Mathematics to the Masses: the Teachings of the Chinese Mathematician Hua Loo-Keng

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1 Purpose of the Paper

This article has been written to draw once more the attention of the international community of scientists on work and life of the great Chinese mathematician Hua Loo-Keng. He led the mathematical sciences through a period of great political turmoil, reoriented mathematical research and above all put a great deal of effort into the popularization of mathematics. In mass campaigns he taught hundreds of thousands of Chinese workers how to apply simple mathematical methods in their daily work. This article focuses on Hua's teaching of mathematics to the masses rather than on his theoretical work. For various reasons we ask once again attention for Hua Loo-Keng. First of all, his life and work illustrate the interaction between science and political development. An interaction in two directions. His work on applied mathematics was influenced very much by the social and political developments in the People's Republic of China, and his work contributed to strengthening the political processes as well. The interaction between socio-political development and science is still an important issue, although the debate on this issue seems to fade away. Which processes determine the development of science and the items on research agenda's is still a relevant question. The tremendous problems faced by humanity such as degradation of environment or development problems may require much more conscious choices of scientific activities. Life and work of Hua Loo-Keng reveal the far-reaching consequences of the choices he made,

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choices which were not evident and are debatable indeed. A second reason to write this paper is the following. There exists a persistent prejudice amongst mathematicians that only pure mathematics requires full intellectual creativity and that application of mathematics in practice is of a lower standard, not a challenge for real scientists. Hua's work shows in a clear way how application of mathematics in the real world requires much creativity and intellectual power of the highest quality. Last but not least it is tried to illustrate in this paper what type of applications Hua was dealing with during the mass campaigns and to discuss critically the merits of his approach. We start in Section 2 with a survey of Hua's life and work in the context of China's political developments. In Section 3 we try to explain why Hua Loo-Keng was able to be so successful in his mass campaigns. By discussing various examples, in Section 4 Hua's teaching during the mass campaigns is illustrated. We end the article with an evaluation in Section 5 of the lessons for the present day which can be drawn from his life and work, in both industrialized and developing countries. In the discussion on lessons for developing countries an extensive use will be made of one of the authors' experiences in African countries.

2 Life and Work

In order to understand Hua's work better, it is important to know his personal background as well as some aspects of Chinese culture and of the political developments in the People's Republic of China.

There is an extensive biography in English of Hua Loo-Keng (Salaff, 1977) in which a good deal of attention has been given to the political developments in China up to 1972 and to Hua's role in them. Moreover, many bibliographic notes about Hua's life have been published (see e.g. Halberstam, 1986; Hu, 1982; Hua and Wang, 1989; Li, 1989; Wang, 1986; Zeng, 1983 and 1988).

Hua Loo-Keng came from a rather poor family in China. He was born in November 1910 in a small town called Jintan in Jiangsu Province[1]. After nine years of schooling his family was unable to support a high school training for him. Instead, his father sent him to a vocational school for accountancy in Shanghai. Even so, due to financial difficulties after one and

[1]All the Chinese names in this article will be spelt according to the "Pin Yin" system which is now standard in the People's Republic of China, except internationally accepted names like Chiang Kai-Shek, Hua Loo-Keng and Mao Tse-Tung.

a half years he had to return home to assist his father in running a small grocery shop. In his nine years at school, Hua Loo-Keng was a troublesome boy and his school record was not as good as one might imagine. His mathematical exercises were not neat but were full of alterations — he was always looking for different and better methods of solution (cf. Hu, 1982). His talents in mathematics were first recognized by his school mathematics teacher Wang Wei-Ke. When Hua returned home after his short stay in Shanghai, his father was not happy about his work in the shop since he seemed to be obsessed with reading irrelevant books on mathematics. Observing this, Wang Wei-Ke arranged a job for Hua in the school. His job was simply to clean up the classrooms and to assist other teachers if necessary, but this also gave him the opportunity to read the books on algebra, geometry, calculus, etc., which Wang Wei-Ke obtained for him. He was then about eighteen years old. One year later, he contracted typhoid fever. The doctor believed that there was no chance that he would survive, but he did, although the disease left him lame in his left leg for the rest of his life. This period was crucial for his career. First of all, he became convinced that doing mathematics would be the only suitable profession for him due to his poor physical and material conditions. Secondly, he had to develop a way to learn everything by himself. Later he always emphasized in his teaching that independent thinking is of great importance (cf. Wang *et al.*, 1984). Although he was extremely talented, he always gave the credit for his achievements to his hard work and method of study.

In 1930 he read a paper in the Science Journal published in Shanghai written by a professor called Su Jia-Ju. The paper was about a solution method for finding roots of polynomials of order 5. Hua found errors in the paper, submitting a note entitled "Reasons why Su Jia-Ju's method for solving an algebraic equation of order 5 cannot hold" — his first paper — to the same journal, where it was published. This paper was written in an unconventional manner, but was extremely clear and concise. This surprised Professor Xiong Qin-Lai, the director of the mathematics department of Qinhua University which is one of the best universities in China. Professor Xiong was even more surprised when he learnt that Hua Loo-Keng had no formal mathematical education, and he invited Hua to come to Qinhua. Since nobody knew him there, the department asked him first to send a photo in order to be able to pick him up from the station. From the photo Hua Loo-Keng's looks may not have been extraordinary, but his extraordinary intelligence soon became apparent. At the beginning, his job in Qinhua was not too different from the previous one at his home school. He was an assistant in the department — more or less a secretary and he also took care of the library. There are many stories about his remarkable method of reading books from the library. He would take a book, read the table of contents and introduction, and then turn off the light and imagine writing the book himself. After a while he checked with the book. In this way he went through all the essential points quickly and enjoyed the reading of the book better. Soon he began to follow advanced courses in the department. In one and a half years, he finished all the courses and became a lecturer. This was very unusual in a society with rigid hierarchies, since Hua Loo-Keng had no academic diploma.

