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Analytical Chemistry in Croatia

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Analytical chemistry started to develop in Croatia as an independent scientific discipline at the Royal Agricultural and Forestry College in Križevci (1860). Lectures in analytical chemistry began at the University of Zagreb in the school year 1875/76 within the University Institute of Chemistry. Today, analytical chemistry is taught as an independent course at eleven university faculties, in Zagreb, Split, Osijek and Rijeka. This paper presents a comparison of the compulsory contents of basic *curricula* in analytical chemistry in Croatia with the WPAC Euro*curriculum*.
Scientometric analysis of the Croatian scientific output covered by the *Analytical Abstracts* shows that during the 1980–1996 period Croatian analytical chemistry scientists published 442 papers, 89.6% of which were also indexed in *SCI*. Croatian analytical chemists most frequently deal with spectroscopic, chromatographic and electroanalytical methods. Distribution of the scientific analytical publications with respect to the number of authors, analytical method used and the number of total and independent citations is graphically presented.

Key words: analytical chemistry in Croatia, historical review, education, scientometric analysis.

HISTORICAL REVIEW

Analytical chemistry started to develop in Europe as an independent scientific discipline at the end of the 19th century thanks to the efforts of Justus Liebig (1803–1873). His ideas fell upon fertile soil in Croatia, as well.

Pavao Žulić (1831–1922) organised the first analytical chemical laboratory in the First Gymnasium in Zagreb. A laboratory for the analysis of soil, fertilizers, plants and food products was set up in 1860 at the Royal Agricultural and Forestry College in Križevci. Analytical chemistry was taught in independent courses at that college from 1877 onwards and the eminent chemists who organised the scientific and lecturing work there included Gustav Pexidr (1859–1931), Milutin Urbani (1876–1955), Marko Mohaček (1888–1962) and Vladimir Njegovan (1884–1971).[1]

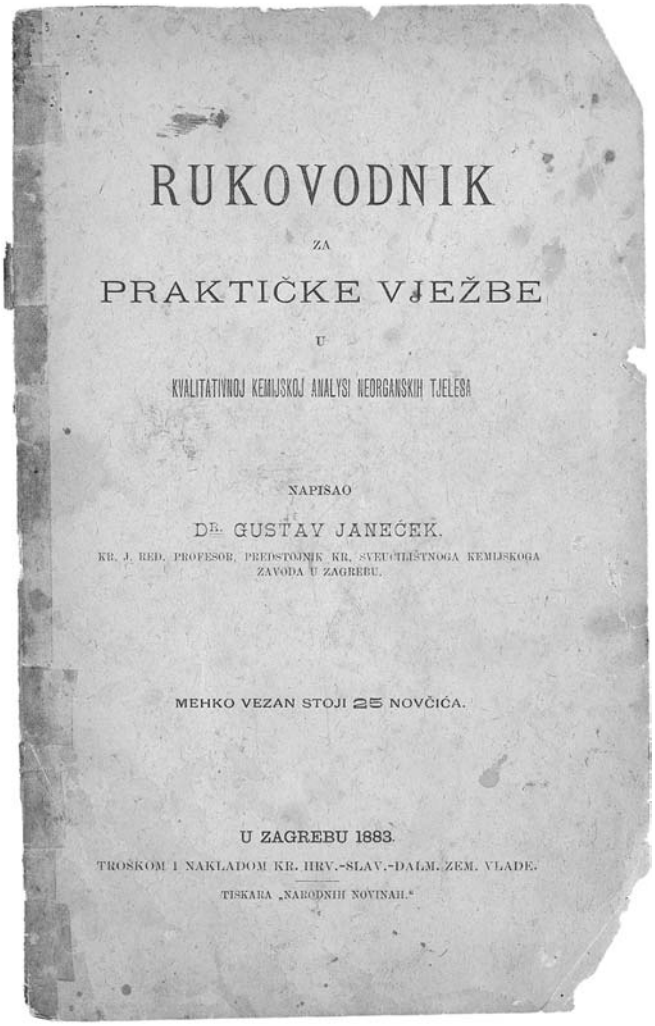
Another name that should not be omitted is that of Srećko Bošnjaković (1865–1907) who in the 1880s opened a private laboratory for the analysis of food-stuffs, which was the first step in the inception of the Royal Croato-Slavonian Land Analytical Chemistry Institute in Zagreb (1897).[2]

Lectures in analytical chemistry began at the University of Zagreb in the 1875/76 school year within the University Chemistry Institute which had just been established. The first professor was Aleksandar Veljkov (1847–1878). He was succeeded by Gustav Janeček (1848–1929), who published the first scientific paper in this discipline in Croatia. Janeček also published the *Guide to Practical Laboratory Sessions in Qualitative Chemical Analysis of Non-Organic Substances* (Figure 1), which was written in the Croatian language (Zagreb 1883, 1907).[3]

The first University Institute for Analytical Chemistry in Croatia was set up in 1919 in the chemical engineering department of the Technical College in Zagreb (now the Faculty of Chemical Engineering and Technology). It was founded by Vladimir Njegovan. His successor, Vjera Marjanović-Krajovan (1898–1988), was the first woman in Croatia to defend a doctoral thesis in technical sciences. Ivan Marek (1863–1936) should also be mentioned; he perfected a furnace for elemental organic analysis, which enabled worldwide progress in elemental analysis.[4]

Analytical chemistry was introduced in 1922/23 as a course of pharmaceutical studies at the Faculty of Philosophy, and with the founding of the Faculty of Pharmacy in 1943, the responsibility for the analytical courses was taken over by the Chair of Analytical Chemistry, with Gilbert Flumiani (1889–1976) as its first professor.[5] He was succeeded in 1946 by Ivan Filipović (1911–1998), while Antun Gertner (1918–1993) was the head of the Institute for many years.

