and finally to Tokyo University. Toshie Takata was his student.

<sup>51</sup>Yamasaki did his PhD in 1982 at the Virginia Polytechnic Institute and State University under the supervision of Frank Quinn.

- (It) Ryuuichi Ito (b. April 18, 1944), graduated Waseda Univ. Mar. 1967. PhD. 1983.
- (Kas) Takumi Kasai (b. June 3, 1946), graduated Waseda Univ. Mar. 1969. PhD. 1977. Computational Complexity.
- (Ma) Seishi Makino (b. Nov. 21, 1961), graduated Waseda Univ. Mar. 1987. Computer Science.
- (Mo) Etsuro Moriya (b. Jan. 7, 1947), graduated Waseda Univ. Mar. 1970. PhD. 1976. Computer Science.
- (Nakai) Nakai (b. Feb. 24, 1957), graduated Waseda Univ. Mar. 1979. PhD. 1985 (On topological types of polynomial map germs, Kyoto Univ).
- (Nakam) Tsuyoshi Nakamura (b. March 3, 1947), graduated Waseda Univ. Mar. 1969. PhD. 1982 (Waseda Univ.), DMS. 1983 (Nagasaki Univ.). Statistical Sciences.
- (Nar) Hiroshi Narushima (b. Sept. 30, 1943), graduated Waseda Univ. Mar. 1967, D.Sc. Dec. 1977 (Waseda Univ.). Discrete Mathematics, Computer Science.
- (Nishin) Tetsuro Nishino (b. Feb. 3, 1959) graduated Waseda Univ. Mar. 1982, D.Sc. Dec. 1991. Computer Science.
- (Nishim) Takashi Nishimura (b. Feb. 5, 1958), graduated Waseda Univ. Mar. 1983, D.Sc. Dec. 1988. Singularity theory.
- (Sa) Ken Sawada (b. Feb. 28, 1953), graduated Waseda Univ. Mar. 1975, D.Sc. Dec. 1981, Waseda Univ. (Extended orbits of diffeomorphisms and Omega-explosions).
- (So) Teruhiko Soma (b. June 26, 1955), graduated Waseda Univ. Mar. 1980.
- (Su) Shao-Chin Sung (b. Sep. 8, 1969), graduated Waseda Univ. Mar. 1993, Computer Science.
- (Ta) Sei'ichi Tani (b. June 5, 1963), graduated Waseda Univ. Mar. 1987. PhD. 1996. Computer Science.

- (To) Yoshio Togawa (b. Jan. 1953), graduated Waseda Univ. Mar. 1975, D.Sc. Mar. 1978, Waseda Univ. Dynamical Systems.
- (Tsu) Kensei Tsuchida, (b. Mar. 29, 1958), graduated Waseda Univ. Mar. 1982. D.S. 1994. Computer Science.
- (Yak) Takeo Yaku (b. Oct. 21, 1947), graduated Jiyu Gakuen College Mar. 1970. M.Sc. Waseda Univ. Mar. 1972. Ph.D. Waseda Univ. Dec. 1977. Computer Science.
- (Yam) Makoto Yamamoto (b. Jan. 26, 1953), graduated Waseda Univ. Mar. 1976. Doctor of Science 1982. Topological graph theory.

## 5 Other mathematicians whose work is related to knot theory

Of course not all mathematicians interested in knot theory are students or grand students of Terasaka. We give below three examples of a world famous mathematician whose work is related to knot theory:

- (Mats) Yukio Matsumoto (b. 1944) graduated from Tokyo University in 1967 under the supervision of Tamura<sup>52</sup>. Matsumoto visited the Institute for Advanced Study (in 76-78) where he met José Montesinos (leading Spanish mathematician) and they started a very fruitful collaboration. Matsumoto is now the president of Mathematical Society of Japan. Matsumoto's students include:  
 Ken'ichi Kuga, Zjunici Iwase, Katura Miyazaki, Masahico Saito (master<sup>53</sup>), Ken'ichi Ohshika, Osamu Saeki (1992, PhD, Tokyo University), Kiyoshi Ohba, Kazumasa Ikeda, Nariya Kawazumi, Tomotada Ohtsuki, Kazunori

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<sup>52</sup>Ichiro Tamura, well known specialists in Differential Structures and Characteristic Classes, was a student of Shōkichi Iyanaga (see footnote 5), who was in turn a student of Teiji Takagi (1875–1960), specialist in class field theory, one of the first great Japanese mathematicians. Takagi studied in Germany (in Gottingen, 1899-1901, under Hilbert and Klein) sent there by the Japanese Government as was the norm for young able people 100 years ago. His teacher was Rikitaro Fujisawa (1861-1933) who represented Japan at the ICM in 1900, [Iy].