It was there that Hua developed his interest in additive number theory. He once sent out three papers at the same time for publication in foreign journals and all were accepted. His name became known abroad and this resulted in an invitation from Hardy in 1936 to visit Cambridge, where he stayed two years. Hardy advised him to finish a doctoral thesis, but Hua decided not to pursue a degree, since this would restrict the area of his study. In fact Hua had no academic degree until 1979 when he received an honorary doctorate from Nancy University in France. His independent approach to study at Cambridge was indicative of his character, always following the path which he believed to be most useful, however unorthodox it might be. In his two years stay in Cambridge, he published more than ten papers on various problems in number theory. Some of his results are still significant (cf. Hua, 1983).

In 1938, Japan invaded China. Hua felt that his country needed him, so he cancelled his planned visit to the Soviet Union, and returned to China immediately. From 1938 to 1945 he was a professor in the South-West United University in Kunming, Yunnan Province, in the southern part of China. This university was formed by the merging of Qinhua University and Beijing University which were dispossessed by the Japanese. During the eight years of the Sino-Japanese War, it was one of the very few Chinese academic institutions. Many famous Chinese scientists were trained there. Kunming was in the unoccupied area, but suffered a lot from bombardments. The working conditions were extremely poor. Some of his important work was completed during that time, e.g. his well known book "Additive Prime Number Theory" although this was published in China only many years later.

From 1946 till 1949, he worked in the USA, first at Princeton and then at Illinois University, having been sent to the USA by the Nationalist Government of Chiang Kai-Shek, together with several other young scientists.

Some people claim (see e.g. Salaff, 1977, p. 213) that by sending these young scientists to the USA the Nationalist Government hoped to get access to advanced technological knowledge, in particular nuclear science. However, there is no reason to assume that any such access was possible. During that period Hua wrote outstanding theoretical papers on number theory and many other topics from a wide mathematical spectrum, e.g. group theory and analysis of functions of several complex variables.

When Mao Tse-Tung removed Chiang Kai-Shek and the People's Republic of China was created in 1949, Hua made the choice to return to China. In an open letter to all Chinese students staying in the United States, he tried to convince them to go back to China as well. He used such arguments as "a foreign garden can never be your own garden", and that the new China needed their skills. Hua Loo-Keng returned to China in 1950. Unlike some of his returning colleagues, Hua was well received there. He was immediately appointed Director of the Mathematics Department of Qinhua University and two years later became Director of the Institute of Mathematics of the reorganized Academia Sinica. Like all university staff members Hua became very much involved in reforming campaigns. Students and teachers were organized in groups to study Marxism-Leninism and the Thoughts of Mao Tse-Tung and to analyse their own behaviour and attitudes. In these years, Hua Loo-Keng wrote an article (see Salaff, 1977) which contained much self-criticism. In this article, which is entitled "We should have only one tradition, the tradition of serving the people", Hua criticized the elitist traditional system of education in China, and the orientation of Chinese research towards foreign western countries. He urged students to break with selfish traditions and to serve the people. He apologized for his mistakes and recognized the leadership of the Communist Party in the process of personal transformation. He showed his determination to teach basic principles of science and technology to the masses.

In the early fifties, Hua continued his theoretical work. Three books were published, one on Additive Prime Number Theory, one called Introduction to Number Theory and a third one on Harmonic Analysis of Functions of Several Complex Variables. In those years, theoretical publications were still appreciated in China, and the third book won the Natural Science Prize of Academia Sinica in 1957. Meanwhile he also wrote articles in newspapers and magazines especially about education. Learning is a step-wise process, he wrote, not a process of repetition, which has been the main obstacle of creative thinking in China. Students must think independently, experience obstacles in the scientific research process and have the courage to be creative. He pleaded for steady, industrious and innovative work. His essays were later published as a book (see Wang *et al.*, 1984).

During that period, Hua represented China at various conferences abroad, e.g. the World Council of Peace in 1954 and the New Delhi Conference of Asian nations. In 1956 he was elected a member of the Central Committee of the China Democratic League. This league, the core of which consisted of intellectuals and artists not being members of the Communist Party, played a peculiar role. It functioned as a "democratic party" under the leadership of the Communist Party and was tolerated since it could contribute to the so called United Confrontation, uniting non-communists inside and outside China.

In the period of the First Five Year Plan (1953-1957) the People's Republic of China enjoyed one of its most flourishing periods. In 1956 and early 1957, the so called Hundred Flowers Blooming Together campaign s-tarted. The campaign was initiated by the Communist Party to encourage intellectuals to speak out and criticize the party. It was said that this would help the party for its rectification. Many intellectuals responded. The China Democratic League suggested to the State Council that students should be assigned jobs according to their expertise and that scientists should be free from overwhelming social and political activities. These ideas, together with other suggestions and criticisms, were later considered to be anti-socialist and against the leadership of the Party. The campaign was soon followed by a massive rectification of intellectuals and later by the anti-rightist movement, in which hundreds of thousands intellectuals and senior university students were physically attacked. The Rightists, who together with Landlords, Rich Farmers, Counter-revolutionarists and Bad Elements were called the "Five Black Classes", were persecuted severely then and in later years. Being an example of a self-made expert, Hua Loo-Keng managed to survive in this great political turmoil. He again made public statements of self-criticism, and was very depressed at that time. Hua continued to be a member of the Central Committee of the China Democratic League, and as such he participated in the second session of the Congress (1959), one of several such sessions which he attended during his lifetime, although he joined the Communist Party of China only in 1979.