The Chair for Analytical Chemistry was founded in 1960 at the newly established Faculty of Chemical Technology in Split and in the Departments of the Faculty of Technology in Sisak. The independent Institute for Analytical Chemistry at the Faculty of Science was established only in 1962, despite the long tradition of teaching these courses. The first head of the Institute was Ladislav Filipović (1905–1960), who was followed for a short


RUKOVODNIK

ZA

PRAKTIČKE VJEŽBE

U

KVALITATIVNOJ KEMIJSKOJ ANALYSI NEORGANSKIH TJELESA

NAPISAO

DR. GUSTAV JANEČEK.

KR. J. RED. PROFESOR, PREDSTOJNIK KR. SVEUČILIŠTNOGA KEMIJSKOGA ZAVODA U ZAGREBU.

MEHKO VEZAN STOJI 25 NOVČIĆA.

U ZAGREBU 1883.

TROŠKOM I NAKLADOM KR. HRV.-SLAV.-DALM. ZEM. VLADE.

TISKARA „NARODNIH NOVINAH."

Figure 1. The first analytical chemistry textbook in Croatian.

period by Cirila Đorđević (1926), and then by Marko Herak (1922) who advanced the teaching and scientific activity of the Institute during his long-term tenure as its head.[6]

The Laboratory for Analytical Chemistry has existed since 1979 at the Faculty of Food Technology and Biotechnology. It was organised and headed by Sedeslav Žilić (1918–1979) until his death.

A list of the chairs in analytical chemistry in Croatia with a list of full and associate professors and assistant professors is given in Table I.

TABLE I

Chairs and analytical chemistry faculty members in Croatia

University of Zagreb

Faculty of Science	Tenure
Ladislav Filipović (1905–1969)	1962–1965
Cirila Đorđević (1926)	1965–1968
Marko Herak (1922)	1968–1992
Marija Široki (1932)	1965–1993
Zlata Štefanac (1926)	1970–1981
Vladimir Katović (1935)	1963–1977
Biserka Tamhina (1937–2000)	1962–2000
Zlatko Meić (1938)	1992–
Zvjezdana Cimerman (1948)	1975–
Faculty of Pharmacy and Biochemistry	
Gilbert Flumiani (1889–1976)	1943–1946
Ivan Filipović (1911–1998)	1946–1954
Antun Gertner (1918–1993)	1959–1980
Milan Pećar (1920–1976)	1962–1976
Petar Strohal (1932–1976)	1967–1975
Darinka Kodrnja (1932)	1960–1995
Vladimir Grdinić (1939)	1964–1979
Dubravka Pavišić (1940)	1965–
Nikola Kujundžić (1948)	1971–
Svjetlana Luterotti (1950)	1975–
Faculty of Chemical Engineering and Technology	
Vladimir Njegovan (1884–1971)	1919–1943
Bogdan Šolaja (1883–1956)	1919–1924
Vjera Marjanović-Krajovan (1898–1988)	1924–1970
Marija Gyiketta-Ogrizek (1911–1988)	1939–1978
Zvonimir Pinterović (1904–1954)	1943–1945
Sedeslav Žilić (1918–1979)	1947–1957
Miroslav Hlavaty (1924–1969)	1950–1969

TABLE I (cont.)

Konstantin Moskaliuk (1929)	1957–1978
Karmen Mažuranić (1928)	1960–1993
Zvonimir Šoljić (1935)	1961–
Ivan Eškinja (1934–1999)	1962–1999
Marija Kaštelan-Macan (1939)	1963–
Štefica Cerjan-Stefanović (1939)	1963–
Vladimir Grba (1939–1990)	1965–1990
Mira Petrović (1965)	1988–
Fedor Abaffy (1926–1990) (Departments in Sisak)	1960–1966
Darko Maljković (1935) (Departments in Sisak)	1965–1979
Dubravka Maljković (1936) (Departments in Sisak)	1960–1979
Faculty of Food Technology and Biotechnology	
Sedeslav Žilić (1918–1979)	1957–1979
Ema Plavšić (1923–1997)	1960–1980
Jagoda Eder-Trifunović (1925)	1957–1991
Nada Kolb (1940)	1970–
Faculty of Metallurgy	
Darko Maljković (1935)	1979–
Dubravka Maljković (1936)	1979–1995
Faculty of Textile Technology	
Konstantin Moskaliuk (1928)	1978–1999
Ljerka Bokić (1942)	1978–
University of Split	
Faculty of Technology	
Božena Pelech-Tucaković (1909–1991)	1960–1978
Danica Prugo (1929–1998)	1960–1991
Anka Žmikić (1936)	1960–
Njegomir Radić (1943)	1970–
Silvestar Krka (1947)	1970–

Since the very beginning, scientific work has been constantly developed at the Institutes mentioned by name, but also at the numerous other faculties and institutes. After a period in which the emphasis was placed on traditional methods of analysis, scientific work applying numerous chemical and physico-chemical methods soon intensified, in keeping with the development of modern analytical instrumentation.

The scientific achievements of analytical chemists active today in Croatia will be the subject of a separate chapter, so that only brief mention will be made here of the fields of analytical chemistry that are dealt with by analytical chemists at Croatian universities, and in which Croatian analytical chemists have achieved notable results. They are as follows: the study of equilibrium in homogeneous and heterogeneous systems; development and application of selective chemical sensors; research into molecular structure and process dynamics; synthesis, characterisation and application of new analytical reagents; elemental organic microanalysis; radiochemistry; research into the mechanism of metal complexing and development of new methods for their extraction; study of microreactions in the solid phase; development and application of new spectroscopic methods; optimisation of chromatographic systems, particularly in thin-layer chromatography and ion chromatography; preparation of the representative sample; development of electroanalytical methods and potentiometric sensors; development of microanalytical procedures for chemical systems with important therapeutic and toxicological components; application and development of analytical techniques aimed at environmental protection and quality assurance of processes and products in the chemical, pharmaceutical, food processing, textile and similar industries.[6,7,8]