<sup>53</sup>Saito and Miyazaki obtained their PhD at University of Texas at Austin under the supervision of C.Gordon.

Kikuchi, Kazuhiko Kiyono, Chuichiro Hayashi, Toru Ikeda, Goro Fujita, Kazuo Habiro, Yuichi Yamada, Akiko Shima, and Shigeru Tamura.

(Fu) Shinji Fukuhara (now at Tsuda College) was born in 1945 and graduated in March 1968 from Tokyo University, under the supervision of Ichiro Tamura. His students include:

Noriko Maruyama (Dr. Sci., 1994), Jinko Kanno, Haruko Miyazawa (formerly Aida, Dr. Sci., 2000), Miyuki Okamoto (doctorate under S.Suzuki at Waseda University), Naoko Kamada (formerly Ishii), Kazuko Onda.

(Matu) Takao Matumoto (now Hiroshima University). Born 1946, graduated in 1968 (Tokyo University) under the supervision of Ichiro Tamura. Then his advisor was Tokushi Nakamura (M1) and he obtained his master degree at Tokyo University under the supervision of Akio Hattori (in 1970). He did his doctorate in France (Orsay) under the supervision of Laurent C.Siebenmann. Mitsuhiro Sekine was Matumoto's student working in Knot Theory.

## **6 Names of some Japanese topologists born before 1946**

Kunizô Yoneyama (1877-1968), Takeo Wada (1882-1944),

Keitarô Haratomi (1895-1968), Kôshiro Nakamura (1901-1985),

Kinjirô Kunugui (1903-1975), Hidetaka Terasaka (1904-1996),

Hiroshi Okamura (1905-1948), Shôkichi Iyanaga (1906–)

Motokiti Kondô (1906-1980), Atuo Komatu (1909-1995),

Takeshi Inagaki (1911-1989), Shizuo Kakutani (1911–),

Kiyoshi Aoki (1913–), Makoto Abe (1914-1945)

Takeshi Yajima (1914-1998), Kiiti Morita (1915-1995),

Kunihiko Kodaira (1915-1997) Ryozi Sakata (Shizuma) (1916-1985),  
Tatsuzi Kudo (1919-), Hiroshi Uehara (1923-),  
Hidekazu Wada (1924-), Shin'ichi Kinoshita (1925-),  
Hiroshi Noguchi (1925-), Jun-iti Nagata (1925-),  
Keiô Nagami (1925-), Minoru Nakaoka (1925-),  
Nobuo Shimada (1925-), Tatsuo Homma (1926-),  
Ichiro Tamura (1926-1991), Hiroshi Yamasuge (1926-1960),  
Katsuhiko Mizuno (1926-), Ichiro Yokota (1926-),  
Hiroshi Toda (1928-), Masahiro Sugawara (1928-),  
Ken-ichi Shiraiwa (1928-), Kunio Murasugi (1929-),  
Junzo Tao (1929-), Tsuneyo Yamanoshita (1929-),  
Yoshihiro Saito (1930-1997), Fujitsugu Hosokawa (1930-),  
Youko Hashizume (Tao) (1930-), Nobuo Yoneda (1930-1996),  
Shôrô Araki (1930-), Tokusi Nakamura (1930-),  
Kôzi Shiga (1930-), Haruo Suzuki (1931-),  
Masahisa Adachi (1931-1993), Yasutoshi Nomura (1932-),  
Seiya Sasao (1933-), Kunio Ôguchi (1933-),  
Takaaki Yanagawa (1935-), Hiromichi Matsunaga (1935-),  
Yoshihiro Shikata (1936-), Teiichi Kobayashi (1936-),  
Fuichi Uchida (1938-), Mamoru Mimura (1938-),  
Keiko Kudo (Kamae) (1939-) Kazuaki Kobayashi (1940-),  
Shin'ichi Suzuki (1941-), Mitsuyoshi Kato (1942-),