In 1959, Hua was appointed Vice-President of the newly founded China University of Science and Technology which was separated from Academia Sinica in 1958 with the aim of rapid promotion of advanced science and technology in China by teaching large numbers of students mainly from working class families. In that period, Hua wrote some volumes of his textbook "Introduction to Advanced Mathematics". These volumes are simple, clear, interesting and yet showed no lack of rigour. They attracted a lot of young people in China.

In the late fifties, economic life in China showed many changes. Mao Tse-Tung believed that Communist Development in China would consist of three stages. The initial stage was called the "new democratic" stage allowing private ownership. It was to be followed by the "socialist" stage emphasizing collective ownership, the final stage was the "communist" one where each type of private or collective ownership was to be abolished. During years of economic progress, especially after the good harvest in 1958, it was believed that the "socialist" stage could be entered and that this stage could be gone through quickly. The party set out three ideological lines, which were known as the "Three Red Flags", one of which was the Great Leap Forward. Under these flags many changes were introduced. People's cooperatives were imposed on a large scale both in the rural areas and in the urban centers. A nation-wide rural backyard steel making campaign was started. Many initiatives were taken to industrialize and modernize the country. A flood of extremely exaggerated statistical data appeared, relating to both industrial and agricultural sectors all over the country. The whole event was followed by severe famine from 1959 to 1962. Millions of people were later reported to have died of hunger in Anhui Province alone. Bad weather during these three years, loans by the Soviet Union which had to be refunded immediately and the sudden withdrawal of experts by the Soviet Union after relations between China and that country were broken in 1958 were blamed for the crisis. Responding to the Great Leap Forward campaign, many scientists tried to contribute to economic development. Hua Loo-Keng was very active amongst them. At that time he started to develop a keen interest in applications of mathematics to actual technological and economic problems in China. Together with some of his students, he started in 1958 to visit transportation departments to promote the use of operations research methods. He initiated the use of Input-Output analysis in formulating national economic plans.

During that same period, intellectuals and students were also encouraged to do physical labour. Hua and his students participated in agricultural activities. This experience led him to start to apply linear programming and graphic methods to agriculture (see e.g. Hua *et al.*, 1962) He put a lot of effort into it, giving great publicity to the results and starting a campaign to explain his approach in popular language. For foreign mathematicians, the style of his campaign may be peculiar, but in the Chinese culture such a style is quite common. During meetings of groups of local people in Shandong Province, he gave vivid illustrations of the use of graphical methods to solve linear programming problems, wrote rhymes and verse in praise of linear programming, organized on-the-spot workshops and radio broadcasts, etc..

From 1963 to 1965, the Chinese economy was recovering from the crisis. Liu Shao-Qi, the Chairman of the People's Republic of China at that time, also held the portfolio of economic affairs. Liu stimulated large scale industrialization, especially in the urban centers; he started to dissolve people's cooperatives and to allow private profits. Mao Tse-Tung, as Chairman of the Communist Party, was supposed to be in charge of ideological matters, and he emphasized rural development and small scale industrialization in the rural areas. Both Mao and Liu feared the existence of revisionism in the Party and the danger of class enemies taking over the leadership. Again, many cadres, intellectuals and artists were criticized as "bourgeois" trying to reinstall capitalism. This time, the criticism of the intellectuals heralded the disastrous Great Proletarian Cultural Revolution.

Hua's experiences and those of his students during the years 1958-1965 in the field of transportation and agriculture encouraged him to extend his activities. In 1965, together with a team of students, he launched a mass campaign to promulgate simple operations research and statistical methods in the industrial sector of China's economy and to identify ways of implementing these methods in practice. Not long afterwards, in 1966, the Great Proletarian Cultural Revolution was started by Mao Tse-Tung. He hoped to dissolve what was then called the bourgeois commanding headquarter headed by Liu Shao-Qi. A long lasting political turmoil began, which officially ended in 1976. Hua was under enormous political pressure and had an extremely difficult time especially at the beginning of the Cultural Revolution. A lot of his manuscripts, including the uncompleted part of "Introduction to Advanced Mathematics", "The Input-Output Method", "Mathematical Methods in Transportation Problems" were confiscated and lost (cf. Wang *et al.*, 1984). Hua Loo-Keng had some personal contacts with Mao Tse-Tung, and Mao wrote to Hua on several occasions, encouraging him to continue working with and for workers and peasants. Hua Loo-Keng mentioned these contacts in one of his speeches (see Academia Sinica, 1977) after the fall of "Gang of Four". Certainly, Mao's protection helped Hua Loo-Keng considerably.

