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Creativity in a Scientist's Life : an Attempt of Analysis from the Standpoint of the Science of Science

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CREATIVITY IN A SCIENTIST'S LIFE: AN ATTEMPT OF ANALYSIS FROM THE STANDPOINT OF THE SCIENCE OF SCIENCE

Assuming that scientific creativity is not very well known, and, as a rule, less popular among a wider public than, say, literary or artistic creativity, the author asserts that this is harmful both to science and to scientists. In order to contribute, if only to some extent, to the improvement of this situation, a scientifically precise analysis of creativity in science has to be taken up.

THE STARTING-POINT OF THE STUDY

This study does not claim any far-reaching generalization of its results. Nevertheless, I hope it may be of interest to scientists or even to people who are not involved in science directly but interested in it if only because science was, is and will always be one of the most powerful factors in mankind's progress and culture.

The empirical material used in this study is strictly limited. It consists of a group of 70 scientists, whose names I have chosen undeliberately; they have been selected in a cursory survey of the easily accessible biographical sources in the library of the Institute of Botany of the Polish Academy of Sciences at Cracow. Thus, the group of 70 names is but a small sample of the large total number including all botanists of the more recent times. This is not a strictly random sample, though, such as is used by statisticians or biometricians, because after a random selection of 50 long-lived botanists of different specializations I have added 20 other names with a view to make the group more representative. Of course, only those have been included in the sample who *1*) had devoted all their lives primarily to science, *2*) whose lives I could get acquainted with in detail from their biographies or sometimes from my own memory, and 3) those who had left an uninterrupted scientific output in the form of printed publications, *i.e.* without longer intervals of inactivity.

The group consists exclusively of botanists. It seems, however, that the regularities observed in the lifetimes and the scientific activities of our group of botanists are similar to, or even identical with, those which could be observed in groups of scientists representing different natural sciences (geologists, geographers, zoologists *etc.*). To a small extent, I have taken notice of these among the zoologists and geologists whom I observed marginally. Whether the regularities observed can be recognized as essentially valid for all scientists, or some of these even for all creators in any field of cultural creativity, is a question that can be answered only after separate further investigations.

SPECIFIC FEATURES OF THE SAMPLE OF 70 BOTANISTS

That the sample analysed here is sufficiently representative is, I think, attested by the following features.

1. The sample includes scientists from 18 European and American countries. The particular scientists have not been included in the sample by way of mere raffling, but nevertheless in a fairly random manner and without preconceived choices. Poland is represented by 11 names, Germany has 11 representatives, Sweden 6, Czechoslovakia 6, the Soviet Union 5, Britain 4, Austria 4, France 4, Switzerland 4, the Netherlands 3, Italy 3, the United States 3, Canada 1, Mexico 1, Norway 1, Hungary 1, Denmark 1, Brazil 1.

2. Our list includes those names of deceased scientists who had published their works exclusively or mainly in the 20th century. A small percentage of them had published their papers in the second half of the 19th or towards the end and at the beginning of the 20th centuries.

Table 1

Groups of botanists according to the years of publications

Specification	Number of persons	Percentages
Published papers exclusively in the 19th century (Čelakovski, Delpino, Hartig, Miquel, de Bary and Korshinski)	6	9
Majority of papers published in the 19th century	10	14
Published papers at the end of the 19th and the beginning of the 20th centuries	10	14
Published papers exclusively in the 20th century	44	63
Total	70	100

3. Table 2 contains the basic list of the group of 70 scientists arranged according to the durations of their lifetimes. It is called basic because it contains several additional data apart from the durations of their lives. This Table will be referred to several times later on. It is also important because each scientist is given a number in it, which will occasionally stand for his full name.

In order to obtain a simplified and clear picture of the respective lifetimes of the scientists Table 3 has been arranged according to the decreasing order of the consecutive periods of five years reached by the scientists.

Table 3

Duration of lifetimes of scientists from the sample of 70

Five-year periods of life	Number of scientists	Five-year periods of life	Number of scientists
93—90	4	59—55	7
89—85	2	54—50	3
84—80	9	49—45	0
79—75	12	44—40	1
74—70	15	39—35	1
69—65	8	34—30	0
64—60	7	29—25	1

If we assume the 70th year of a scientist's life as the latest retirement age, in our group 42 scientists (60 per cent) reached and survived it, mature age (40—69) was reached by 26 persons (37 per cent), and 2 scientists (3 per cent) died in young age, *i.e.* at less than 40. It follows that the group analysed here is relevant for a study of the interdependence between scientific creativity and the durations of their lives, for almost all (68 out of 70) members of the group lived a full life, *i.e.* youth, maturity and old age, attaining also full scientific creativity, or else they lived at least into maturity (partly or in full). Obviously, it has not been attempted to include in the list young botanists who died prematurely and had not reached mature age and, consequently, had manifested their potential scientific creativity to a small extent only.

4. Another common feature to all members of the group is that the periodicity of their lives is not dependent on whether the given person was a professional or amateur botanist.

5. A further specific feature of the group is the diversity of the specializations represented by the scientists.

Table 4 lists 15 specializations of the group of 70 scientists. This list is not accurate, and in some cases it is perhaps not true. This is due to the fact that I could have easily been mistaken in establishing the primary fundamental specialization of the scientists; in more profound and competent analyses research specializations listed as second or third may

Table 2

List of the scientists constituting the sample according to their age, posts and production

Number	Name	Post	Country	Age	Dates of birth and death	Number of publications		Research specializations
						scientific	others	
1	2	3	4	5	6	7	8	9
1	Jules Pavillard	PU Grenoble and others	France	93	1868—1961	98	—	*Algology*, systematics, sociology of plants
2	Bohumil Němec	PU Prague and others	Czechoslovakia	93	1873—1966	454	215	*Physiology*, cytology, anatomy
3	Agnes Chase	Custodian at museum	United States	90	1869—1959	67	—	*Agros tology*, systematics
4	Edwin Bingham Copeland	PU California, Berkeley	United States	90	1873—1964	186	—	*Physiology*, taxonomy, agricultural botany of tropical countries
5	Bolesław Hryniewiecki	PU Warsaw and others	Poland	88	1875—1963	158	—	*Plant geography*, floristics, history of botany, plant anatomy, preservation of nature
6	Paul Victor Fournier	Teacher at monastic schools, D.D	France	87	1877—1963	50	—	*Floristics*, systematics
7	Jules Offner	PU Grenoble	France	84	1873—1957	157	—	*Mycology*, pharmacology, floristics, plant geography
8	Emil Godlewski, Sr.	PU Cracow	Poland	83	1847—1930	80	—	*Physiology*, agrochemistry
9	Carl Scottsberg	PU and manager of botanic garden Göteborg	Sweden	83	1880—1963	294	—	*Geography*, florostocs, taxonomy, algology
10	Adolpho Ducke	Self-taught amateur	Brazil	83	1876—1959	132	—	*Dendrology*, floristics, systematics, plant geography
11	Louis Charles Lutz	PU Paris	France	81	1871—1952	155	—	*Mycology*, physiology, cytology, teratology
12	Th. Arch. Sprague	Scientist at botanical garden Kew	Britain	81	1877—1958	279	—	*Systematics*, taxonomy
13	Wilhelm Detmer	PU Jena	Germany	80	1850—1930	78	—	*Physiology*, agrobotany
14	Oskar Drude	PU Dresden	Germany	80	1852—1933	178	—	*Plant geography*, systematics
15	Karl Goebel	PU Munich and others	Germany	80	1855—1935	207	—	*Organography*, morphology, ecology
16	F. W. Ch. Areschong	PU Lund	Sweden	78	1830—1908	68	—	*Anatomy*, physiology, systematics
17	Stanisław Sokołowski	Pat Higher School of Forrestry, Lwów	Poland	78	1865—1943	160	—	*Dendrology*, forest cultivation
18	Robert Wilhelm Kolbe	Amateur, Ph. D.	Sweden	78	1882—1960	87	—	*Algology*, diatoms
19	Sandór Jàvorka	Custodian at museum	Hungary	78	1883—1961	141	—	*Floristics*, systematics of vascular plants
20	Maximino Martinez	PU and manager of museum, Mexico	Mexico	78	1888—1964	78	—	*Floristics*, systematics, medical plants
21	Otto Renner	PU Munich, Jena	Germany	77	1883—1960	127	—	*Genetics*, systematics, physiology
22	Hugh H. Thomas	Doctor of law and botanist	Britain	77	1885—1960	49	—	*Palaeobotany*, evolution of seed plants
23	Otto Rosenberg	PU Stockholm	Sweden	76	1872—1948	60	—	*Cytology*, genetics
24	Josef Podpěra	PU Brno	Czechoslovakia	76	1872—1954	148	219	*Geography and sociology of plants*, bryology, floristics
25	Richard Kräusel	PU Frankfort on Main	Germany	76	1890—1966	175	—	*Palaeobotany*
26	Felix Eugen Fritsch	PU London	Britain	75	1879—1954	106	—	*Algology*, anatomy, systematics of higher plants
27	Kurt Noack	PU Berlin and others	Germany	75	1888—1963	49	46	*Plant physiology*, biological chemistry
28	Renato Pampanini	PU Florence	Italy	74	1875—1949	306	—	*Floristics*, plant geography, preservation of nature
29	Jaroslav Peklo	PU Prague	Czechoslovakia	74	1881—1955	73	—	*Physiology*, phytopathology, cytology, morphology, paleobotany
30	Federico Delpino	P Higher School and manager of botanical garden Genua	Italy	72	1833—1905	117	—	*Biology of flowers*, general biology, morphology
31	E. F. Glinka-Janczewski	PU Cracow	Poland	72	1846—1918	70	—	*Developmental morphology*, anatomy, systematics, genetics
32	August F. Ch. Went	PU Utrecht	Netherlands	72	1863—1935	180	—	*Physiology*, pathology
33	Claf Hagerup	Custodian of museum	Denmark	72	1889—1961	46	—	*Morphology*, ecology, plant geography, systematics
34	Nikolai A. Maksimov	PU Petersburg and others	Soviet Union	72	1880—1952	243	—	*Physiology*, experimental ecology