EDUCATION IN ANALYTICAL CHEMISTRY

After more than a century of its growth, »analytical chemistry today is a scientific discipline that develops and applies methods, instruments, and strategies to obtain information on the composition and nature of matter in space and time«.[9] Sudden advances in instrumental techniques at the end of the 20th century, along with physical and biochemical techniques of detection, introduction of the computer, the fact that analytical measurement of data is the basis of vitally important decisions in medicine, environmental protection, and the development of materials and quality assurance of processes and products have given a new impetus to this important chemical discipline. In view of the ongoing progress in the economic unification of Europe, the Working Party on Analytical Chemistry (WPAC) of the Federation of European Chemical Societies (FECS) has proposed the adaptation of mandatory contents of basic *curricula* in analytical chemistry.[9]

We will mention only the basic areas of study recommended by the WPAC Euro*curriculum*: general topics (aims of analytical chemistry, analytical process); chemical analysis (unit operations, methods and their applications); physical analysis (elemental analysis, compound and molecule-specific analysis, microbeam and surface analysis, structure analysis); and, computer-based analytical chemistry (chemometrics, interfacing analytical instruments and computers, quality assurance and quality control).

According to the research carried out by WPAC at European universities in 1989/90, around half of them still teach according to the classical analytical *curriculum*, but the vast majority of universities support an extended analytical chemistry *curriculum* that includes the basic principles, modern methods and major applications in material science, food production, environmental systems, pharmaceutical and biomedical sciences, biotechnology, arts and archaeology.

And what is the situation in Croatia? Analytical chemistry is taught as an independent course at eleven university faculties, in Zagreb, Split, Osijek and Rijeka. Table II gives a list of these courses with the pertaining total annual number of hours of lectures, seminars and laboratory sessions.[10–12] In addition, there are courses which deal with the characterisation of material, process and product quality control, environmental protection and the chemistry of water, food products, medicines, and the like. It should be noted that the content of Croatian university courses in analytical chemistry is based on the relevant available *curricula*, but no more detailed analysis of the teaching units within particular courses has been done for this purpose. By comparing the compulsory contents of the basic *curricula* in analytical chemistry in Croatia with the WPAC Euro*curriculum* the following may be concluded:

Croatian university courses in analytical chemistry for the first and second year students comply with the Euro*curriculum* category of general topics and chemical analysis. Unfortunately, in most cases the analytical process involving sampling and the preparation of samples, separation of analytes, selection of optimal methods of determination, and the evaluation of data aimed at obtaining the information sought is covered in a much lower number of lecture hours than recommended. At the Faculty of Science, the compulsory course entitled Analytical chemistry covers topics dealing with the analytical process (20–30%) depending on the study group. At some, particularly technical, faculties, the subject is covered in detail in courses which deal with the examination of material and product quality, but as these courses are given to students from the third year onwards, and only in individual study groups, a large number of students is not provided with sufficient information on this basic part of analytical chemistry. The major part of the proposed content that the Euro*curriculum* categorises as

TABLE II

Total teaching hours of analytical chemistry in Croatia

University of Zagreb

Faculty of Science

Courses:
Analytical chemistry (AC)
Instrumental analytical methods (IAM)

Study groups:		
1. Teacher of chemistry	AC	240 (75 lec, 45 sem, 120 lab)
	AC (IAM)*	120 (120 lab)
	IAM	90 (60 lec, 30 sem)
2. Teacher of physics and chemistry	AC	210 (60 lec, 30 sem, 120 lab)
3. Teacher of chemistry and biology	AC	210 (60 lec, 30 sem, 120 lab)
4. Teacher of biology	AC*	105 (30 lec, 15 sem, 60 lab)
5. Chemical Engineer	AC	240 (75 lec, 45 sem, 120 lab)
	AC (IAM)*	120 (120 lab)
	IAM	90 (60 lec, 30 sem)
6. Biology-ecology Engineer	AC*	105 (30 lec, 15 sem, 60 lab)
7. Biology-molecular biology Engineer	AC	105 (30 lec, 15 sem, 60 lab)
8. Geology Engineer	AC*	180 (60 lec, 120 lab)

Faculty of Chemical Engineering and Technology

Courses:
Analytical chemistry (AC)
Instrumental and process analysis (IPA)
Quality testing (QT)
Characterisation of nonmetal materials (CNM)
Environmental analytical chemistry (EAC)
Quality assurance (QA)

Study groups:		
9. Engineering 10. Processes and products	AC	120 (60 lec, 60 lab)
	IPA	60 (30 lec, 30 lab)
	EAC*	45 (30 lec, 15 lab)
	QA*	45 (30 lec, 15 sem)
11. Materials	AC	120 (60 lec, 60 lab)
	IPA	60 (30 lec, 30 lab)
	QT	60 (30 lec, 30 lab)

TABLE II (cont.)

	CNM	60 (30 lec, 30 lab)
	EAC*	45 (30 lec, 15 lab)
	QA*	45 (30 lec, 15 sem)
Faculty of Pharmacy and Biochemistry		
Courses:		
Analytical chemistry (AC)		
Drug analysis (DA)		
Study groups:		
12. Pharmacy	AC	240 (60 lec, 30 sem, 150 lab)
	DA	180 (15 lec, 30 sem, 120 lab)
13. Medical biochemistry	AC	240 (60 lec, 30 sem, 150 lab)
Faculty of Food Technology and Biotechnology		
Courses:		
Analytical chemistry	(AC)	
Instrumental analysis	(IA)	
Food analysis	(FA)	
Study groups:		
14. Food technology	AC	120 (30 lec, 15 sem, 75 lab)
	IA*	60 (30 lec, 30 lab)
	FA*	90 (30 lec, 60 lab)
15. Biotechnology	AC	120 (30 lec, 15 sem, 75 lab)
	IA*	60 (30 lec, 30 lab)
Faculty of Textile Technology		
Courses:		
Analytical chemistry	(AC)	
Physico-chemical methods of analysis	(PCA)	
Study group:		
16. Engineer of textile technology	AC	60 (30 lec, 30 lab)
	PCA	90 (45 lec, 45 lab)
Faculty of Metallurgy		
Course:		
Analytical chemistry	(AC)	
Study group:		
17. Metalurgy	AC	135 (60 lec, 75 lab)

TABLE II (cont.)