Actually Mao started the cultural revolution in the educational sector. He encouraged the "rebellion" of young students to challenge all authorities, organizations and leaders. He believed that previous rectification movements had not been successful in eliminating the danger of the reinstallation of capitalism by the existing enemy class inside the Communist Party. This could only be done by a new revolution from the masses up to the top of the Party. The massive “rebellion actions” resulted in a state of great chaos throughout the country. No organization could function, no one could stay out of the “revolution”. Many leaders of the Communist Party were attacked physically by “red guards” (high school or university students) and other aggressive elements, and later the massive persecution extended to academic authorities, cadres and other people. Large numbers of people were attacked, publicly humiliated, put in jail or killed. This chaotic state lasted for almost four years, during which no university enrolled a single student. Different political groups arose each claiming to be loyal to Mao, and fought against each other during the radical movement. Mao said later that the cultural revolution was one of the two important things he did in his life. The other was the creation of the People’s Republic of China.

In these years Mao introduced (“The Order of the 7th of May”) a new educational system. Schools were to be set up as communities, where agricultural, industrial and military training had to be combined. There emerged a lot of the so called “May 7” cadres’ schools and communist universities. “The educational system needs a revolution”, Mao said, “education must be combined with physical labor and with basic production activities.” The word “practice” was exaggerated to an absurd extent, being taken to mean instant and visible usefulness in everyday life. Nearly all academic activities were ignored and stopped, all “theoretical authorities” were persecuted, and all traditional and academic systems were criticized and abandoned. The less formal education one had, the better.

During the Cultural Revolution, Hua Loo-Keng tried hard to continue his campaign of applying and popularizing mathematical methods. It showed again his ability to work under harsh conditions. The fact that Hua concentrated on the industrial sector is not surprising, since industrialization was considered to be the backbone of development, and not only heavy industry in the urban centers, but also rural industry providing equipment for farm mechanization and rural development. The policy to make industry the leading factor of agricultural development resulted in a great number of factories and enterprises all over the country. Hua Loo-Keng and his team travelled through more than 20 provinces, municipalities and autonomous regions in China, including hundreds of cities covering almost all of the vast country. He and his team visited thousands of factories and gave as many lectures and talks during these visits. Millions of workers and professionals attended his lectures. Sometimes his audience for one lecture could be more than hundred a thousand people. The usual routine was for the problem-solving team to visit a factory for one week. The visit started with working sessions in the factory to discuss production problems. Later in the week Hua would give a lecture in the main hall on Optimum Seeking Methods and Overall Planning Methods, after which the team visited individual workshops to explain how to apply those methods. The team claimed to have solved 10,000 problems in one province alone (see Hua and Wang, 1989). These sessions provided the team of trouble-shooting mathematicians with a permanent flow of new practical problems. During that time Hua Loo-Keng wrote two readers, which became extremely popular, "Popular Lectures on Optimum Seeking Methods" (published in 1971) and "Popular Lectures on Overall Planning Methods" (published in 1965). The Optimum Seeking Methods and the Overall Planning Methods were not only applied to industry, but they were also reported to have been used even in shops. The campaign was so popular that the readers were distributed to almost every technical department and institution throughout the country. An educational film called "Optimum Seeking Methods" was also made and widely shown (Academia Sinica, 1977). Never had mathematicians reached so many people.

The campaign went on when the "Gang of Four" was crushed (soon after Mao Tse-Tung died in 1976) and the Cultural Revolution ended. After Deng Xiao-Ping took office in 1978, the open door policy was announced. People started to concentrate on the development of the country's economy, rather than on political struggle. In this transformation period, the work of Hua Loo-Keng was very much appreciated. In 1983, while he was still alive, a six-hour long television series was made and broadcast in China about his early life. This was most unusual in China, especially for a scientist.

Hua Loo-Keng died of a heart attack in 1985 while giving a lecture in Tokyo. In total he wrote more than 10 books and 200 scientific papers. Because of his great work in popularizing mathematics and optimization techniques, he became known to almost everybody in China, and is regarded as a national hero.

3 A Few Observations

Hua Loo-Keng's success in bringing mathematics to the masses is difficult to comprehend for those who are not familiar with the conditions, personal, cultural and political, in which he lived and worked. A few observations on these conditions may contribute to an appropriate evaluation of that work. First of all, his personality was clearly crucial. Hua himself was self-made and very hard working. Lacking formal academic training himself, he did not put much stress on formal education. On the contrary, he promoted self-learning again and again. This was not in the Chinese educational tradition, which was, in contrast, authoritarian, being based on the Confucian Philosophy of preservation of nature and society. Students were expected to be docile, copying lessons which were dictated to them, the reverse of self-learning.

Why then did the popularization of mathematics fall on such fertile ground? The idea of explaining what is complicated, including mathematics, in simple terms, is deeply rooted in Chinese culture. There is a Chinese saying "Difficult In, Easy Out", which is taken as a principle for scholars and teachers. The meaning is that one should study difficult theory, master it and make it easy to understand for others, and Hua Loo-Keng's teaching is a very good example of this principle. Hua's popularization of mathematics corresponded very well with some of Mao Tse-Tung's thoughts on education. In his essay "On Practice" (see Mao, 1975), first published in 1935, Mao Tse-Tung was very critical of the elitist nature of the traditional Chinese educational system. He recommended teachers to "speak in the popular language" and "to make what you say interesting" (cf. Swetz, 1974). Mao's views were reflected during the First Plenary Session of the Chinese People's Political Consultative Conference on 21st September 1949, when it was decided in Art. 43 on the role of science: "Efforts should be made to develop national sciences to place them at the service of industrial, agricultural and national defense construction; ... scientific knowledge should be popularized". Of course, Hua's popularization campaign was especially so successful, since his examples were all taken from the workplace, from daily practice. A further contribution to the popularity of Hua's campaign came from the political drive to increase production, which was welcomed with general enthusiasm because of the particular historical context. China had been humiliated by the western powers, not only physically but also psychologically. For thousands of years, China had considered itself as the center of civilization, the "Central Kingdom" of the world. Then the western powers showed up with much more advanced technology, China was completely defeated and was forced to accept various humiliating treaties with the west, and the dream seemed to be over. Mixed feelings towards western ideology and technology developed: a feeling of inferiority and at the same time, and for different reasons, of superiority. The Chinese learned the importance of a strong defensive capacity heavily dependent on modern science and technology. There was a strong desire to improve the country's status and to catch up with the western powers as quickly as possible. Especially after the creation of the People's Republic of China, much was expected from the Communist Party. The Chinese people supported the Party's policies with tremendous enthusiasm. In these circumstances, it is not surprising that Hua's mass campaign, aiming to increase production, was warmly received by the mass of the people. At that time, mass movements were fashionable throughout the country. On the one hand, this provided the environment for Hua's campaign, and on the other hand, his prestige and the success of his campaign contributed to the general popularity of such mass movements.