35	František A. Novak	PU Prague	Czechoslovakia
36	S. G. Navashin	PU Petersburg and Kiev	Soviet Union
37	Zygmunt Wóycicki	PU Warsaw and Lwów	Poland
38	Paul Wilhelm Magnus	PU Berlin	Germany
39	Carl Schröter	P Polytechnic Zurich	Switzerland
40	Robert Chodat	PU Geneva	Switzerland
41	Harald Kylin	PU Lund	Sweden
42	Ernest Gäumann	PU Zurich	Switzerland
43	Jadwiga Wołoszyńska	PU Cracow	Poland
44	L. J. Čelakovski	PU Prague	Czechoslovakia
45	Edward Strasburger	PU Bonn and Jena	Germany
46	Oscar Juel	PU Uppsala	Sweden
47	Richard Wettstein	PU Vienna	Austria
48	W. L. Krishtofovitch	PU Leningrad, Moscow and others	Soviet Union
49	Ernst Gilg	P and custodian of museum Berlin	Germany
50	Hugo Zapałowicz	Doctor of law	Poland
51	Noel Yvri Sandwith	Custodian of museum Kew	Britain
52	Jens Holomboe	PU Oslo	Norway
53	Clarence Emmeren Kobuski	Amateur	United States
54	Robert Hartig	PU Munich and others	Germany
55	Franz Firbas	PU Göttingen	Germany
56	John Briquet	Manager of museum and botanical garden Geneva	Switzerland
57	F. A. W. Miquel	PU Amsterdam and others	Netherlands
58	Melchior Treub	Manager of botanical garden Buitenzorg	Netherlands
59	Achille Forti	Docent at Modena and Padova	Italy
60	R. F. Marie Victorin	PU Montreal	Canada
61	H. Handel-Mazzetti	Custodian of museum Vienna	Austria
62	Anton de Bary	PU Strasburg and others	Germany
63	Friedrich Vierhapper	P Veterinary Academy Vienna	Austria
64	Wincenty Siemaszko	P Higher School of Agriculture Warsaw	Poland
65	Marian Raciborski	PU Lwów and Cracow	Poland
66	S. P. Kostitchev	PU Petersburg	Soviet Union
67	Karel Hrubý	PU Brno and Prague	Czechoslovakia
68	Josef Brunnthaler	Amateur	Austria
69	S. I. Korshinski	PU Tomsk and Petersburg	Soviet Union
70	Antoni Żmuda	Doctor, assistant at Cracow Univ.	Poland

P — Professor; PU — Professor at the University of.

72	1892—1964	98	324	*Floristics*, systematics, plant geography, ecology, morphology
71	1859—1930	78	—	*Cytology*, morphology, physiology
71	1871—1942	102	—	*Cytology*, anatomy, mophology, plant geography
70	1844—1914	611	—	*Developmental morphology*, systematics, mycology, floristics
70	1855—1928	185	—	*Plant geography and ecology*, algology, peat-bog and meadow investigations
70	1865—1949	464	—	*General botany*, anatomy, physiology, systematics, algology, bacteriology
70	1893—1963	150	—	*Algology*, biology, systematics, morphology, anatomy, physiology, cytology
70	1893—1963	253	—	*Mycology*, pathology, systematics, physiology
69	1882—1951	55	—	*Aloglogy*, palaeobotany
68	1834—1902	192	—	*Morphology*, floristics, systematics, history of botany
68	1844—1912	124	—	*Cytology*, anatomy, physiology
68	1863—1931	89	—	*Anatomy*, physiology, cytology, systematics, mycology
68	1863—1931	115	—	*Systematics*, morphology, anatomy, ecology, plant geography, palaeobotany
68	1885—1953	347	—	*Palaeobotany*, geology, plant geography, systematics
66	1867—1933	202	—	*Systematics*, pharmacognosy
65	1852—1917	54	—	*Plant geography*, floristics, geology
64	1901—1965	184	—	*Systematics*, floristics
63	1880—1943	277	—	*Floristics*, plant geography, ecology, history of botany
63	1900—1963	65	—	*Dendrology*, floristics
62	1893—1902	156	—	*Dendrology*, pathology, physiology
62	1902—1964	103	—	*Plant geography*, palynology, systematics
61	1870—1931	273	—	*Systematics*, plant geography, taxonomy
60	1811—1871	305	—	*Taxonomy*, floristics, morphology, anatomy, plant geography, physiology, history of botany
59	1851—1910	103	—	*Systematics*, anatomy, cytology, biology of flowers
59	1878—1937	134	—	*Algology*, hydrobiology, history of botany
58	1885—1944	107	177	*Systematics*, plant geography, ecology, organizer of science
58	1882—1940	144	—	*Plant geography*, floristics, systematics
57	1831—1888	94	—	*Comparative and developmental morphology*, mycology, algology, cytology, anatomy, systematics, bacteriology
56	1876—1932	73	—	*Systematics*, floristics, plant geography, ecology
56	1887—1943	33	—	*Mycology*, phytopathology, ecology
54	1863—1917	160	—	*Palaeobotany*, comparative morphology, plant geography, mycology, cytology, algology, preservation of nature
54	1877—1931	168	—	*Physiology*, biochemistry, microbiology
52	1910—1962	174	—	*Genetics*, entomology
43	1871—1914	39	—	*Algology*
39	1861—1900	49	—	*Plant geography*, floristics, ecology, general biology
27	1889—1916	29	—	*Floristics*, systematics, ecology

Table 4

Division of the sample of 70 scientists according to their principal specializations *

Principal speclializations	Number of scientist from Table 2	Number of scientists
1. Agrostology	3	1
2. Algology	1, 18, 26, 41, 43, 59, 68	7
3. Anatomy	16, 46	2
4. General biology	40	1
5. Biology of flowers	30	1
6. Cytology	23, 36, 37, 45	4
7. Dendrology	10, 17, 53, 54	4
8. Physiology	2, 4, 8, 13, 27, 29, 32, 34, 66	9
9. Floristics	6, 19, 20, 28, 35, 52, 70	7
10. Geography and ecology	5, 9, 14, 24, 39, 50, 55, 61, 69	9
11. Genetics	21, 67	2
12. Comparative and developmental morphology	15, 31, 33, 38, 44, 62	6
13. Mycology	7, 11, 42, 64	4
14. Palaeobotany	22, 25, 48, 65	4
15. Systematics (taxonomy)	12, 47, 49, 51, 56, 57, 58, 60, 63	9

* Names of scientists in the second column have been substituted by their numbers from Table 2.

have to be shifted to the first place. Nevertheless, the possible mistakes in this respect do not deprive the data of Table 4 of all value for a description of our group of 70 scientists, because the Table nevertheless shows that the members of the group represented at least 15 different botanical specializations.

PRODUCTIVITY INDEXES

A scientific life finds its expression primarily in scientific publications and, therefore, publications are the principal basis for an evaluation of the creativity of each scientist. Although they are the main but not the only form of expression of scientific creativity, the quantitative output becomes almost the only palpable basis in comparisons of all kinds. The other forms, which are often equally important, are much more difficult to grasp, i.e. to be defined in such a way that they could express accurately and univocally the differences between the particular scientists. In this study, such features characterizing the scientific creativity and, at the same time, the social value of the group of scientists have not been disregarded but, first and foremost, the output of printed scientific papers has been recognized as important. Obviously, their quality rather than quantity is most important, but in lists similar to ours it is the quantity that comes to the fore, since it is difficult and sometimes arbitrary to define the value of the papers which are inspiring science, such that establish new trends, discover new facts and working methods, carry out syntheses and contribute to putting into practical application (especially in economic life) theoretical discoveries. Values of this kind cannot be expressed numerically. This notwithstanding, I have also attempted to take into account this difficult evaluation of the quality (value) of the scientific output of each of the 70 botanists.

It is relatively easy to notice that a full life of a scientist consists of four natural periods: *I* — the period of youth (absorbing or assimilating knowledge), *II* — the period of flourishing creativity, which consists primarily in manifesting one's inborn creative abilities in print, *III* — the period of maturity which finds its expression in selective scientific production, in teaching and social activities, and *IV* — the period of old age, with all the accompanying specific circumstances. It is to be said at once that the highest productivity, i.e. quantitative production, of scientific creative work occurs as a rule in period *II*, less often in period *III*.

Table 5 presents the indexes of the productivity as shown in printed publications by each of the 70 botanists. Of course, the number of publications by each of the 70 botanists. Of course, the number of publications only is involved, and not an evaluation of their quality. The indexes have been calculated by dividing the sum of publications within each of the four periods by its duration expressed in years.

The indexes of the scientists' production calculated for the four periods of their lives refer often not only to their scientific publications but sometimes also to all those papers which they have ever published (popularizing papers, obituaries, occasional articles, book reviews, reports read at scientific congresses and conferences, and even small notes). It could be useful to make a careful selection from the whole of a scientist's printed output in order to separate scientific papers from all the other ones and next to take into consideration exclusively the scientific papers (possibly including handbooks and popularizing works). The rest would be left out. However, in my opinion, such a procedure would not be right, since both the full productivity and the full creativity of a scientist's life are adequately expressed only by the whole of his production, both quantitatively and qualitatively. Even those publications which are distinctly non-botanical may furnish valuable data concerning the scientist's personality and to establish his place within the national and world histories of science.

For these reasons I have decided to include in one presentation all the publications of each of the 70 scientists, *i.e.* both scientific papers in the broadest sense and publications on social and related issues, no matter how far they might diverge from botany proper. Nevertheless, in a few cases another way has been taken: when a scientist's non-scientific activities were so different and abundant that they constituted as if another line of his life's work. To this group belong botanists who were either

Table 5

Productivity index for four periods expressed by the ratio of the number of publications to the durations of the periods in years

Number in basic list	I	II	IIO	III	IV
1	0.7	2.7	2.7	2.4	0.4
2	5.0	6.2	6.8	3.0	0.8
	1.8	7.7	8.4	9.6	2.9
3	0.7	1.7	1.7	1.5	0.4
4	3.4	5.2	5.5	2.2	1.4
5	1.7	2.5	2.3	3.6	1.4
6	—	2.8	2.8	1.3	0.4
7	1.2	2.3	2.6	4.7	2.0
8	0.3	1.9	1.9	1.9	0.6
9	2.2	4.9	5.8	5.1	2.6
10	—	2.3	5.6	2.9	2.8
11	3.5	6.0	8.3	2.5	0.1
12	3.2	8.6	11.2	4.5	1.1
13	2.2	3.7	4.0	0.9	0.05
14	3.4	4.4	5.3	2.0	0.8
15	3.4	4.1	4.4	3.1	—
16	0.3	2.2	2.7	1.0	0.6
17	3.4	5.6	7.0	2.4	0.2
18	—	4.3	5.2	(0.2)	2.7
19	0.7	3.1	3.8	2.4	2.2
20	0.3	1.3	0.8	2.9	0.8
21	1.6	2.4	2.3	2.3	2.6
22	2.3	0.9	1.0	0.3	0.7
23	1.0	2.2	1.6	0.9	0.6
24	3.2	3.5	4.4	2.3	1.3
	5.7	4.9		2.8	2.6
25	1.6	6.2	6.0	2.6	—
26	3.3	1.8	1.8	1.7	2.0
27	0.1	1.6	2.1	1.3	—
28	3.7	8.3	7.1	7.8	2.2
29	—	3.1	3.2	1.2	0.7
30	1.2	2.9	3.2	3.2	3.2
31	2.0	1.5	2.0	1.3	—
32	2.0	4.2	4.7	3.7	3.0
33	0.3	1.2	1.7	1.2	0.6
34	1.0	4.1	6.2	4.5	11.1
35	1.2	4.2	4.9	1.5	0.6
	1.3	4.2	4.5	9.5	2.8