University of Split		
Faculty of Technology		
Courses:		
Analytical chemistry	(AC)	
Process analysis	(PA)	
Material testing	(MT)	
Study groups:		
18. Chemical technological processes	AC	105 (60 lec, 30 sem, 15 lab)
19. Environmental protection	PA	60 (30 lec, 15 sem, 15 lab)
	MT	90 (30 lec, 60 lab)
Faculty of Natural Sciences, Mathematics and Education		
Course:		
Analytical chemistry	(AC)	
Study group:		
20. Teacher of biology and chemistry	AC	210 (75 lec, 45 sem, 90 lab)
University of Osijek		
Faculty of Food Technology		
Course:		
Analytical chemistry (AC)		
Study group:		
21. Food processing Engineer	AC	120 (30 lec, 15 sem, 75 lab)
Faculty of Pedagogy		
Course:		
Analytical chemistry (AC)		
Study group:		
22. Teacher of chemistry	AC	195 (60 lec, 30 sem, 105 lab)
University of Rijeka		
Medical School		
Courses:		
Analytical chemistry (AC)		
Instrumental methods (IM)		

TABLE II (cont.)

Study group:		
23. Sanitary engineer	AC	210 (90 lec, 120 lab)
	IM	60 (30 lec, 30 lab)

* – elective course,
lec – lecture,
sem – seminare,
lab – laboratory.

chemical analysis is taught in courses in analytical chemistry, although the number of hours of the courses varies from faculty to faculty. The recommended number of lecture hours in chemical analysis is found at the science, pedogogical, pharmaceutical and medical faculties, while the number of recommended hours at the technical faculties is reduced to almost a half, with the explanation that students from the third year onwards can partly learn about the subject in applicative analytical courses.

The content recommended in the Euro*curriculum* under physical analysis is taught at Croatian universities under courses in: instrumental and process analysis, instrumental analytical methods, instrumental methods and physico-chemical methods, with a total number of between 60 to 90 hours, which is far below the recommended number of 154 hours of lectures. It should be emphasised, however, that a large part of the content foreseen by physical analysis at Croatian universities is taught as part of non-analytical courses (organic chemistry, physical chemistry, electrochemistry, characterisation of material, *etc*.), so that, depending on the faculty and the study group chosen students can attain a satisfactory level of knowledge about such methods.

On the other hand, courses in chemometrics and quality assurance, for which the Euro*curriculum* recommends a fund of 42 hours, are practically neglected in the analytical chemistry course programmes at Croatian universities. They are taught only briefly at Faculty of Science and partly at some technical faculties as part of courses which cover quality testing and quality control, while students who want to increase their knowledge of these subjects are directed towards elective courses or post-graduate studies.

To help them master the essential contents of analytical chemistry, students have access to literature from abroad as well as to numerous textbooks in Croatian. Apart from the above mentioned *Guide to Practical Laboratory Sessions in Qualitative Chemical Analysis of Non-organic Substances* by Gustav Janeček, the first analytical chemistry textbook in Croatian, Table III lists all the university textbooks published to date, which encompass mainly general topics and chemical analysis, and, to a lesser extent, instrumental and automatic analysis.

TABLE III

University textbooks of analytical chemistry in Croatian

Vladimir Njegovan
– *Qualitative Chemical Analysis*, University of Zagreb, Zagreb 1923, 1948.

Vjera Marjanović-Krajovan
– *Qualitative Chemical Analysis*, University of Zagreb, Zagreb 1947, 1962.
– *Quantitative Chemical Analysis*, University of Zagreb, Zagreb 1949, 1961.

Marija Gyiketta-Ogrizek
– *Qualitative Chemical Analysis (Laboratory Manual)*, University of Zagreb, Zagreb 1948, 1957.
– *Quantitative Analytical Chemistry (Laboratory Manual)*, University of Zagreb, Zagreb 1958.
– *Semimicro Qualitative Analysis (Laboratory Manual),* University of Zagreb, Zagreb 1960, 1964, 1972.

Marija Gyiketta-Ogrizek, Ivan Eškinja
– *Qualitative Chemical Analysis (Laboratory Manual)*, University of Zagreb, Zagreb 1973, 1976.

Marija Gyiketta-Ogrizek, Zvonimir Šoljić
– *Quantitative Chemical Analysis (Laboratory Manual)*, University of Zagreb, Zagreb 1976, 1982.

Sedeslav Žilić
– *Quantitative Analytical Chemistry*, University of Zagreb, Zagreb 1966.
– *Qualitative Chemical Analysis (Laboratory Manual)*, University of Zagreb, Zagreb 1966.
– *Quantitative Chemical Analysis (Laboratory Manual)*, University of Zagreb, Zagreb 1966.

Sedeslav Žilić, Ema Plavšić
– *Calculation in Quantitative Analytical Chemistry*, University of Zagreb, Zagreb 1969.

Fedor Abaffy
– *Analytical Chemistry (Collection of Problems)*, Školska knjiga, Zagreb 1973.
– *Introduction in Physico-Chemical Methods of Analysis*, University of Zagreb, Zagreb 1963.

Darko Maljković
– *Instrumental Analysis*, University of Zagreb, Zagreb 1970.
– *Automatic Analysis*, University of Zagreb, Zagreb 1974.

Ivan Filipović
– *Introduction in Qualitative Chemical Analysis*, University of Zagreb, Zagreb 1957.

TABLE III (cont.)