Masako Fukuda (1942–), Katsuo Kawakubo (1942-1999),  
Goro Nishida (1942–), Akihiro Tsuchiya (1942–),  
Yaichi Shinohara (1942–), Hajime Sato (1944–),  
Hiroshi Ikeda (1944–), Ryuichi Ito (1944–),  
Yukio Matsumoto (1944–), Shinji Fukuhara (1945 –)

## 7 **Ralph H.Fox**

Ralph Hartzler Fox was born March 24, 1913. A native of Morrisville, Pa., he attended Swarthmore College for two years while studying piano at the Leefson Conservatory of Music in Philadelphia [C-F, Fo-8]. He received his master's degree from the Johns Hopkins University. He obtained his Ph.D. from the Princeton University in 1939 under the supervision of Solomon Lefschetz (1884–1972). Fox was married, when he was still a student, to Cynthia Atkinson. They had one son, Robin. After receiving his Princeton doctorate, he spent the following year at Institute for Advanced Study in Princeton. He taught at the University of Illinois and Syracuse University before returning to join the Princeton University faculty in 1945 and staying there until his death in 1973.

He devoted most of his career to mathematical topology, and in particular to knot theory: the study of different ways of placing closed curves or loops in three-dimensional space.

At the International Congress of Mathematicians, Cambridge, Mass., 1950, Fox gave a talk on “Recent development of knot theory at Princeton” [Fo-7]. He gave a series of lectures at the Instituto de Matemáticas de la Universidad Nacional Autónoma de México in the summer of 1951. He lectured to the American Mathematical Society (1949), to the Summer Seminar of the Canadian Mathematical Society (1953), and at the Universities of Delft and Stockholm, while on a Fulbright grant (1952) [Fo-3]. His influential book, *Introduction to Knot Theory* [C-F], was based upon lectures given at Haverford College under the Philips Lecture Program (spring 1956). The last papers of Fox were published in *Fundamenta Mathematicae* and *Osaka Journal of Mathematics* [Fo-5, Fo-6].

Fox career is summarized nicely in the book dedicated to his memory [Neu]: “The influence of a great teacher and a superb mathematician is measured by his published works, the published works of his students, and perhaps foremost, the mathematical environment he fostered and helped to maintain.”

One of Fox’s interests was the ancient Japanese board game of Go (which he learned as a graduate student). He represented the United States in the first international Go tournament, held in Tokyo in 1963, and later received the fourth Dan degree conferred by the international Go organization in Tokyo.

Fox was an active Quaker.

He died December 23, 1973 in the University of Pennsylvania Graduate Hospital, where he had undergone open-hearth surgery. He was survived by his widow, the former Cynthia Atkinson<sup>54</sup>, and their son, Robin H. of Minneapolis [Fo-8, Fo-10].

Fox’s Ph.D. students include:

A.L.Blakers (the first student of Fox, 1947), R.C.Blanchfield, W.A.Blankinship, E.J.Brody, R.H.Crowell, D.M.Dahm, C.H.Giffen, H.R.Gluck, D.L.Goldsmith, F.J.González-Acuna, H.W.Kuhn, R.H.Kyle, S.J.Lomonaco, Jr., S.B.Mauer, Y.Nakagawa (the last student of Fox, 1973), B.C.Mazur, J.W.Milnor, L.P.Neuwirth, N.F.Smythe, J.R.Stallings, Jr., G.Torres-Diaz, W.C.Whitten and E.F.Whittlesey. A.L.Anger, M.Artin<sup>55</sup>, D.A.Gay and Kenneth A.Perko, Jr. wrote their Princeton Senior Thesis under the supervision of Fox.

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<sup>54</sup>She died recently.

<sup>55</sup>Michael Artin is a son of Emil Artin, and he did his Ph.D under the supervision of Oscar Zariski.

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