Number in basic list	I	II	IIO	III	IV
36	1.5	3.6	3.4	1.5	0.7
37	1.7	4.2	4.5	1.6	0.8
38	9.0	18.5	18.9	17.9	6.2
39	0.8	4.3	4.7	4.4	1.8
40	7.6	29.3	18.9	5.6	5.0
41	1.7	3.5	3.8	3.7	3.6
42	2.9	3.9	4.4	3.1	0.3
43	1.0	2.4	2.0	1.1	0.2
44	1.4	5.8	6.2	4.9	2.9
45	3.0	1.9	3.2	3.3	—
46	1.9	2.2	2.6	1.5	2.0
47	2.2	3.6	3.3	1.3	0.8
48	3.1	6.6	12.0	6.5	6.0
49	2.2	6.5	7.7	2.8	1.6
50	—	0.7	0.7	2.2	—
51	2.2	5.0	6.0	4.0	—
52	4.0	7.4	6.2	4.8	5.5
53	—	1.6	3.1	1.7	—
54	0.3	3.8	4.8	6.0	—
55	2.2	3.0	3.0	1.8	—
56	4.0	8.7	12.3	2.4	—
57	2.6	7.3	9.8	8.6	—
58	3.5	4.1	6.1	1.2	—
59	5.0	2.0	3.3	2.2	—
60	1.4	2.8	2.3	4.1	—
61	3.2	3.6	4.5	4.0	—
62	2.3	3.1	3.4	1.3	—
63	1.4	1.7	2.2	2.6	—
64	1.1	2.2	2.7	0.6	—
65	2.8	7.2	7.9	3.1	—
66	0.8	3.7	4.5	7.9	—
67	7.3	6.0	5.4	5.4	—
68	1.0	2.4	4.4	—	—
69	1.7	2.7	2.0	—	—
70	3.7	(2.6)	—	—	—
Total	2.5	4.3	4.8	3.1	1.9

Note: For numbers 2, 24 and 35 two separate productivity indexes have been calculated: the upper indexes refer to their scientific activities, whereas the lower refer either to their social (or other) activities or to those who had another profession besides (e. g., law) and worked productively in both.

both scientifically fertile and socially active or had two professions and worked productively in both. This group consists primarily of B. Němec (2), J. Podpěra (24), F. Novák (35), R. F. Victorin (60), and K. Hrubý (67). There are further names resembling these either in high productivity (a high index of it) or else in having many interests, but it is impossible to make any strict classification of them here.

Since 40 persons from the group of 70 botanists (*i.e.* 59 per cent) had their maximum quantitative scientific production in period *II,* and 19 persons in period *III,* it can be stated that period *II* is the most important of the four in this respect.

THE FOUR PERIODS IN A SCIENTIST'S LIFE

Description of the first period

Before I proceed to a discussion of the first period I wish to point out that this period is preceded by a preliminary (initial) phase, which is linked up with the education that the future scientist obtains at home and in secondary school. Accurate data concerning this topic cannot be often found in scientists' biographies. Our group has also furnished neither abundant nor precise information. Therefore, the initial phase will not receive as much attention as it deserves.

The initial phase begins often very early, at the age of 15 or 16. In our group this manifests itself most often by taking a vivid interest in the local flora, collecting herbaria, and sometimes also insects or minerals on the one hand, and by reading general works as well as easily available botanical literature, not infrequently surprisingly specialistic (*e.g.,* on algae, fungi, weeds, mosses *etc.*) on the other. Secondary school children, however, take an interest in botany primarily under the condition that they cherish an inborn inclination to it (what is called a liking).

From the standpoint of social benefits, greatest attention is to be paid to the secondary school teacher (at the „gymnasium", „lycaeum" and others), because it is he who evokes in the boy or girl a love to learning from the very outset of his/her education. This category of teachers deserves the closest attention not only from their direct superiors but also from the highest educational authorities, because these teachers are the first to sow the seeds that afterwards yield scientists.

The first period is one of rapid development in the life of a scientist belonging to our group. It is characterized by a process of absorbing scientific knowledge by the young botanists, not only in the field of botany, which might have already been chosen by some of them as „their" science, but also in the other fields of science, such as zoology, geology, chemistry, physics, philosophy *etc.* In period *I,* which may considerably extend over the time-limits of the university education, the assimilation of knowledge in different fields seems to be determined primarily by an inborn scientific inquisitiveness, and the subject-matter may be changed. Therefore, in this period, and especially in its initial phase, temporary or lasting shifts in the subject of a scientist's interests occur. During the critical period of searching for the right way there even occur cases of complete changes in the scientific interests. In effect of this youthful "searching" it may happen that a young botanist becomes a zoologist or *vice versa*, whereas a lawyer or theologist, even advanced in their studies, may choose botany as the field of their future scientific work. There are also cases that a young botanist does not abandon the second field of scientific investigations, and works in both fields throughout his life. An example from our group of 70 scientists is Professor K. Hrubý, who worked simultaneously in botany (genetics) and in entomology.

The process of absorbing knowledge by a young scientist in period *I* manifests itself in abundant readings in scientific literature, especially in the specialization chosen. It seems that the widely known and liked books were and continue to be the most important literature of period *I* (or even of its preliminary phase).

The reading activities usually effect the bringing forth of the first publications of the young scientists; these are usually book reviews, which belongs to the features specific of period *I*. Of course, the writing and printing of reviews (not polemics) of the books read are not an exclusive property of youthful age, for it happens that many scientists write reviews, and especially polemics, in periods *II*, *III* and *IV*. Nevertheless, the frequent publication of reviews by young scientists in period *I* belongs, as I think, to the characteristic features of this period of the scientist's development. A particular example of concentrating reports from the literature read is the case of the outstanding Soviet physiologist Maksimov, who as assistant in botany at the Institute of Forestry at Leningrad must have devoted the whole year 1906 (he was then 26) to intensive readings in the literature and to writing numerous reports.

The intensiveness of the penetration into the scientific literature in period *I* is the principal determinant of the later erudition of the young botanist, which is important and can be strikingly great. But the accumulation of erudite knowledge (reading) may be so rapid and many--sided that the erudition may become superficial and "encyclopaedic", which may retard the commencement of the scientist's own creative researches. In passing from period *I* to period *II*, an extreme erudite may content himself with the intensive assimilation of information from the literature he reads. In extreme cases such an erudite becomes a scientist of low productivity and little or not at all creative. Full of quotations from literature, his papers from period *II* add very little and usually bear the characteristics of being merely contributions. An extreme erudite may be a good academic teacher, but he is unable to establish a scientific school of his own, because he is neither a discoverer nor a creator in any field.

Erudites who remain throughout their lives as if on the level of learning, i.e. assimilating a maximum knowledge gained by someone else, are not represented in our group, because it includes only botanists of high and medium productivity. Moreover, our scheme of the "four periods" of development of a scientific life does not apply to erudites, either.

To the characteristic features of period *I* belongs the acquisition of scientific degrees. If we disregard the lower degrees (such as, *e.g.*, those of demonstrator, junior assistant, or assistant conservator in museums *etc.*), the most important were and continue to be the degrees of doctor and *docent*. Whereas that of doctor is normally acquired towards the end of period *I*, the degree of *docent* comes often only in period *II* or it is not obtained at all because eminent scientists may be appointed professors without previously having been granted the title of *docent*; also, there are scientists who, though working in museums, scientific centres or in industry do not apply for the degree of docent.

It may happen exceptionally that there is no period *I* in a scientist's life, but nevertheless features characteristic of period *II* turn up immediately. This is the case of only four persons from our group. Their first publications, which were somewhat retarded in relation to their respective age, bear the characteristics of original works, proper to period *II*.

Period *I can* be gone through in part in full by young botanists only. This is a further proof of the validity of dividing a scientific life into four separate periods in accordance with the laws of the physiological development of a human organism.

The dividing line between period *I* and period *II* is not very distinct, but it may be clear-cut occasionally. It is rather indistinct in those cases when the first fully original and independent scientific papers appeared very late. This line is very distinct in the lives of those botanists who, in response to different impulses, very quickly turn into creative scientific investigators.

Impulses Affecting Scientific Creativity in the Second Period

The first and foremost impulse is intrinsic in each botanist's own self: it is the indigenous passion for scientific inquiry. This passion can be designated as a peculiar ability, a liking, or even vocation, and it drives him from period *I* in which he assimilated knowledge to a higher level of creative work. The flourishment of a scientist's own creativity comes inevitably as a natural phase of the physiological (biological) development of his organism. The indigenous genial abilities stimulate a genial and many-sided scientific creativity — if they are great the resulting creativity is great, if they are small the creativity is correspondingly small. But, in any case, a true scientist, *i.e.* someone who devotes his life to science, enters necessarily the second period of his scientific life. The exceptions covering the extreme erudites have been mentioned above.

Apart from medicine, psychology and genetics, there seem to be no possibilities of analysing causally the essence of the inborn creative abilities of each scientist. On the other hand, the external impulses stimulating creative scientific activity, especially at the moment of the scientist's passage from period *I* to period *II*, can be defined more or less precisely.

To the most important impulses belong: *1* — encouragement and example from eminent scientists, usually the first academic teachers of the young botanist, *2* — personal contacts with other outstanding scientists and a shorter or longer scientific practice in their research centres (laboratories, field-work centres, museums *etc.*), *3* — direct contacts with nature by participating in scientific expeditions to exotic countries, or organizing analogous excursions by oneself. There is one additional impulse stimulating scientific creativity or bringing about its periodic recurrence. This important role of stimulating creative activity is performed by the change either in the research method, or in the subject--matter of the researches, or even in the change of the place, time and conditions of work.

Scientific travels are that impulse which stimulates the perception, comparison and the search for causal relationships occurring between natural phenomena—abilities given to everyone by nature —in order to know the interdependencies between them and their physical setting. Here we should put in the first place individual scientific travels or participation in team expeditions. An examination of our group of 70 botanists is particularly interesting from this point of view. The overwhelming majority of them carried out long-run botanical investigations during expeditions in distant countries, or else they spent much time in field-work, especially sea-board stations, in exotic botanical gardens, on distant islands or in not easily accessible jungle, mountains or deserts. It is difficult to resist the impression that, with a few exceptions, nearly all botanists of our group cherished a deep desire to study the life of plants in distant areas. The direct contact with nature—especially untouched nature—was for many of them not only a satisfaction of a strong desire but also provided them with an inexhaustible abundance of observations and materials on which they often made their most important dicoveries *in natura* or afterwards in laboratories and herbaria.