Ivan Filipović, Petar Sabioncello – *Laboratory Handbook*, Book 1, Tehnička knjiga, Zagreb 1968, 1972. – *Laboratory Handbook*, Book 2, Tehnička knjiga, Zagreb 1962, 1978. – *Laboratory Handbook*, Book 3, Tehnička knjiga, Zagreb 1965.
Štefica Cerjan-Stefanović – *Fundamentals of Analytical Chemistry*, University of Zagreb, Zagreb 1983.
Marija Kaštelan-Macan – *Analytical Chemistry*, Part I, University of Zagreb, Zagreb 1984, 1991.
Zvonimir Šoljić, Marija Kaštelan-Macan – *Analytical Chemistry*, Part II, University of Zagreb, Zagreb 1985, 1991.
Ivan Eškinja, Zvonimir Šoljić – *Qualitative Inorganic Chemical Analysis (Laboratory Manual)*, University of Zagreb, Zagreb 1984, 1992.
Zvonimir Šoljić – *Calculation in Analytical Chemistry*, University of Zagreb, Zagreb 1987, 1998. – *Fundamentals of Quantitative Chemical Analysis (Laboratory Manual)*, University of Zagreb, Zagreb 1987, 1995.
Srećko Turina – *Thin-Layer Chromatography*, SITH, Kemija u industriji, Zagreb 1984.
Ivan Piljac – *Electroanalytical Methods*, RHC, Zagreb 1995.

After publication of the WPAC joint textbook which will have chapters on: general topics, chemical analysis, physical analysis, computer-based analytical chemistry and total analytical processes, it is to be expected that also Croatian universities will fully adapt their programmes to bring them into line with the European recommendations, thus enabling improvement of student mobility and faster inclusion of the Croatian economy into European integration processes.

SCIENTOMETRIC ANALYSIS OF THE CROATIAN SCIENTIFIC OUTPUT COVERED BY THE *Analytical Abstracts* IN THE 1980–1996 PERIOD

During the 1980–1996 period, scientists from the Republic of Croatia published 442 papers covered by the CD version of the *Analytical Abstracts* (*AA*); 396 of these (89.6%) were also indexed in the CD version of the *Sci-*

ence Citation Index (*SCI*), whereas 46 papers were covered by the *AA* only. In the same period, the *SCI* in the scientific subfields Analytical chemistry and Electrochemistry covered 512 papers published by scientists affiliated to research institutions within the Republic of Croatia. The annual fluctuation of the number of papers covered by the *AA* and the *SCI* is given in Figure 2. It is interesting to note that, during the last five years, every published paper indexed in the *AA* was simultaneously covered by the *SCI*. Previously, this was not the case. For example, the year with the largest scientific output of Croatian origin according to the *AA* was 1987 with 32 published papers, while only 30 Croatian analytical papers published in that year were covered by the *SCI*. According to the *SCI,* the published output of Croatian analytical chemists was largest in 1992 with 43 papers, but only 27 papers were covered by the *AA*. The reason for this discrepancy is the fact the *AA* exclusively collects papers dealing with the subject of chemical analysis, whereas the *SCI* classifies journals into the scientific subfield Analytical chemistry if they contain predominantly analytical papers.

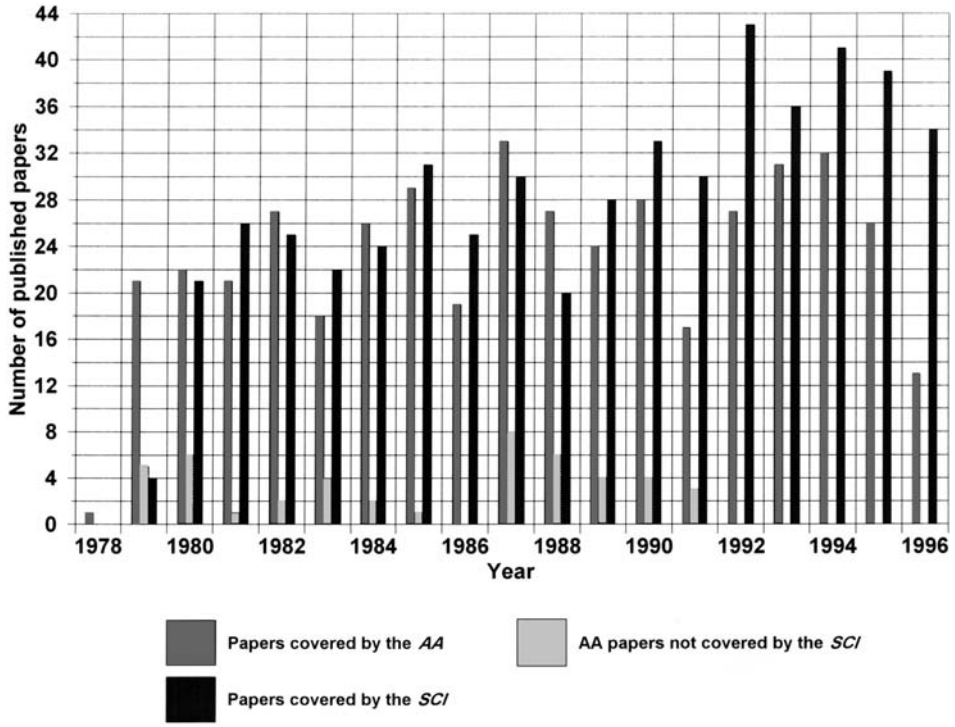


Figure 2. Annual fluctuation of the number of papers published by Croatian analytical chemists and indexed by the *Analytical Abstracts* and the *Science Citation Index* in the 1980–1996 period.

Comparison of the overlapping of the two bases reveals that, out of the total number of publications (442) covered by this study, only 208 *AA*--indexed papers (47.1%) were covered by the *SCI*-scientific subfields Analytical chemistry and Electrochemistry, followed by Pharmacology & pharmacy (54 papers, 12.2%), Nuclear science & technology (41 papers, 9.3%), General chemistry (17 papers, 3.8%) and Spectroscopy (16 papers, 3.6%). The remaining 60 papers (13.6%) were covered by 22 other *SCI*-subfields.