Although Hua Loo-Keng rarely expressed explicitly his own political views in his writings, he certainly supported some of Mao Tse-Tung thoughts, given the many references to Mao Tse-Tung in his early writings. For instance, Chapter 3 of "Popular Lectures on Optimum Seeking Methods" (Hua, 1971) deals with the leadership of the Party and the association with the masses. Of course, most of these references were included because during that time in China every writer was supposed to (or liked to) show his/her dedication to Mao Tse-Tung's thoughts and to the leadership of the party. Nevertheless, it is very likely that Hua Loo-Keng was himself dedicated to socialist development and challenged by Mao's doctrine to base theory on practice.

Mao classified experts in two classes, namely "red experts" and "white experts", representing "proletarian" and "bourgeois" elements respectively. Hua Loo-Keng was apparently considered as a "red" expert, although he was criticized by some of Mao's followers for putting too much emphasis on mathematical expertise in promoting young researchers. Even his works on pure mathematics were criticized as typical examples of theory lacking in practical value (cf. Wang *et al.*, 1984). It is said that Hua Loo-Keng had not entered a library for ten years during the cultural revolution and could only do theoretical research late at night in his home (cf. Hu, 1982).

4 Optimum Seeking Methods and Overall Planning Methods

In this section we will illustrate the type of mathematics discussed by Hua in the factories. Optimum Seeking Methods and Overall Planning Methods were the main techniques he applied during his mass campaign. Optimum Seeking Methods are methods to minimize or maximize a function in one or more variables. In public lectures in factories Hua concentrated on methods to minimize or maximize functions of one variable, a type of optimization problem which is highly relevant in numerous industrial applications, for example, making a product of specified quality within a minimum process time corresponds to minimization of a function, making a product of highest quality within a specified time to maximization. In these situations the setting up of experiments to determine optimal process conditions can be considered to be an iterative process to optimize the value of a function. In fact, Hua's Optimum Seeking Methods were very much related to design of experiments. The idea that a fairly simple method to minimize a function could be useful in improving quality or increasing production in industry was very appealing indeed.

However, even this type of technological problem is much more complicated in practice. Usually, many factors influence the quality of a product and the process time. Moreover, the quality of a product is usually characterized by several properties, and improving one property often worsens another. Hua Loo-Keng was very much aware of this, and discussed the problem in the very first example of his reader "Popular Lectures on Optimum Seeking Methods" (Hua, 1971). He used as an example the problem of making "Mantou" (a popular Chinese food, a type of steamed bun) in canteens. An important additive is sodium, which contributes to the Mantou's taste. The sodium content should be optimal. But what is optimal? Everybody has a different taste. He suggested making Mantous with different sodium contents each day and asking customers to asses them. In this way he derived an optimality index. He remarked that in reality not only sodium, but also other factors such as yeast, type of flour etc. also influence the taste.

A large number of examples illustrating the practical value of Hua's Optimum Seeking Methods to increase Chinese industrial production was included in a monograph published by Academia Sinica in 1977. At the end of this section, we shall show a few examples. We note that the publication, which appeared in the post cultural revolution period, also had a strong propaganda interest.

In Hua's Optimum Seeking Methods, the golden section method, which in China is known as the 0.618 method, plays an important role. Hua showed that it is possible to demonstrate the use of this method in a simple way. As an illustration he discussed the setting up of a series of experiments

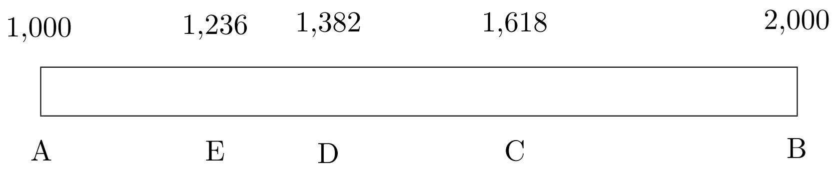

Figure 1: Illustration

to find the optimum amount of carbon in one ton of steel (known to be between 1,000 and 2,000 grams) according to a certain criterion. He asked the audience to keep a number in mind: 0.618. Then he took a strip of paper and marked the two ends A and B (see illustration) by 1,000 and 2,000 grams.