The Polish version of this paper includes precise data concerning the scope of the impact of each particular botanist's scientific travels on their creativity. Here two examples seem to be sufficient.

Karl Goebel from Munich, who was an outstanding disciple of de Bary and founder of a school of his own as well as a keen observer of the morphology and life of plants in nature and in the laboratory, throughout his life collected on his dissection table thousands of species of exotic plants in order to build on this huge material a new original construction of an "organography of plants" as well as to write the first outline of an *Experimental Morphology*. At the end of his life he stated that scientific travels had always been the greatest joy of his life. He made such travels throughout his life. In the east he first travelled in India, Ceylon and Java, in the western hemisphere he went through South America (Venezuela, Parana, British Guiana and the Andes up to 4500 m.), then through Australia and New Zealand, finally went to the United States, Brazil, and, at the age of 70 (sic!) he travelled for the last time once more to Java and Sumatra. He intended to go to Java after retiring but died in an accident in the 80th year of his life.

C. Skottsberg began his scientific travels very soon (at the age of 21) as participant of the Swedish expedition on the "Antarctic" which lasted for three years, and, afterwards, throughout his life he made either team-expeditions or botanical individual excursions on the islands and continents of the far south of South America, the islands of the Pacific (Don Juan, Hawaii and others), of the Indian Ocean, in the Arctic, in Africa and Europe. It can be safely said that everything that he had accomplished in the geography of plants, algology, and the systematics of vascular plants he owed to the discoveries made in the course of his scientific expeditions. He was thus first of all a great scientist--traveller, and his teaching activities as professor at the university of Göteborg must be mentioned in the second place only.

What has been said about the importance of investigating natural phenomena in nature itself shows that this constitutes a powerful impulse, inexhaustible in its richness and diversity, which stimulates original creative work primarily in the second period of scientific development of every naturalist. This fact implies clear indications for all institutions concerned with the education and the future of young botanists passing from period *I* to period *II*; they must be provided with favourable conditions to participate in scientific expeditions, both on land and on sea, as well as support for their plans—if these are justified—to go not only to famous laboratories but also to the still undamaged virgin nature.

A further group of impulses evoking, or periodically renewing, the diminishing scientific creativity are the changes introduced in scientific researches in three aspects: changes of the material studied, change of the method employed, and finally change of place of work when a scientist moves to a completely new centre. It must be emphasized that this diversified group of impulses has a stimulating effect on a scientist's work in each period of his scientific life, but it is of particular importance in periods *II* and *III.*

Here are but a few examples of changes that were favourable for the scientific creativity of several members of our group of 70 botanists.

Jules Pavillard, who under the influence of Braun-Blanquet changed his algological interests to phytosociology at the age of more than 50 (in 1922) became an original and influential propagator of this branch of botany, which was then very young.

R. Chodat was one of the many-sided students of plants. He was a florist, a systematist (the monograph of *Plearococcus*); he worked in the geography, ecology, anatomy, cytology and physiology of plants, he worked creatively in bacteriology and biochemistry (ferments, oxydases), he grew cultures of algae; finally, as an outstanding specialist on the flora of the Alps he founded an Alpine observation garden, where he organized courses. Besides, he had a vivid interest both art and philosophy.

Marian Raciborski, genially talented and many-sided, in the first phase of his creative activity an outstanding palaeobotanist, afterwards morphologist, physiologist, anatomist and cytologist. Author of brilliant monographs of Javanese ferns, fungi and algae. Founder of *Flora Polska* (Polish Flora), as well as of the Polish botanical school, organizer of science, social worker and popularizer.

Not less than 46 botanists, *i.e.,* 65.7 per cent out of our group of 70 botanists, changed essentially the subject-matter of their research work entering different fields of botany. There are almost no one-sided specialists among them, which is very significant.

It seems that one factor that checked the progress of specialization in the course of the last century was primarily a very wide range of lectures, especially at universities, which were often linked up with practical classes in different botanical disciplines (both descriptive and experimental) as well as frequent naturalist excursions (not only floristic), which were obligatory for all students of botany. An equally important factor contributing to the many-sidedness of students' interests was the fact that professors did not lecture on the same branches of botany, but changed their topics and ranges frequently.

The freedom of teaching for professors and that of learning for students—moderated by the reasonableness and experience of the academic authorities—furnished, in my opinion, a more favourable atmosphere for the unrestricted development of young scientifically talented people than today.

A radical change in the teaching and learning, especially at the universities, on large scale occurred in many countries after the second world war. Even if we ascribe the best intentions to the introduction of far-reaching changes in the previous style of learning and teaching, the reasonableness of these changes is supported by asserting that every science has grown both thematically and methodologically to such an extent that it is impossible to get well acquainted with all the branches it consists of. For instance, it is maintained that a botanist cannot work creatively at the same time in morphology, anatomy, cytology, genetics, floristics, taxonomy, geography of plants, ecology and palaeobotany (and this is but a rough division of botany!), and therefore a specialization is necessary in order to know well only one, or even part of, sector of botany to work creatively in it.

This view cannot be accepted. The analysis of the many-sided original and creative scientific activity of our sample of 70 botanists in the course of the last hundred years shows that it was not a privilege of a few individuals of extraordinary abilities to work in an original and creative way in several different sectors of botany, but also that the same effect (though on a lower level) was achieved by many other botanists.

Moreover, this kind of changes in the field or method of work undoubtedly enriches and stimulates creative work. A temporary or transitory specialization is advantageous, since it not only stimulates but also deepens scientific creativity. But a long-lasting or constant specialization planned beforehand (or imposed) diminishes the scientific horizon of the young scientist and is an obstacle in his many-sided development. A specialist with narrow horizons can perform the function of popularizing science on a large scale only exceptionally and with great difficulties. On the whole, the value of his social activities is radically diminished.

The eminent Polish chemist and scientist of wide horizons, the recently deceased Professor Janusz Supniewski said the following statement on specialization at the general assembly of the members of the Polish Academy of Sciences in December 1963 (*Nauka Polska* 1964, vol. 12): "A narrow specialization determines quicker effects. On the other hand, it is necessary to look upon the specialized field of research from a wider perspective of the related disciplines. At present, specialization prevails, but integrative tendencies are also paving their way."

Though being in full agreement with this wise opinion, I cannot help expressing the apprehension that those very desirable integrative tendencies are and will be suppressed in the nearest future by the widely spread opinion of certain specialistic Scientific Institutes (controlled, among others, by ministries and enterprises) that it is supposedly only specialization that can secure a rapid progress in scientific researches, and, for this very reason, specialization ought to be given strong support to.

The Climax of Scientific Creativity in the Second Period

What is the essence of scientific creativity? This question has been asked so frequently and controversially by many more or less competent authors that I am not going to pay much heed to it here. One of the newer definitions of "creativity" has been recently given by E. P. Torrance, Professor of Educational Psychology at the University of Minnesota (quoted from *Daedalus, Journal of the American Academy of Arts and Sciences,* Summer 1965); it runs as follows: "Creativity is a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements and disharmonies, and so on; identifying the difficulty; searching for solutions; making guesses, or formulating hypotheses about the deficiencies; testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results."

Let us also quote from the same source J. B. Wiesner's definition, which differs from that of E. P. Torrance: "Creativity is principally used to mean activity resulting in contributions that have novelty and value in the intellectual sphere of human experience, including the sciences, as well as literature, music, and the visual arts."

One can frequently read that success in research work is sometimes provided by intuition. According to J. D. Brown (in the same source) intuition "is a mysterious quality of subconscious association of ideas — the combination of ideas to form new ideas. It requires a vast complex of accumulated knowledge... The intuitive instinct of a creative scholar can be dulled by his own habits of mind or by his environment."

According to L. S. Kubie (from the same source), what he calls the "preconscious processes" are the most pervasive and continuous and it is just these mental processes that play a great role in the creative activity of man.

After this digression in the ambiguous concepts of creativity and intuition let us turn to description of period *II*.

Because we have already shown (cf. p. 10) that both the productivity (its indexes have been shown in Table 5) and the diversity and originality of the scientific problems solved are greatest in this period, it has been recognized that the whole of period *II* is the flourishment of scientists' talents and it is marked by the highest intensiveness in their other activities. However, the "optimal subperiod" comprised in it is the most striking phenomenon of the period. It has been called *IIO* (*O* = optimum, or maximum creativity) because the scientist's creativity flourishes best then, and his productivity index reaches its maximum in it (cf. Table 5).

Subperiod *IIO* is only part of period *II* and not a separate period in a scientist's life. This statement is supported by the fact that subperiod

IIO does not occupy one constant place within the whole of period *II*, but it may occur either at its beginning, or in its middle, or at its end. It can be stated that the whole of period *II* covered exactly *IIO* in one or two cases only. Thus, within period *II* subperiod *IIO* appears to be a variable and movable part.

The subperiod *IIO* is conspicuous because it is, as a rule, the most productive period in a scientist's life and it characterizes best his creative individuality. This is the reason for its having been noticed previously; it has been assumed that it lasts for *ca.* 10 years, and that it comes somewhere in between the 30th and the 40th year of a scientist's life.

From S. H. Clarke's article on "Fruitful Careers in Science" (*New Scientist,* 22 April 1965) we learn that, according to his own observations, the age of about 33 to 35 seems to be the crucial stage in the life of the scientist. By that time the scientist has, as a rule, "settled down" in his place of work and chosen the specialization he intends to work in. Clarke's observations, to be true, refer to scientists working in industry, but, *mutatis mutandis,* they seem to be attributable to all other scientists. They certainly refer to our group of 70 botanists.

One problem connected with the optimal subperiod *IIO* is the answer to the following question: is the optimal creativity lasting about 10 years a universal phenomenon which is constant and fairly invariable, or is it a variable phenomenon? It is obvious that the answer to this difficult question cannot be furnished merely on the basis of the analysis of our group of 70 scientists. We may, though, approximate this question by taking into consideration the subperiod *IIO* and classifying the botanists in three groups according to their dates of birth. Table 6 presents the results of these comparisons.

Table 6

The sample of 67 botanists divided into 3 groups according to years of birth

Group	Number of botanists	Years of birth	Duration of subperiod *IIO*		Age of botanists in *IIO*		
			min.-max.	*M*	min.-max.	$M \pm m$	$\pm\ \sigma$
			years				
1	22	1811—1863	7—12	10.22	25—50	35.73±0.36	5.39
2	22	1865—1879	5—13	10.—	24—52	36.13±0.39	5.73
3	23	1880—1910	6—15	9.43	26—50	38.40±0.40	5.88

It is evident that in the course of the 100 years of work of our group of 70 scientists neither the average length of *IIO* (about 10 years) nor the average age of the scientists who worked most intensively in this subperiod underwent any essential change. The third (youngest) group of them differs somewhat from the two other groups, but there is actually no difference between them since the slight shift — or retardation — of the end of subperiod *IIO* must be explained by the difficulties in the work of scientists, especially the difficulties in getting scientific papers published during the first and, partially, also during the second world war.