The 442 papers considered in this study were published by 1292 authors or, on average, by 2.92 authors per paper. This number is smaller than that obtained in previous studies for the chemists from the Ruđer Bošković Institute (3.05 authors per paper),[13] or the average value (4.02 authors per paper) for the scientific output of the Republic of Croatia for the period 1980–1995.[14] The distribution of papers with respect to the number of authors is given in Figure 3. Papers with the largest number of authors were published in the *SCI* scientific subfield Nuclear science & technology, i.e. 4.93 authors per paper. Further representative examples would be 2.64 authors per paper indexed in Analytical chemistry, 2.89 authors per paper indexed in Pharmacology & pharmacy, 2.00 authors per paper in General chemistry, and 3.25 authors per paper indexed in Spectroscopy.

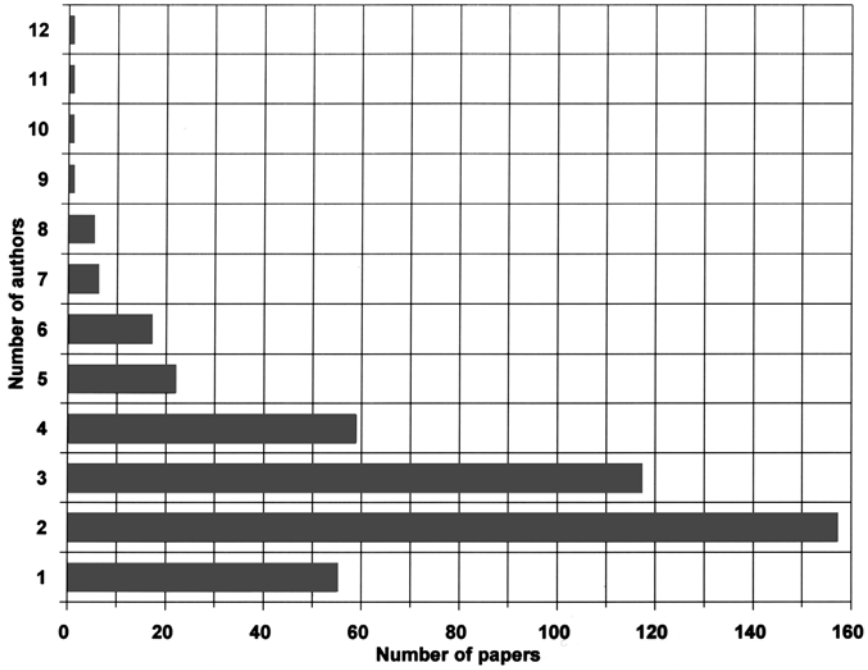


Figure 3. Distribution of the scientific publications of Croatian analytical chemists with respect to the number of authors.

Croatian analytical chemists most frequently deal with spectroscopical methods (142 papers), chromatographical methods (114 papers), and electroanalytical methods (96 papers). The most representative individual analytical method used was voltammetry & polarography (59 papers), followed by X-ray spectroscopy (57), ultraviolet spectroscopy (47), thin layer chromatography (38), and potentiometry (32 papers). The distribution of papers with respect to the prevailing methodology is shown in Figure 4. A paper dealing with X-ray spectroscopy was, on average, published by 4.74 authors, whereas a paper dealing with UV spectroscopy was published by about half that number of authors, *i.e.* 2.34.

The most frequently chosen journal (50 papers or 11.3% of all) was the domestic *Acta Pharmaceutica (Jugoslavica)* (covered by the *SCI* until 1991) with an average impact factor (AIF) of 0.332, calculated from the *Journal Citation Reports*,[15] with 50. The second-ranking journal with 40 papers (9.0%) was *Analytica Chimica Acta* with AIF of 1.742, followed by *Nuclear Instruments Methods in Physics Research, Section B* with 33 papers (7.5%) and AIF of 1.228. Further frequently chosen journals were: *Fresenius´ Journal of Analytical Chemistry* (21 papers, 4.8%; AIF = 1.063), *Kemija u indus-*

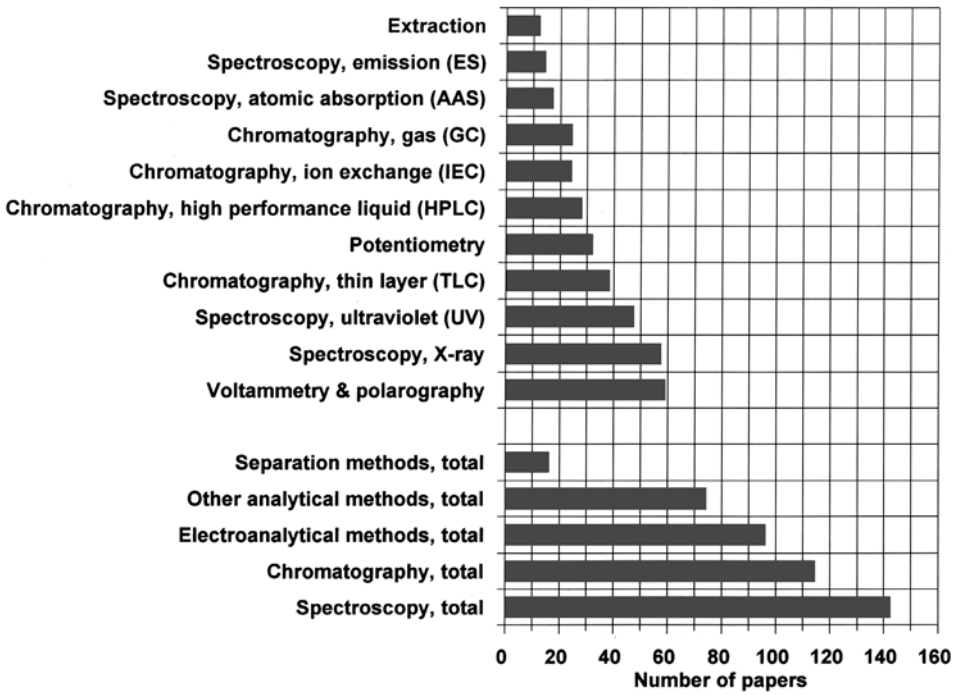


Figure 4. Distribution of papers with respect to the analytical methods used.

triji, a domestic journal not covered by the *SCI* (18 papers, 4.1%), *Mikrochimica Acta* (17 papers, 3.8%; AIF = 0.628), as well as *Analyst* (AIF = 1.627) and the *Journal of Radioanalytical & Nuclear Chemistry* (AIF = 0.546), each with 16 papers (3.6%). The total number of domestic and international scientific journals chosen by Croatian chemists for publication of all the 442 papers covered by the *AA* was 97.