The point C such that AC 0.618 times the length of AB was marked by 1,618 gram. He folded the strip AB in the middle and marked the point D which is symmetric with respect to 1,618 by 1,382 gram. Two experiments should be carried out corresponding to C and D, with carbon contents of 1,618 and 1,382 grams. If the experiment with 1,382 grams showed the better result, then the right side of the paper strip from 1,618 could be torn off. He folded the new paper strip again in the middle and marked the point E being symmetric to 1,382, by 1,236 grams. A new experiment with carbon contents of 1,236 grams should be carried out, and the results of the experiments with 1,236 and 1,382 grams compared. Supposing that the 1,382 experiment gave a better result, Hua then explained that the left side of the paper strip from 1,236 could be torn off as well. This procedure went on until the differences in experimental results were sufficiently small. He showed that every time the length of the paper strip had been reduced by a constant fraction: 0.618. He stated without giving a proof that this is actually the best possible approach in certain sense.

In his reader, Hua discussed cases where more than one factor (variable) need to be considered. In fact, he dealt with the two factor case, which he could illustrate using a square piece of paper with the two sides representing two factors. In both one and two factor cases, generalized convexity of the objective function is required. Hua Loo-Keng managed to explain that without getting into technicalities. Moreover, he introduced in his early popular reader (Hua, 1971) many other methods, such as steepest descent and some other simple direct methods (without using derivatives). He also explained how to treat cases where more than one experiment is allowed at one time (parallel experiments). In the later edition of his book "Optimum Seeking Methods" (Hua, 1981), many mathematical proofs were provided as well. Hua referred many times to Mao Tse-Tung's teaching which says that "In every complicated process influenced by many factors, there must exist one factor which dominates the others. Once this key factor has been found, others will follow more easily". Based on this argument Hua suggested that for a complicated practical problem all possible influencing factors should be analysed and classified according to their importance. By ignoring less important factors problems of only small sizes would be obtained. In many cases this would already give satisfactory results. Actually he was advocating quick and effective heuristics. In many published examples this approach is indeed followed (see also below). In his reader, Hua Loo-Keng claimed that his approach of the Optimum Seeking Methods provided the means to reach the target of the Communist Party "To construct socialism in a fruitful, quick, good and economical way".

Overall Planning Methods deal with problems in project management. In a project several tasks have to be fulfilled. Tasks have precedence restrictions and the execution of each task takes a certain time. In which order should the tasks be carried out in order to finish the whole project in the shortest time? Overall Planning Methods refer to the Critical Path Method (CPM), the Program Evaluation and Review Technique (PERT), etc.. This type of problem can be explained using graphs. Hua Loo-Keng introduced the problem in his "Popular Lectures on Overall Planning Methods" (cf. Hua, 1965 and Wang *et al.*, 1984) with a simple example of making tea. He described a situation where water has to be boiled, tea pot and cups have to be washed. There is an obviously logical way to order the jobs to save time. He structured the situation by drawing a network representing jobs and relations, which was easily acceptable to the audience. "This is a simple matter, but as an introduction it leads to a method in production management", he explained, "If it gets a bit more complicated, really one might get confused by decisions to be made. In modern industry, often it is not as simple as making tea. There are more tasks, hundreds and thousands or even more with complex relations. Often it can be the case that everything is ready except for a few spare parts, so the completion time is delayed. Or you make an effort to speed up the process, but do not concentrate on the key points. So by overworking day and night, finally you finish a task in a hurry. But then you find out that you actually have to wait for some other tasks to be finished." These lectures impressed a lot of people. They easily accepted these "clever methods" in their daily life and work.

The optimization and planning methods are intuitively easy to understand and the mathematics involved is elementary. Hua did not explain difficult mathematical concepts like integration or differentiation, but helped people to develop a sense of optimization and planning.

The results of the mass campaigns have been reported to be enormous. Hua included in his reader (Hua, 1971) the following example, reported by the Shanghai Oil Refining Factory. It roughly reads as follows:

We accepted at the end of 1969 a research task to find an additive to lower the condensation point of certain lubrication oil. To our knowledge, this additive should consist of five materials. The composition of the additive would affect the condensation point very much. Also, the amount of additive in the oil has an effect on the result. Using our own experience and foreign literature, we had done more than 100 tests in half a year within the range indicated by the foreign literature. The best result had the effect to decreasing the condensation point from -16^0C *to* -42^0C*. We thought it was the final result and were about to stop the experiments. Just then, Comrade Hua Loo-Keng came to popularize Optimum Seeking Methods. We spent merely two more weeks doing more than ten tests and decreased the condensation point further to* -46^0C*. The procedure was as follows:*

– We found that the composition of the additive was the key factor in this matter. The more additive the better, it seemed, in bringing down the condensation point, but the effect did not increase noticeably for more than 0.5% additive. So we fixed the amount at 0.5%. We further found that among these five materials, two of them could be dropped. Since the three remaining materials A, B *and* C *add up to 100%, the problem reduced to a two-factor problem.*

– The amount of A was first fixed at 25%. According to experience, the range of amount of B was set from 0.100 at 0.600 mole. Applying the optimum seeking method to determine the amount of B we found a composition in which the amount of B was 0.134 mole, with condensation point -46^0C*.*

– We then fixed the amount of B to be 0.134 mole, and tried to find the best amount of A. Finally, we found it was still around 25% (in weight).

In the monograph of Academia Sinica, 1977, in total 451 applications were listed. In the monograph, factories reported applications, all claiming successful results. We quote here two examples to illustrate the way of presentation. The first one from Long Quan Wu Limestone Ore Division of the Capital Steel Company is entitled “Using Optimum Seeking Methods in Finding the Composition of Explosives”.