In my opinion, the problem touched upon here belongs to the most interesting ones from the standpoint of the science of science. But this problem can be discussed only over a wide span of time and on much broader materials than those furnished by our group of 70.

Producer and Creator—Scientist and Scholar

In determining the productivity of each scientist of our group two figures have been used: the number of all printed papers, and the productivity indexes in the four periods of scientific life. However, productivity expressed solely by the sum of papers published does not prove by itself that the given person was a scholar, who by his own creative work contributed to the progress of the science. Nor is every member of our group called a scholar. We should like to reserve this denomination for those who were very talented and devoted to science and who wrote such scientific papers which were new, original and essentially contributed to the progress of the discipline.

In this sense, even the highest productivity is not sufficient for a scientist to be ranked together with the scholars—makers of science. This is attested by the names contained in Table 7.

The following characteristics of the first two botanists are intended to explain the exceptionally rich, one could even say record writing fertility of the four botanists from the first group.

B. Němec, a peasant's son of unusual vitality and great scientific abilities, had a long and exceptionally productive period of scientific and social work. He was a disciple of Čelakovski (afterwards of Stahl, Strasburger, and Warming), had great merits for botany in general, and for botany in Czechoslovakia in particular. The physiology of plants, cytology as well as physiological genetics owe to him many discoveries (the role of the statoliths, regeneration, impregnation, micro-elements and others). He was an efficient organizer, Rector of Charles' University at Prague (1923), founder of the modern Botanical Institute, founder and editor of the *Studies of the Institute of Plant Physiology of Charles' University at Prague* and *Biologia Plantarum,* he also edited two popular scientific magazines, *Vesmir* and *Ziva.* He educated many disciples. He edited handbooks and encyclopaedias. Well known abroad, he lectured at London University in 1927. In period *II* and partly in

Table 7

A list of 67 botanists arranged according to the number of publications

Number from basic list	Name*	Age	Number of publications	Productivity index *IIO*	Remarks**	Group
2	*B. Němec*	93	215 + 454 = 669	{6.8, 8.4}	*III* = 9.6	Group I 401—667 publications
38	P.W. Magnus	70	611	18.9	*III* = 17.9	
40	*R. Chodat*	70	464	18.9		
35	F. A. Novák	72	98 + 324 = 422	{4.9, 4.5}	*III* = 9.5	
24	J. Podpěra	76	148 + 219 = 367	4.4		Group II 201—400 publications
48	*W. L. Krishtofovitch*	68	347	12.0		
28	R. Pampanini	74	306	7.1		
57	*F. A. Miquel*	60	305	9.8		
9	*C. Skottsberg*	83	294	5.8		
60	*R. F. Victorin*	58	284	2.3	*III* = 4.1	
52	J. Holmboe	63	277	6.2		
56	J. Briquet	61	273	12.3		
42	*E. Gäumann*	70	253	4.4		
34	*M. A. Maksimov*	72	243	6.2		
15	*K. Goebel*	80	202	4.4		
44	*L. J. Čelakovski*	68	192	6.2		Group III 101—200 publications
4	E. E. Copeland	90	186	5.5		
39	*K. Schröter*	70	185	4.7		
51	N. J. Sandwith	64	184	6.0		
32	*A. F. Ch. Went*	72	180	4.7		
25	E. Kräusel	76	175	6.0		
14	O. Drude	80	178	5.3		
67	K. Hrubý	52	174	5.4		
66	*S. P. Kostitchev*	54	168	4.5		
17	S. Sokołowski	78	160	7.0		
65	*M. Raciborski*	54	160	7.9		
5	*B. Hryniewiecki*	88	158	2.3	*III* = 3.6	
7	J. Offner	84	157	2.6	*III* = 4.7	
54	*R. Hartig*	62	156	4.8		
11	L. H. Lutz	81	155	8.3		
41	H. Kylin	70	150	3.8		
19	S. Jávorka	78	141	3.8		
61	H. Handel-Mazzetti	58	144	4.5		Group III ctd. 101—200 publications
59	A. Forti	59	134	3.3		
10	A. Ducke	83	132	5.6		
21	O. Renner	77	127	2.3		
45	*E. Strasburger*	68	124	3.2		
30	*F. Delpino*	72	117	3.2		
47	*R. Wettstein*	68	115	3.3		
26	*F. E. Fritsch*	75	106	1.8		
58	M. Treub	59	103	3.0		
55	*F. Firbas*	62	103	3.0		
37	*Z. Wóycicki*	71	102	4.5		
1	J. Pavillard	93	98	2.7		Group IV 40—100 publications
27	*K. Noack*	75	95	2.1		
57	*A. de Bary*	60	94	9.8		
46	*O. Juel*	68	89	2.6		
18	R. W. Kolbe	78	87	5.2		
8	*E. Godlewski*	83	80	1.8		
36	*S. G. Navashin*	71	78	3.4		
13	W. Detmer	80	78	4.0		
20	*M. Martinez*	78	78	0.8	*III* = 2.9	
63	F. Vierhapper	56	73	2.2		
29	J. Peklo	74	73	3.2		
31	*E. Janczewski*	72	70	2.0		
16	*F. W. Areschong*	78	68	2.7		
3	A. Chase	90	67	1.7		
53	C. E. Kobuski	63	65			
23	O. Rosenberg	76	60	1.6		
43	J. Wołoszyńska	69	55	2.0		
50	H. Zapałowicz	65	54	0.7	*III* = 2.2	
6	P. V. Fournier	87	50	2.8		
69	*S. I. Korshinski*	39	49	2.0		
22	*H. H. Thomas*	77	49	1.0	*I* = 2.3	
33	*O. Hagerup*	72	46	1.7		
64	W. Siemaszko	56	43	2.7		

* Italics are used to indicate the most outstanding scientists, organizers and teachers. ** Max. prod. indexes if in periods *III* or *I*.

period *III* he was principally active in science. In periods *III* and *IV* he devoted himself primarily to the reconstruction of education in the newly independent Czechoslovak state working as popularizer, social worker and politician. His record number of papers (669) must be divided into scientific and social publications (cf. Fig. 1).

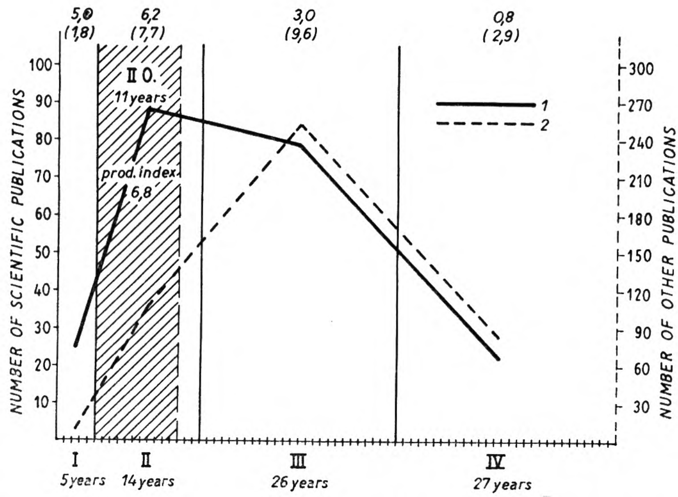

Fig. 1. Bohumil Němec (1873—1966). Scientific and social biodiagram
1—scientific papers (215), *2*—other publications (454)

Scholar and social worker, organizer of science, outstanding teacher. *IIO* lasted for 11 years (at the age of 27-38). In periods *I* and *II* scientific publications prevail, in periods *III* and *IV* social activities come to the fore.

P. W. Magnus (38), second in succession as to the number of publications (611) lived only 71 years. A disciple of Areschong, Alexander Braun and de Bary, he worked in many fields, although he was primarily a mycologist. Throughout his life he was interested in scientific literature in many fields and was a creative erudite. His publications, which are quantitatively so abundant, were usually short papers, which he printed in the journal of the Botanical Society of the Province of Brandenburg (Botanischer Verein der Provinz Brandenburg), of which he was president. He did not leave any longer works. He attained his maximum scientific production in periods *II* and *III*. As professor of botany at the University of Berlin he read excellent lectures, but he has very few disciples and did not found a school of his own. Socially, he was rather passive.

In analogy to our discussion of the first group of scientists who hold the record of total production (*i.e.* of scientific and other works), we ought to analyse the scientific and other production of the other three groups among the group of 70 scientists. Such an analysis, though, would take to much space, and therefore it must be abandoned. We restrict ouselves here to stating that the number of original scientific papers (which decides on the scientific rank of the scientist) is not directly proportionate to the total number expressing the whole pro-

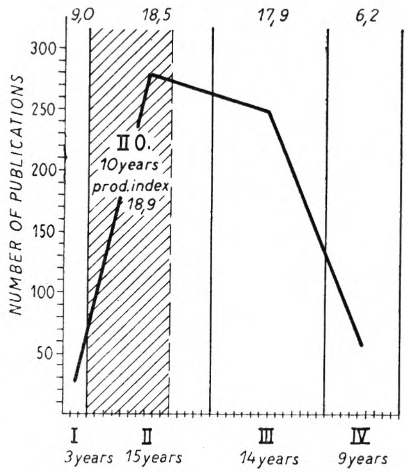

Fig. 2. Paul Wilhelm Magnus (1844—1914). Scientific biodiagram

A very productive and many-sided erudite, organizer and editor. He published 611 scientific publications, usually short ones. *IIO* lasted for 10 years (at the age of 28-37).

duction. The scientists devoted fully to science, finding their fulfilment and achieving their best results in it, frequently (not always) devote all their time to scientific work and can find neither the time nor the wish to write other papers, which have been called here social activites.

Many creative scientists write exclusively scientific works. From the standpoint of the interests of science, this fact is advantageous, but from the standpoint of the social utility of the scientist it is unadvantageous. A scientist who is put off the course of the social life contributes only one-sidedly to enhancing the culture of his country, whereas a scientist who, apart from his strictly scientific works—either popularizes the achievements of science or organizes scientific life in his country, is a high-class citizen of his country in addition to being a scientist. In particular, for the countries that are in the phase of organizing their science—which in our case referred to Canada and Mexico—the double role of the scientist is of particular importance. Therefore, the highest scientific rank has been given here to two pioneering organizers of botany in their countries: to R. F. Victorin from Canada (284 publications), and to M. Martinez from Mexico who left only 78 publications (both scientific and others) but was the initiator and organizer of the most important organizations and botanical publications in his country. Both scientists consciously played the role of pioneers in the development of science in their countries. After the first world war when Poland and Czechoslovakia regained their political independence and were organizing in new conditions their science a number of eminent scientists devoted themselves whole-heartedly to this task and leaving their scientific work-places (which were often abroad) set out ardently to fulfill new social, organizational, editorial, popularizing and other tasks. Out of our group of 70, this course was followed in Poland by M. Raciborski, E. Godlewski, Z. Wóycicki, and B. Hryniewiecki; in Czechoslovakia by B. Němec and J. Podpěra.