The average value of the impact factor of the journals that published the 396 papers covered by both the *AA* and the *SCI* was 1.148. The *SCI*-subfields with the highest average impact factors that included Croatian analytical papers were: Research & experimental medicine (11 papers; AIF = 1.945), Oceanography (3 papers; AIF = 1.788), and Energy & fuels (2 papers; AIF 1.676). It is well known that the average impact factors of different scientific subfields vary considerably. Introduction of a relative impact factor (average impact factor of Croatian papers in a particular scientific subfield divided by the average *SCI* impact factor of the same subfield) allows comparison of the output in different scientific subfields.[14,16] The relative impact factor of Croatian papers covered by both the *AA* and the *SCI*-subfield Nuclear science & technology is 1.65, *i.e.* within this subfield, Croatian scientists chose journals with an impact factor 65% above the *SCI* average value. Papers published in journals covered by the *SCI* subfield Research & experimental medicine have a relative impact factor 1.18, whereas those in the subfield Analytical chemistry have a relative impact of 1.05. Other *SCI*-subfields including analytical papers of Croatian origin have relative impact factors around 1.00 or smaller.

The total number of citations for all papers covered by this study was 1604, or 3.63 citations per paper. Independent citations contributed with 1045 or 65.1%, whereas self-citations contributed with 559 citations or 34.9%. The classification of papers with respect to the number of total and independent citations is shown in Figure 5.

About 25% of the publications studied herein were not cited, whereas approximately 40% did not receive any independent citation. If we consider only papers published in 1992 or before, we can compare the accumulation of citations over the same standard period of five years (year of publication and four years following publication). In this case, the set of analytical papers to be considered comprises only 340 publications. Out of these, 97 were not cited at all in the respective five-year period, which gives the rate of uncitedness of 28.5%. Applying the same criteria, the world rate of uncitedness for chemical papers published in 1984 is 38.8%.[17] Schubert *et al.*[18] took a different approach, counting the citations from 1981 to 1985, for the papers from the area of analytical chemistry published in the same period (*i.e.* the average paper had a 2.5 year chance to collect citations). This resulted in a world rate of uncitedness of 39%, as compared to 56% for papers from

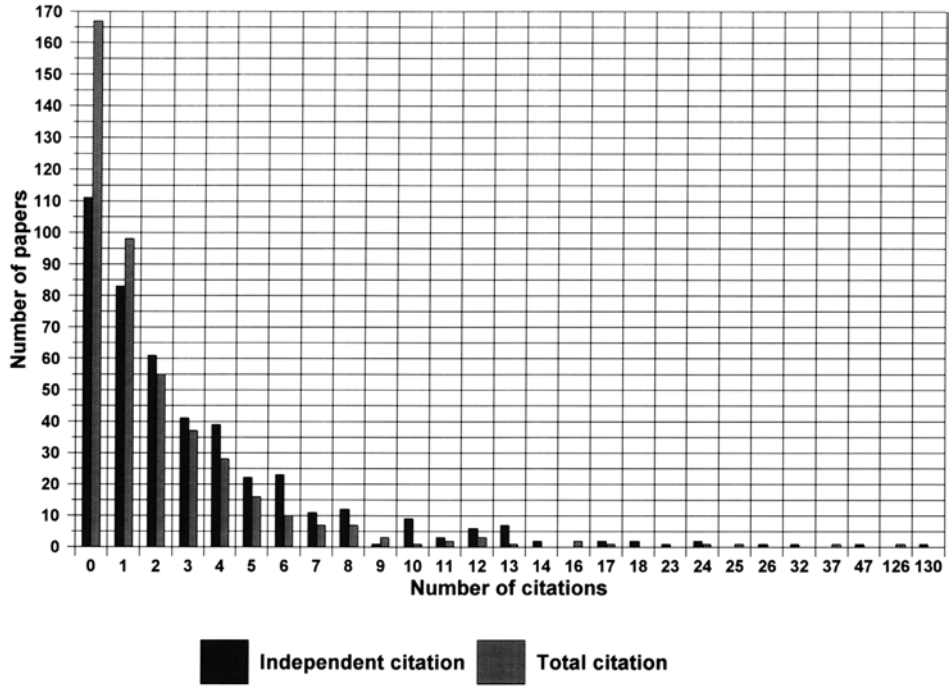


Figure 5. Distribution of papers with respect to the number of total and independent citations.

Croatia. The uncitedness of Croatian analytical papers in the following second five-year period (1986–1990) is 52%, and in the next period (1991–1995) 48%. The difference between the results obtained by the above two approaches suggests that the citation process is slower for Croatian analytical papers than for the world average.

The contribution of analytical papers cited not less than the triple average (8 citations, 1981–1985) is approx. 3% for the *SCI* base,[18] as compared to 2% (1981–1985), 3% (1986–1990), and 5% (1991–1995) for the three five-year periods covered by the Croatian base.