In our mining area, we used to use the No. 2 rock explosive, which is costly and difficult to obtain. Later we used other explosives, but the result was not ideal due to the low blasting power. The workers in our mining area therefore applied the 0.618 method in testing compositions of ammonium-coal explosives. The right composition of diesel oil and wood powder was found with the following formula: ammonium nitrate/diesel oil/wood powder = 100/3/6.5. The resulting explosive has power similar to that of the No. 2 rock explosive, but with three times lower costs. Every explosion can thus save 12,000 yuan for our country, and that amounts to 300,000 yuan per year.

Another short report was from a match factory in the remote region Guanxi.

Every year, about 1,000 m^2 *of wood for producing matches in our factory would get too dry and would be spoiled. It was then used as firewood, and so caused a big waste. We applied Optimum Seeking Methods to adjust the temperature to make the wood moist and also to adjust the corresponding processing procedures. As a result, the quality of matches made of such wood rose to meet the national first class standard. After optimum seeking, from the end of 1974 to the end of 1975 we had used 1,000* m^2 *of previously abandoned wood for producing high quality matches. This saves up to 38,000 yuan.*

As a matter of fact, the popularity of the campaign can also be seen from the great number of books on popularizing Optimum Seeking Methods published during and after the cultural revolution. Applications were shown in the reader by Hua and his team (Hua, 1977) and in the collection of applications compiled by Academia Sinica in 1977. Moreover, many provincial towns compiled books on Optimum Seeking Methods with examples. Most provinces and big cities had their own “Office of Popularizing Optimum Seeking Methods”. To list some of the books compiled by these offices, see e.g. Beijing Group, 1972; Guandong and Guangzhou Office, 1972; Sichuan Office, 1985, and Xie and Tan, 1979. Many more such books have been published.

5 Discussion

Hua Loo-Keng's life and work reveal very clearly the close interaction between political processes and the role of science. The political changes in China have to a great extent determined the direction of Hua's scientific work in the later part of his life. On the other hand, Hua had a great impact on the implementation of political ideas, both by his work and by his scientific prestige. That Hua was considered to be a hero in China reflects the ambiguity of his role. His popularity was due to his original and pathbreaking activities, but making him a hero strengthened his role in the political process as well. Hua being a strong-willed independent thinker had to establish a balance between his role as independent scientist and the political use which was being made of his work by Party and Government. As a prestigious intellectual holding high office he was responsible not only for his success-stories, but also for the political use which could be expected to be made of them. Many mathematicians all over the world have been challenged by Hua's "mathematics for the masses". Although there is good reason to admire his original thoughts and initiatives in popularizing mathematics, the full assessment of Hua's merits depends on a profound evaluation of his political role as well. We do not embark here on such an evaluation, but observe that he has contributed to support a political regime which has been responsible for disasters, failures and mistakes.

Some aspects of Hua's work were important in the specific context of his time, while others are of permanent significance. The success of Hua's practice was partly due to the relatively low educational level of Chinese workers and the technological backwardness of industry. The simple repetition of those mass campaigns would, in present circumstances, be inappropriate, since one of their major purposes is now served to a large extent by the Chinese national system of education, including professional training.

The papers of Hua and his team on the popularization of applied mathematics mainly describe mathematical methods. These papers are - see also the recent publication of an English translation of papers by Hua Loo-Keng (Hua and Wang, 1989) - fascinating and show how very difficult it is to explain mathematical methods in simple language. Indeed, it is a task which perhaps could only be performed by a great mathematician. It is to be noted that Hua called his approach popularization of mathematics. Although he developed in his papers many valuable ideas on transfer of knowledge, nowhere did he explicitly analyze the educational principles involved. Some keywords (reinvention, discovery, intuitive methods, etc.)

show up in both Hua's papers and in standard works on mathematics education (see e.g. Freudenthal, 1973), but the intentions are very different. Hua did not focus on mathematics education, but on the application of some elementary techniques to be understood by people who had almost no background in mathematics. Although mathematics education is increasing in many countries and therefore the general level of knowledge of mathematics is also increasing, in many branches of society there are specialists, who are not (any longer) familiar with mathematics. They would gain very much from the popularization methods of Hua and his colleagues. These methods therefore still deserve international attention.

Hua and his team did not report their experiences with mass campaigns in the thousands of factories. Therefore various questions remain unanswered: how were the problems identified, could the problems really be framed as optimization and planning problems, were the results implemented or was implementation hampered by organizational constraints etc.. As was seen in the previous sections of this paper, the long published list of "selected examples" did not reveal much about these questions. Hua Loo-Keng himself mentioned that he regretted very much not having time to describe his field experiences in detail. This is indeed to be regretted. Such reports would have shown us more clearly the real merits of his approach. It is quite likely that they would have shown that the results were not always very satisfactory, because most problems in practice are much more complex than the presentations in e.g. Hua and Wang's book (1989). Reading the book one gets the impression that industrial problems are just of a technical nature and can be solved by mastering a few techniques. Such a point of view cannot be correct. Production planning whether in small workshops or in large industrial enterprises, requires a much wider variety of skills than operations research techniques alone. Usually there are many important factors, which cannot without great difficulty be incorporated in mathematical models: hierarchical decision relations, uncertain demand and supply, etc.. Mathematical models can play an important, but only partial role. Real solutions can only be the result of an extensive process of interaction between planners and technicians on the workplace and the mathematical modelers. It is a pity that Hua and his team, who would certainly have faced hundreds of unexpected problems, did not mention them. In spite of these critical remarks we should give full credit to some impressive results of Hua's activities. People became aware that they could indeed increase production and workers and technicians started experiments to do so on a large scale.