Thus, even the greatest scientist's teaching and scientific activities are frequently intertwined with his different social duties. It also happens very rarely that a scientist restricts himself solely to scientific production. There is not a single instance of this in our group of 70. One of the most eminent scientists and teachers from this group, if not the greatest, A. de Bary, said in this respect over 80 years ago: „The scientific importance of a scientist is not so much determined by what he has left as, to a much wider extent, by the manner in which he has influenced his contemporaries and, thereby, directly the further progress of science."

Description of the third period

Usually, a scientist passes from period *II* to period *III* gradually. Taken together, these two periods constitute the main part of the activities of a scientist's life, which covers about 40 years—in the 31—71 age brackets. The extreme variants are relatively rare, but cut deeply in both directions: to periods *I* and *IV*.

In spite of the difficulties usually encountered in attempting to establish the dividing line between periods *II* and *III* of a scientific life, period *III* has distinct features specific to itself. The following are particularly important:

1. In period *III* the total own scientific production as a rule decreases, which is conspicuous in Table 5.

2. The original individual production (which reaches its maximum in subperiod *IIO*) is increasingly substituted by scientific works carried out together with others (colleagues or disciples).

3. Among the publications of this period, synthetic scientific works, comprehensive monographs, compendia and handbooks, written occasionally together with co-workers, as a rule come to the fore.

4. In period *III*, the main organizational activities of the scientist are realized, such as foundations of new scientific research centres, field-work stations, museums and botanical gardens.

5. In this period, which is for many scientists one of stabilization in life, they often take the posts of rectors in higher schools or become heads of different scientific and social institutions. Not infrequently they become editors of botanical journals. Reports of all kinds become a quantitatively important position in the total number of their publications in period *III*.

6. As a rule, in period *III* scientists gather around themselves a number of disciples, and by training scientific personnel they influence to a considerable extent the further course of the development of science. Eminent scientists found their own schools which attract disciples from everywhere.

7. One negative feature of scientists who were devoted to science in period *II* may become in period *III* their desire for power and importance, even if this should require the abandonment of scientific work or be incompatible with their teaching duties.

8. In the group of 70 there are also individuals who almost did not change at all after entering period *III*. Throughout period *III* these persons maintained their enthusiasm for science and for their own creative work. To those few, though by no means exceptional, individuals power or social popularity is no attraction; they avoid anything that could possibly divert them from their scientific activities.

Here only 4 examples of a scientist's (botanist's) life in period *III* shall be given.

2 (Němec): period *III* lasted for 26 years, number of publications 79. He was elected to the posts of dean and rector (1923); in the period of the first world war he had long intervals in publishing scientific papers (1914—22). His later activities are marked by publishing academic handbooks (cytology, anatomy and genetics), as well as his own researches, especially in mycology. The last years of period *III* are characteristic—he published several studies in morphology together with his co-workers.

5 (Hryniewiecki): period *III* lasted for 15 years, during which 55 publications appeared. In this period (1934—48) he reached the quantitative maximum of his production, mainly in the field of the preservation of nature and in the history of botany; towards the end of period *III* the number of original scientific papers decreased conspicuously.

15 (Goebel): period *III* lasted for 28 years, during which he published 86 papers. In this period, which extended to his death at the age of 80, he exhibited an unrelenting vitality and prominent scientific creativity. His activities characterizing period *III* were the following: work on the successive volumes of the monumental *Organography of Plants* (he concluded the last volume at the age of 78), the completion of several big biographies and obituaries outstanding botanists (among others, of Marian Raciborski). He founded a new botanical garden at Nymphenburg near Munich as well as a modern botanical institute.

42 (Gäumann): period *III* lasted for 11 years, number of publications 95. In this period he organized a mycological school of his own and

trained many young scientists, together with whom he more and more often published his studies. To his original synthetic works in mycology written in period *II* he added a work of equal value on rusts (1951). He

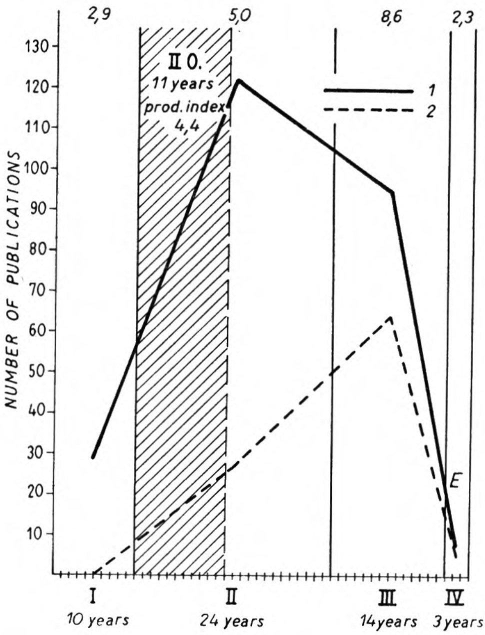

Fig. 3. Ernst Gäumann (1893—1963). Scientific (*1*) and teaching (*2*) bio-diagram

Outstandig scholar and excellent teacher. *IIO* lasted for 11 years (at the age of 33-43). Together with his disciples he wrote 96 scientific papers. He died suddenly of cancer at the moment of retiring. The sum of all papers 253.

was an organizer of scientific life at Zurich and an excellent teacher. He was editor of specialistic journals and a social worker of high rank (Fig. 3).

Science and teaching

Among the several features of period *III* in a scientist's life the first place next to creative work is occupied by the teaching activities connected with this period. This period is the main—sometimes even the only—one of giving off his knowledge and conveying it to his successors. For this reason, teaching conceived of not as an imposed duty but generated from a deeply felt internal need is so important in the life of each scientist. The overwhelming majority of botanists from our sample performed their duty not only by conveying their knowledge but also by arousing enthusiasm for learning among the younger generation. Although the scientist's mission of teaching realized in period *III* cannot be a subject-matter of discussion here, nevertheless, from the standpoint of the science of science, different forms of teaching activities deserve a mention. Relatively easy to be perceived are the following:

1. Influencing the milieu by the example of the scientist's own ethical attitudes and individual work, which can embrace wide and distant circles when he popularizes or propagates his own scientific achievements or the progress in his field of study.

2. Influencing the scientific work of his disciples.

3. Carrying out scientific investigations together with another specialist of the same branch and with equal scientific position.

4. Organization and direction of the scientific investigations of a larger or smaller group of disciples towards a desired objective; this form of teaching activity leads outstanding scientists to a spontaneous foundation of scientific schools of their own.

5. Organization and participation (or participation only) in complex collective scientific investigations.

Each of these five forms of teaching activities can be realized in a diverse manner. If we skip point *1*, which is important as such but too differentiated and thus impalpable, we can state that point *2* can also occur in diverse forms. For instance, such eminent scientists and, at the same time, teachers from our group of 70 as, *e.g.*, K. Goebel (at Munich), R. Chodat (at Geneva), E. Gäumann (at Zurich) and M. Raciborski (at Lwów and Cracow) influenced their disciples and co-workers in diverse manners. We cannot discuss it extensively here because of limited space (more detailed information in this respect can be found in the Polish version of this paper).

We could enumerate a number of eminent botanists from our group of 70 who founded their own botanical schools. The creativity of each of these schools could be a subject-matter of separate studies from the standpoint of the science of science: here want of space makes it impossible. Still less known are the complex scientific investigations in which participate sciences which are different and sometimes fairly unrelated to one another. The recent almost spontaneous developments in Poland and in other countries cause that it has become necessary to discover if only the principles of such complex collective creativity. The need to discover the principal elements of collective creativity from the standpoint of the science of science is nowadays very urgent, even if only to furnish possibilities of preventing too rash granting of scientific degrees to participants of collective investigations. It seems to be most reasonable to grant scientific degrees (especially those of doctor and docent) only by virtue of completing scientific studies individually.

The fourth period

Out of the group of 70 botanists, only 43 persons (61.4 per cent) lived in period *IV*, fully or in part. The remaining number, *i.e.* 27 persons did not reach this final period of a scientist's life. This is due to two reasons: they either died in the course of period *III* or approximately at the end of it, or else continued to exhibit all features of scientific creativity characteristic of period *III* deeply into their old age never exhibiting features of period *IV* (like, *e.g.*, K. Goebel).

In our group of 70 botanists, period *IV* is enclosed in the 54—93 age brackets of a scientist's life, the most frequent being those in between 67 and 73. In the case of botanists who end their period *III* exceptionally early, period *IV* begins as soon as the age of 54—59. In these six years several botanists entered more or less distinctly old age. For these, even the earliest retirement, *i.e.* at the age of 60, was from the formal point of view, belated. But for the absolute majority not only this retirement age but also the two others (those of 65 and 70, respectively) were premature. No matter at what age the scientist was retired, it affected heavily the scientific creativity and productivity of the group of 70 (cf. Fig. 9), because retirement always deprived many of the scientists of the possibility to continue their normal scientific work. Retirement at the age of 70 caused the relatively smallest loss to science, but it was too early for all those botanists who had finished their third period of scientific life after the age of 70.

These remarks are intended to draw attention to the fact of retiring scientists when they still work for science and frequently perform important social activities. If this problem attracts interest, I expect that it will generate a discussion of the question in the ministries, scientific organizations and social circles, which may eventually bring about desirable changes in both the age and the manner of retiring scientists.

The fourth period of a scientist's life has usually features which differentiate it distinctly from the preceding period *III*. To these features belong:

1. the attenuation, or even the abandonment of any original individual scientific activity;

2. the general attenuation of the rate of scientific and social activity, which may terminate in a complete disappearance of it towards the end of the period;

3. the relatively large number of "fertile years", *i.e.* without any publications, which usually grows together with the lapse of time;

4. the frequently occurring increase of popularizing activities;

5. the growth of interest of many botanists in the history of their science, especially in the biographies of botanists;

6. the writing of autobiographies or genealogical treatises;

7. the occurrence at the end of life of a kind of "finish" in the form taking a vivid interest either in purely scientific problems, or in the desire to write the last original work, which can take the form either of an academic handbook or scientific monograph;

8. the focusing of interest on a science quite different from botany, often on that in which he was interested in his youth or that which was his hobby throughout his life.

Because we cannot discuss here these features successively for all 70 botanists, I present only four examples.