Scientometric data can be analyzed in the sense of finding centers of exellence associated with certain individuals and institutions. The top-rating group in this sense deals with X-ray fluorescence and proton-induced X-ray emission; its principal investigator published 51 papers covered by the *AA* (50 are also covered by the *SCI*, AIF = 1.07), and received 283 citations (179 of which are independent citations), *i.e.* 5.5 citations per paper, and 3.5 independent citations per paper, respectively. This group is located at the Ruđer Bošković Institute. The second-rating group is located at the same Institute, and is dealing with voltammetry and polarography. Its principal

TABLE IV

The most frequently cited analytical papers published by Croatian scientists and covered by the *Analytical Abstracts* in the 1980–1996 period

Ružić-I.:

»Theoretical aspects of the direct titration of natural waters and its information yield for trace-metal speciation.«

Anal. Chim. Acta, 1982, **140** (1), 99–113.

Address: Ruđer Bošković Inst., Center for Marine Res., Zagreb, Croatia

130 citations, 4 self-citations included, impact factor of the journal = 2.448

Bos-A.J.J.; Vis-R.D.; Verheul-H.; Prins-M.; Davies-S.T.; Bowen-D.K.; **Makjanić-J.; Valković-V.:**

»Experimental comparison of synchrotron radiation with other modes of excitation of X-rays for trace-element analysis.«

Nucl. Instrum. Methods Phys. Res., Sect. B, Apr-May 1984, **231 (B3)**, 232–240.

Address: Vrije Univ., Natuurkundig Lab., Amsterdam, Netherlands

47 citations, 10 self-citations included, impact factor of the journal = 1.160

Picer-N.; Picer-M.:

»Evaluation of macroreticular resins for determination of low concentrations of chlorinated hydrocarbons in sea-water and tap-water.«

J. Chromatogr., 1980, **193 (3)**, 357–369.

Address: Ruđer Bošković Inst., Center for Marine Res., Zagreb, Croatia

32 citations, 7 self-citations included, impact factor of the journal = 2.129

Sipos-L.; Nuernberg-H.W.; Valenta-P.; **Branica-M.:**

»Applications of polarography and voltammetry to marine and aquatic chemistry. V. Reliable determination of mercury traces in sea-water by subtractive differential pulse [anodic-stripping] voltammetry at the twin gold electrode.«

Anal. Chim. Acta, 1980, **115**, 25–42.

Address: Nucl. Res. Centre, Inst. Chem., Juelich, Germany

26 citations, 2 self-citations included, impact factor of the journal = 2.036

The names of Croatian scientists are given in bold.

investigator published 35 papers (33 *SCI,* AIF = 1.58), and obtained 209 citations (106 independent); *i.e.* 6.0 citations/paper and 3.0 independent citations/paper, respectively. The third-rating group is located at the Faculty of Pharmacy & Biochemistry, dealing with ion-exchange chromatography and spectrophotometry. Its principal investigator has published 31 papers (27 *SCI,* AIF = 0.62), and obtained 81 citations (29 independent), *i.e*. 2.6 cita-

tions/paper and 0.9 independent citations/paper. The fourth-rating group is located at the Faculty of Technology, Split, dealing with selective electrodes and potentiometry. Its principal investigator has published 24 papers (22 *SCI,* AIF = 1.56), and obtained 84 citations (50 independent), *i.e.* 3.5 citations/paper and 2.1 independent citations/paper.

During the 1945–1989 period, the *SCI* base contained 0.46% papers with 100 or more citations, 1.52% with 50 or more citations, and 4.10% papers cited 25 or more times.[19] This means that each twenty-fourth paper was cited 25 times or more. The Croatian base contains 1 paper with 100 or more citations (0.30%), and 4 papers (1.21%) cited 25 times or more (Table IV). The scientific subfield Analytical chemistry has a lower average impact factor for the journals covered (2.67) than the average for all journals indexed by the *SCI* (3.11).[16] It is thus rational to expect a lower percentage of highly cited papers than for the whole *SCI*.

In conclusion, in Croatia, the scientific production covered by the *AA* represents approximately one-fifth of the total chemical production (*ca.* 2000 papers covered by the *SCI* in the period 1980–1995).[14] Analytical chemists constitute 15–20% of the total number of chemists in this country. The group considered here includes about ten scientists basically educated as physicists, who were, however, dealing with analytical chemistry (X-ray spectroscopy), and part of their papers were covered by the *AA*. The uncitedness of Croatian papers is below the world average, but the contribution of highly cited papers is also below the world average. Comparison of three five-year periods, 1981–1985; 1986–1990; and 1991–1995, reveals a slow increase of scientific output: 121, 130 and 132 papers, respectively.

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16. A. Schubert, W. Glänzel, and T. Braun, *Scientometrics* **16** (1989) 3–478.
17. D. P. Hamilton, *Science* **251** (1991) 25.
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19. E. Garfield, *Current Contents* (7), 3–14, February 12, 1990.

SAŽETAK

Analitička kemija u Hrvatskoj

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Analitička se kemija u Hrvatskoj kao samostalna znanstvena disciplina počela razvijati na Kraljevskom gospodarsko-šumarskom učilištu u Križevcima (1860). Na Sveučilištu u Zagrebu počinje se predavati u ak. god. 1875/76. u sklopu netom osnovanoga Sveučilišnog kemijskog zavoda. Danas se analitička kemija kao nezavisan kolegij predaje na jedanaest fakulteta sveučilišta u Zagrebu, Splitu, Osijeku i Rijeci. U ovom radu prikazana je usporedba temeljnih obveznih sadržaja analitičke kemije u Hrvatskoj s prijedlogom Working Party on Analytical Chemistry europske udruge kemijskih društava.

Scientometrijska analiza znanstvenih radova hrvatskih analitičara na temelju *Analytical Abstracts* pokazuje da su u razdoblju 1980.–1996. publicirana 442 rada, od kojih je 89,6% citirano i u *SCI*. Hrvatski analitički kemičari najviše se bave spektroskopskim, kromatografskim i elektroanalitičkim metodama. U radu je grafički prikazana razdioba znanstvenih publikacija hrvatskih analitičara s obzirom na broj autora, korištenu analitičku metodu te broj ukupnih i nezavisnih citata.