During the last two decades the mathematization of society has taken place rapidly in industrialized countries. The development of personal computers has played an important role in this. In all branches of society: industry, agriculture, finance, public services etc., operations research and statistical techniques are frequently used. Nevertheless, the implementation of results is still far from perfect. The role of e.g. operations research has been severely criticized: it is too sophisticated, too theoretical, researchers do not understand the real problems, uncertainty makes the role of models of limited value, etc.. Communications between experts in different fields and between experts and non-experts have become extremely important. We need to find, or at least to try to find, common languages to understand each other. Hua Long-Keng's practice showed us that it is possible to build this sort of bridge. This is perhaps Hua's most important lesson for future generations. He was able to communicate with laymen on the workfloor and with technicians, not only since he was an excellent teacher, but also because he had a profound interest in the practical problems at stake. Hua and his team were strongly challenged by them and used all their intellectual power and mathematical skills to help to master them. A merger between practice and theory became reality.

Although problem-solving mathematical techniques may be primarily developed for large-scale industries, at an advanced level of technology, the experiences in China have shown that they can offer a lot in low-tech situations as well. This point may be of special importance to developing countries. The problems of many developing countries are tremendous, at all levels and in all sectors: poor infrastructure, risky food production, poor market structure, lack of credit systems, etc.. Many developing countries rely on the agricultural sector as the backbone of their economy, and in this sector farmers face many problems: poor agricultural conditions, low inputs, low yield-levels, uncertain yields due to fluctuating rainfall, pests and diseases etc.. Within the research community there is a lack of understanding of the problems the poor have to struggle with. Village organisations, farmers cooperatives, district-planners, lower echelons and regional branches of government departments and other local bodies do not always have access to the offices where the financing of research projects is being decided on. In addition they often lack the experience needed to come up with specific research proposals, in particular where it concerns research involving mathematics. Yet there are many problems arising in the everyday surroundings of the masses of the people where such research might well be considered, and where mathematical modelling and operations research could make a valuable contribution. Here we can draw an important lesson from Hua Loo-Keng and his colleagues. Mathematicians, statisticians and various other scientists who are usually wrapped up in departmental offices or university lecture-rooms have to step down and enter on field work. This need not be done by Hua-like mass campaigns. Under other circumstances different approaches are more appropriate. This can be illustrated by experiences at the University of Dar es Salaam in Tanzania (see Schweigman, 1979, 1985). In order to make courses in operations research as relevant as possible, the students, who nearly all came from the rural areas, returned to their own villages in the vacations to make analysis of the agricultural problems in their villages with the help of relatives, neighbours and village functionaries. They examined, for instance, whether it might be useful to contract a loan at a bank, whether they ought to acquire an ox-drawn plough, whether it would be best to plant early or late, with an eye to the spread of labour, what acreage should be designated for communal farming, and many other things. The results were worked out at the University and discussed by students and staff. These studies, which made fruitful use of mathematical modelling and simple operations research methods, brought up many crucial points for discussion such as, for instance, that what was best for a village need not be best for the government; that the selling prices of produce were not always in reasonable proportion to the amount of agricultural labour; what could be done about the lack of a market within reach where produce might be sold?; were the farmers to bear the risks of fluctuating world market prices themselves, or would it be better to accept an income that was stabilised by the government but on average much lower?; etc.. Studies like these created an awakening of consciousness, students began to dare to look at problems in the village in an integrated manner. The mathematical approach offered a means of giving an analysis of the problems, and the interaction between the computation of alternatives and the discussion of the influence of political decisions or of the necessity of governmental measures caused the real problem to become clearer. It is emphasized that these studies did not have the immediate effect of solving farmer's problems; such studies can usually have only an indirect effect: new suggestions may be made, existing plans or ideas may be supported or rejected, or sometimes it only helps to discuss problems adequately. Actually solving farmers' problems is usually a very complicated process, and it may take years before, for instance, traditional practices are changed in order to accept a new agricultural method. This may require much effort, extension activities, training, farmers' participation, etc..

In developing countries farmers' initiatives to improve living conditions, like cooperative farming, installation of cooperative cereal banks, of credit systems, etc. deserve a lot of scientific support. Recently, an interdisciplinary research project on food security on the Central Plateau in Burkina Faso, West Africa was set up. One of the objectives was to determine areas of priority for future field research. It resulted (see Schweigman *et al.*, 1989, and Maatman *et al.*, 1992) in field research projects which were all centred around farmer's cooperative initiatives to overcome the agricultural crisis on the Central Plateau. In these projects mathematicians work together with farmers, interviewers, extension officers, economists etc.. There is a strong need for mathematicians and quantitative scientists who are prepared to work in interdisciplinary teams and to develop a profound interest in farmers' problems. They have to be very good at mathematics, and apply all their intellectual energy to explore how mathematical modelling can be used to study the practical problems. Moreover, they have to be able to explain in common language what they are doing and what the results of their efforts are. So, in fact, in that respect disciples of Hua Loo-Keng are required.

Both as pure and as applied mathematician Hua Loo-Keng showed great originality. Some people may argue that his move from pure mathematics to low-to-the-ground applications is a loss for science. This point of view is not shared by the authors of this article. The permanent flow of practical problems provides mathematicians with a rich resource of theoretical problems as well. Daily life problems can be a challenging inspiration even for pure mathematicians.

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