5 (Hryniewiecki, age 88): period *IV* lasted for 24 years, during which he published not less than 59 titles. In this period he devotes himself almost exclusively to the history of botany, writes many obituaries as well as popular articles and is very active in the field of the preservation of nature. During the last six years of his life he did not publish any paper and evidently finished his scientific and social activity in the natural process of aging.

9 (Skottsberg, age 83): period *IV* lasted for 7 years (he died of cancer), number of publications 18; very creative and of full vitality until his last years. At the age of 76 he completed and published an excellent monograph on the flora and the plants of the island Juan Fernandez. Throughout the period he had a vivid interest in the problems of the preservation of the nature of the Pacific. He exhibited no traits of senility.

12 (Sprague, age 81): period *IV* lasted for 18 years, number of publications 19. He did not publish anything during the wartime only. He wrote many popular scientific papers. Towards the end of his life, at the age of 79, he wrote a valuable popular book on the Canary Islands. Shortly before his death, he wrote in a popular manner on evolution and devoted himself to his favourite interest — eighteenth century ceramics.

15 (Goebel, age 80): a scholar of the highest rank, of high scientific creativity and outstanding professor and organizer. Although he lived to the age of 80 (he died in an accident), he did not break up his original scientific work. Formally, he retired at the age of 75, but this fact did not affect his production at all. It can be assumed that he never passed into senility; at the age of 78 he published part II of volume III of his monumental work on the organography of plants.

A close examination of the activities of the 15 most long-lived botanists from our group of 70 can convince everyone that even the oldest not infrequently managed to preserve their full vitality and produced abundant, sometimes amazingly original scientific works until the last years of their lives. Only those numbered 1, 3, 5, 6, 7, 13 can be regarded as having grown old naturally in period *IV*.

Out of the remaining material which furnishes an insight into the nature of scientific and social activities of those 45 botanists from the group of 70 who entered the age of senility I wish to mention but a few facts of particular significance.

An example of a life tragedy (as well as scientific) of a scientist retired prematurely (at the age of 60) is furnished by the life of K. Noack, professor at the University of Berlin. He was an outstanding and creative physiologist and chemist, in a sense — a harbinger of modern biochemistry and, at the same time, an excellent professor surrounded

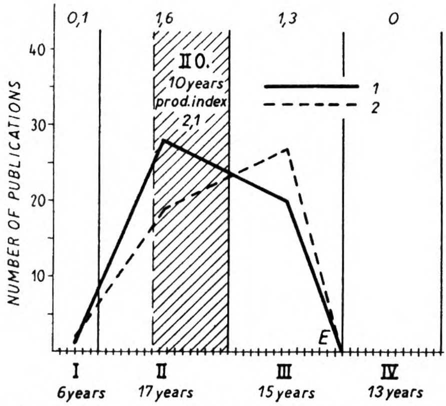

Fig. 4. Kurt Noack (1888—1963). Biodiagram of scientific and teaching activities; *1*—scientific papers, *2*—doctoral dissertations supervised

Physiologist and chemist, excellent teacher, stopped any scientific and teaching activities at the moment of being pensioned off (*E*). *IIO* lasted for 10 years (at the age of 37-46).

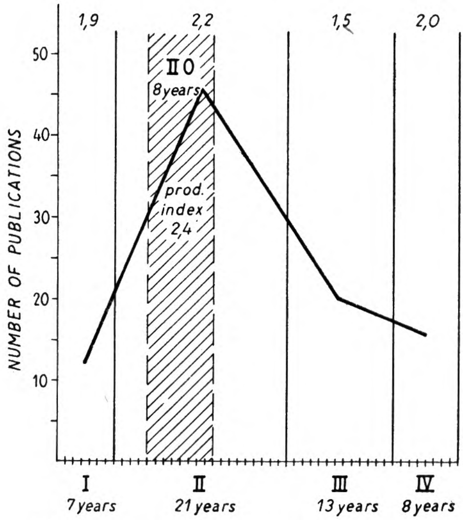

Fig. 5. Oscar Juel (1863—1931). Scientific biodiagram

Specialized in mycology, worked also in cytology and physiology. Excellent organizer of science and teacher, trained many disciples. *IIO* lasted for 8 years (at the age of 32-39). Total number of papers 94.

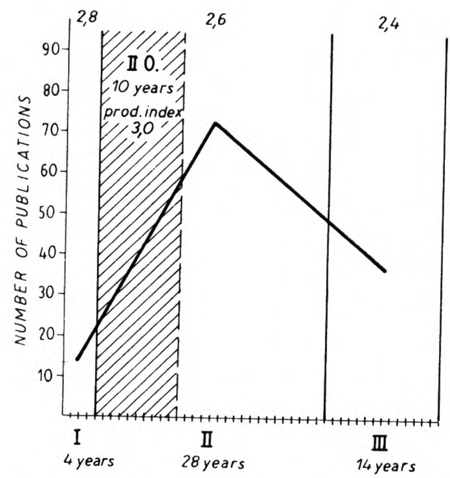

Fig. 6. Edward Strasburger (1844—1912). Scientific biodiagram

Great scholar and teacher, founder of his own school (in which he trained 49 scientists). *IIO* lasted for 10 years (at the age of 27-36).

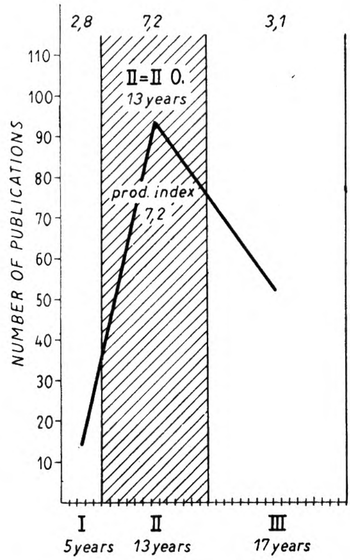

Fig. 7. Marian Raciborski (1863—1917). Scientific biodiagram

Scholar, eminent professor, organizer of science. Period *II* covered exactly subperiod *IIO* and lasted 13 years (at the age of 27-37). Founder of his own scientific school. Total number of publications 160.

by a group of young scientists. His discoveries in investigations on antocyan, chlorophyle, and bacteriochlorophyle, on the chemism of the yellowing of leaves (his last work in 1944), on hormones and many other items made him famous throughout the world and made it possible for him to found a school of his own. After having been retired from his chair he had suddenly to abandon all experimental and teaching activities; from this moment he broke off publishing any papers. This state of affairs lasted for 15 years. Being an eminent physiologist and experimentator, he had to content himself until his death at the age 75 with administrative activities, which were alien to him, as secretary of the Academy of Sciences at Berlin (Fig. 4).

In addition to the data on the "finishes", *i.e.* the last scientific and popular scientific works of particular importance written towards the

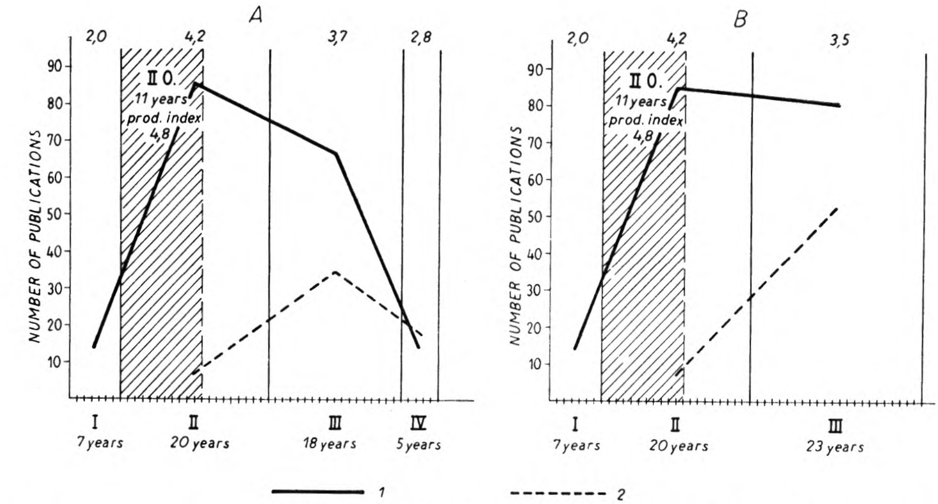

Fig. 8. August Ferdinand Went (1863—1935). Scientific and teaching biodiagram in two versions: *A*—assuming the existence of period *IV*, *B*—assuming that Went died in period III; *1*—own scientific publications, *2*—doctoral dissertations supervised

A many-sided and productive scientist, excellent teacher and founder of his own school (in 1901-33 he supervised 60 doctoral dissertations), outstanding organizer of science in Holland and editor. In 1933 retired at the age of 70, he worked in Leyden since 1934 where he was given a chair (1934), but died in 1935. His scientific and teaching activeness exhibited after 70 justifies the assumption that he did not pass from period *III* (version *B*).

end of their lives in period *IV*, the following "finishes" are worth remembering.

J. Podpěra, in the last few years of his life (especially between 72 and 75), published a valuable and original systematic monograph on *Bryum* mosses in 8 parts.

H. H. Thomas' "finish" was full of new ideas on the historical evolu-

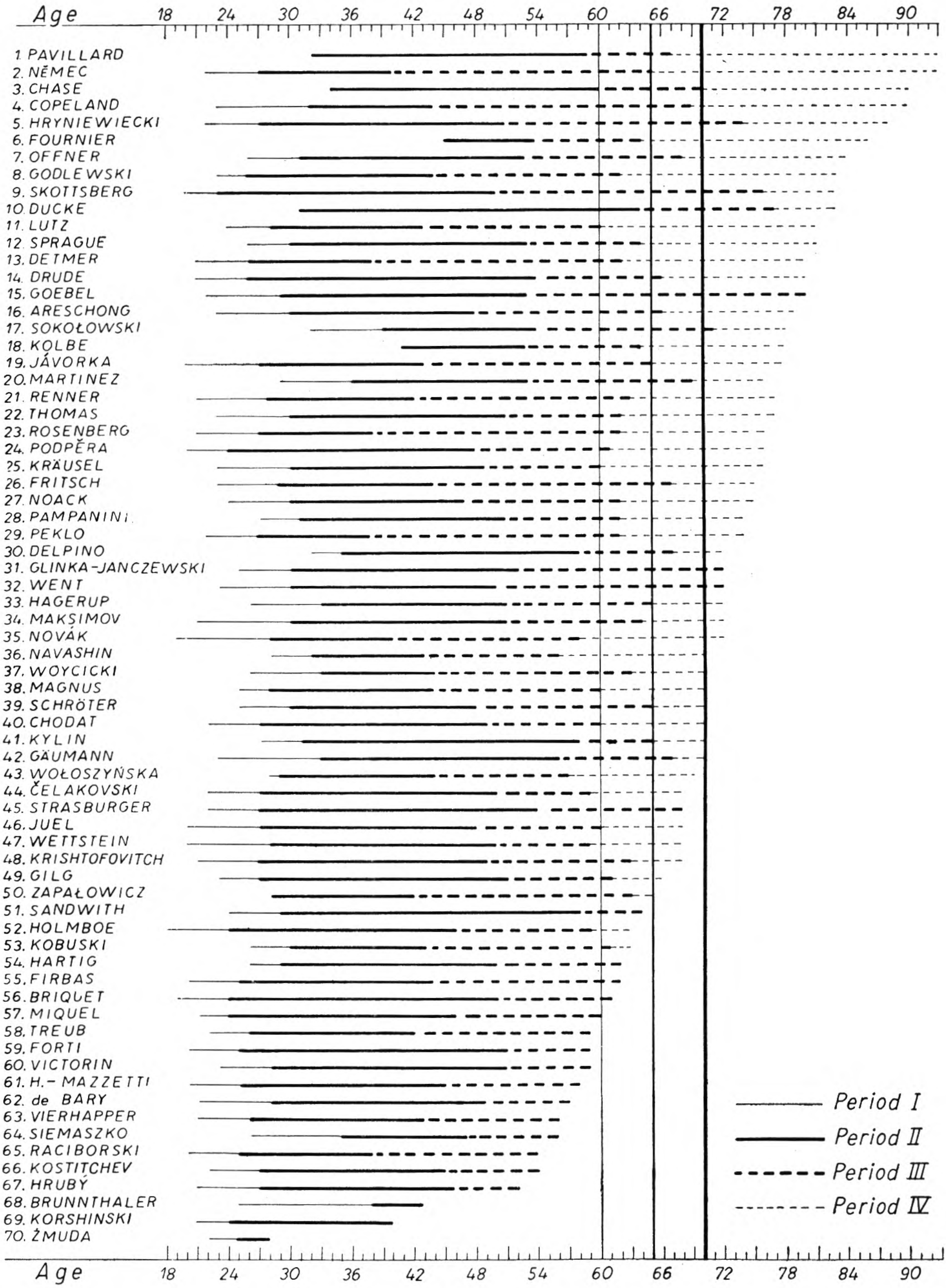

Fig. 9. Individual scientific creativity in periods I—IV

tion of angiospermous plants; he described them together with his disciple professor Harris at the age of 75.

A. Forti's "finish", who was an algologist, was devoted exclusively to Italian art (Veronese) in connection with his researches in the history of botany.

M. A. Maksimov, an outstanding physiologist and experimental ecologist devoted his "finish" (after 70) to the completion of an excellent

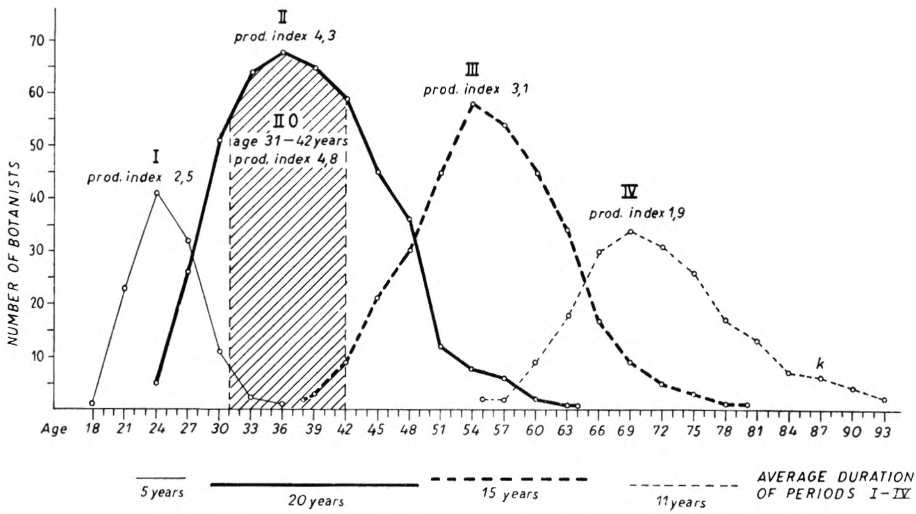

Fig. 10. The relationship between age and the creativity during the four periods of scientific work

popular book on the life of plants, of which 100,000 copies were sold in the Soviet Union and which had many editions and was translated into many languages of the particular Soviet republics. This book performed a very important role of popularizing the knowledge of the life of plants, their importance and economic uses throughout the territory of this immense country.

Retirement age

The examples mentioned refute downrightly the widely held view that a professor or another scientist after 60 or 70 plays no significant role in the scientific and social life of the nation. I think that the only way to change this view, which is harmful both for science and for social activities, is a scrupulous examination either by the highest scientific institution (here, by the Polish Academy of Sciences) or by the Ministry of Education and Higher Schools (or else by a joint commission of these two organs) of all those circumstances that may contribute to retaining at work in one or another way those scientists who, of course, deserve it. Though the establishment of the organization and the rules of operation of such a Scientists' Retirement Commission is beyond my competence I wish to state that the foundation of it is an important requirement of our culture.

The exclusion from scientific and social work of those scientists at retirement age who are still in full power and in the course of creative and teaching work or perform important social tasks is a refutation of the validity of the democratic principle of utilizing for progress all resources which are at the disposal of the nation. In some countries outstanding old scientists are entrusted with special missions from governments either as individual councillors or experts in their specialization or are appointed temporary or constant councillors in organizing scientific research centres, or in supervising the scientific personnel in their specialization. The utilization of outstanding scientists in retirement age in one or another form is not only socially advantageous but it also contributes to attenuating the psychic burdens of the retired scientist who lives on a state pension.

Age and creativity—no matter how they may manifest themselves in man's life—are interdependent, though not directly. Aristotle wrote his greatest works at about 24, whereas Verdi composed two excellent operas after 70, and Leonardo da Vinci reached the apex of his creativity as an old man. Winston Churchill became prime minister of Great Britain in the difficult period of the second world war at the age of 66, *i.e.* formally a year after having reached retirement age. The vitality and the creativity of each individual are its indigenous features, often distinctly hereditary. It has been said that "nobody dies of old age", or that man can live for 120 years, though he dies a little bit each day together with the decrease of the rate of regeneration of cells in his body. Until these and other problems of aging have been solved by gerontology, it remains as a fact that the rash recognition of the 65th or 70th year as the end of the work and the creativity of eminent scientists is scientifically unjustified.

A CLASSIFICATION OF SCIENTISTS

In conclusion I wish to discuss shortly another interesting problem: is it possible to classify scientists into certain sufficiently strictly defined groups or types? This question which had been repeatedly asked in the past has not lost any of its popularity, both among scientists themselves and among the wider public interested in science and culture.

In order to present this naturally complex problem in the shortest form let us refer to a recent classification of this kind which was suggested by the German researcher F. Barnetzky in his study "Kreativität der Wissenschaft" (*Spectrum,* vol. 11, 1965, No. 3). Taking principally as basis F. Barnetzky's classification, which isolates 4 groups of scientists, we can separate, in my opinion, 5 groups of scientists.

1. Erudites—diligent, occasionally pedantic, well-read in specialistic literature, but unimaginative and deprived of creative intuition; devoting their life mainly to absorbing ever-growing amounts of information. Their original scientific production is small. They may be good teachers, but they cannot influence considerably their disciples, nor can they found an original or creative teaching-centre or establish schools of their own (even if they had many disciples). As little productive, this type of scientists has no representative in our group of seventy botanists.

2. Extreme individualists, sensitive, prone to depression, easily disheartened in their work on a subject, easily vulnerable by criticism, but sometimes of high abilities, content themselves with their own company avoiding their colleagues and, as a rule, having no disciples. Their scientific production may be small in quantity but it is usually very original.

3. Scientists capable of creative work, endowed with a great imagination, in constant search for new problems that may arouse their enthusiasm but they exhibit no perseverance and often change their interests. They can be good scientists if supervised by a capable organizer.

4. Outstanding scientists, capable of complete devotion to concentrated effort in working; but tending to be solitary, avoiding wider contacts, unwilling to enter any co-operation.

5. Outstanding self-dependent scientists, enthusiasts of science, endowed with imagination and intuition, searching for new ways, unrelentingly facing difficult problems, sociable, usually excellent teachers, sympathetic supervisors of both individual and collective works by their disciples, good organizers, devoted social workers and good popularizers.

Out of these five groups, the fifth, the third, and the fourth contribute most to the development of science. The fifth groups is the most creative both scientifically and socially, and it is the main factor of progress in science. Each of these five groups can be subdivided into more or less distinct types, which we shall not deal with here.

Is the classification of scientists, which is principally in accordance with Barnetzky's division, the only correct? I think it is not. The science of science ought to attempt to make a more precise classification of scientists. Its starting-point could be an accurate characteristic of each scientist separately by diagrams of their individual scientific lives (biodiagrams) which ought to be enriched by exposing the differentiation between scientific and social activities (cf. Figs. 5—8).

CONCLUSION

I have devoted several months of meticulous work to an analysis of the scientific creativity of the sample of 70 botanists. I have got well acquainted with each of them separately, and I have analysed comparatively the whole group of them. I have not found two identical individuals, but, at the same time, I have found that all of them are subject to principally identical regularities occurring alongside the process of growing older. The four periods of scientific life occur in every scientist's life, since they are determined by human nature. The establishment of this fact is a small contribution but—I dare say—one of those which could perhaps become an encouragement for students of science to further studies of the secret of scientific creativity.

The analysis carried out here of the scientific creativity of the group of 70 botanists has been fairly many-sided but not exhaustive. Among others, the impact of the two world wars has been deliberately omitted. Among the scientists comprised by the analysis there are three groups: those who survived the first world war only (1914—18), those who survived both the first and the second, and those who survived the second war only (1939—45). Many scientists did not survive these wars. Our young and very promising botanist A. Żmuda (70) was killed in battle in 1916, and the talented mycologist W. Siemaszko (64) died prematurely in misery after the complete destruction of his laboratory at Warsaw in the second world war (1943). These are given only by way of example.

Both world wars not only had thousands of victims among scientists, but they also left traits in the scientific production of those who survived them, which may manifest itself in different forms. Even a coursory look into the losses both in scientific production and the diminution of scientific creativity of the botanists from the group of 70 furnishes much significant material in this respect which encourages more accurate investigations. I think, though, that this subject ought to be elaborated on a much wider basis than that which we had at our disposal. The precise researches concerning the wartime losses of science ought to be carried out not only in every country but by way of an international agreement throughout the world. Expressed on a world-wide scale, they may become one more argument stimulating mankind against war.

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