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FEATURE ARTICLE

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Eurocurriculum II for Analytical Chemistry approved by the Division of Analytical Chemistry of FECS

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Introduction

The Division Analytical Chemistry (DAC) of the Federation of European Chemical Societies (FECS) recommends the following "Eurocurriculum II for Analytical Chemistry" as a guideline for teaching analytical chemistry at universities. The recommendations are based on the established "Eurocurriculum I" and take into consideration the current proposals of the European Chemistry Thematic Network (ECTN) for harmonization of Chemistry curricula throughout Europe (Bologna Process). The ECTN proposal is in an advanced state of discussion.

As in "Eurocurriculum I", the following recommendations consider two levels of education, namely, basic and advanced. The basic part is compulsory for the BSc level (Eurobachelor). The advanced part is compulsory for extended education in analytical chemistry (MSc, PhD). This paper outlines the recommendations for the content of the basic compulsory part.

For historic reasons, analytical chemistry has not yet been given the status of an independent field in chemistry at many universities. This is in great contrast to the demands of society for professional chemists in general. The following recommendations are aimed at comprehensive but concise courses on fundamentals in contemporary analytical chemistry. Problem solving and quality assurance are the dominating didactic principles. The course content covers essentials of both quantitative and structural analysis.

The following recommendations focus on procedures, methods, and contemporary techniques in analytical chemistry. All chemical topics with predominant orientation towards substances should be covered in the corresponding fields of chemistry (e.g., inorganic chemistry, organic chemistry, biochemistry). The scope of courses in physical chemistry is the theoretical foundation of chemistry, whereas the goal in analytical chemistry is to deal with "real" samples.

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Eurocurriculum I

The discussion is based on the activities of the former FECS Working Party of Analytical Chemistry, published in a series of papers entitled "Education and Training in Analytical Chemistry (Eurocurriculum I)". In part I of this series, the development of the concept was described [1]. Part II defined the goal of education in analytical chemistry: analytical chemistry is problem solving[2]. As outlined in part III, analytical chemists fall into two categories: generalists and specialists [3]. This suggests the orientation of basic education (BSc) in analytical chemistry towards a more general knowledge. Any specialization – in particular at universities with chairs in analytical chemistry – demands extended education (MSc or PhD). Part IV proposed the assignment of 17% of the total teaching time to analytical chemistry [4]. A survey of curricula of analytical chemistry throughout Europe resulted in the definition of four "supporting pillars" in education of analytical chemistry [4]:

- spectroscopy
- chromatography
- chemical sensors
- chemometrics and computer-based analytical chemistry.

Current situation

During its 2002 Annual Meeting in Dortmund, the FECS/DAC discussed the implications of the Bologna Process to education in analytical chemistry. The current development called for an adoption of the above-described "Eurocurriculum I" to the new situation. The national FECS/DAC delegates decided to form a task force to advance in accordance with the Bologna Process. A draft "Eurocurriculum II for Analytical Chemistry" was intended to be discussed and approved during the 2003 Annual Meeting in Thessaloniki. This goal was indeed achieved, and the national delegates unanimously approved "Eurocurriculum II". It shall provide support for ongoing discussions in universities all over Europe to update their curricula.

The situation outside analytical chemistry is being developed by activities of the European Chemistry Thematic Network (ECTN), which undertakes efforts to harmonize basic chemistry curricula throughout Europe (the chemistry "Eurobachelor"). A paper written by T.N. Mitchell (Dortmund, DE) and R.J. Whewell (Glasgow, UK) was discussed at the ECTN Annual Meeting 2002 (Perugia, IT) and was made available afterwards. For the BSc degree in chemistry it lists compulsory modules (Analytical Chemistry, Inorganic Chemistry, Organic Chemistry, Physical Chemistry, Biological Chemistry), semi-optional modules (Computational Chemistry, Chemical Technology, Macromolecular Chemistry), and non-chemical modules (Mathematics, Physics, Biology). The expectation was expressed, that there would be compulsory Mathematics and Physics modules. It was also stated that "...there are indications that the 180 credit degree will become more common than the 240 credit degree." The Perugia paper formed the basis for the subsequent discussion within the FECS/DAC task force.

An intentional distribution of credits in an earlier ECTN paper had to be shifted after extensive discussions. In the new BSc model, 15 credits out of 180 were assigned to analytical chemistry. Since the Eurobachelor proposal comprises both compulsory and optional modules, 15 credits (8.5% of the total BSc teaching time) have been regarded as the minimum needed for basic education in analytical chemistry. Additional (optional) modules may considerably vary between universities; nevertheless a recommendation for optional modules will be worked out as well.

Necessary adaptations

The 15 credits (8.5% of the total BSc teaching time) allocated in the ECTN proposal to analytical chemistry are only half of what was considered as necessary in "Eurocurriculum I" (17% of total teaching time). On the other hand, "Eurocurriculum I for Analytical Chemistry" included extensive parts devoted to general chemistry, mainly in "Chemical Analysis I" (Table 1) [4].

The ECTN proposal distinguishes general chemistry from analytical chemistry, that is, it supports the international development towards independence of analytical chemistry from any other chemical field. "Eurocurriculum II" will follow this line.

The FECS/DAC recommendations are based on and make use of existing knowledge and practical skills of general chemistry, due to time limitations it can no longer contain material from modules of that field. The allocated 15 credits have to concentrate on problem solving in the core topics of analytical chemistry. It should be emphasized that an education purely based on methods (e.g., spectroscopy, chromatography, chemical sensors, chemometrics) could be part of any curriculum in each field of chemistry. A sustainable curriculum in analytical chemistry requires orientation towards analytical fundamentals, exemplified in real-life applications.

Table 1 Eurocurriculum I: recommendations for compulsory contents of basic and advanced curricula in Analytical Chemistry [4]

Component	Contents
A. General Topics	The Analytical Process
B. Chemical Analysis I	Unit Operations Methods and Applications
C. Physical Analysis I	Elemental Analysis Compound Analysis Surface Analysis Structure Analysis
D. Computer-based Analytical Chemistry	Chemometrics I Computer Hard- and Software Interfacing Instruments and Computers

A number of existing curricula are still subdivided in parts such as qualitative analysis, quantitative analysis, instrumental analysis, structural analysis. This kind of subdivision reflects 150 years of historic development. Contemporary analytical chemistry in industry and the public service is mainly instrumental analytical chemistry. Any distinction between "instrumental analytical chemistry" and "non-instrumental analytical chemistry" does not meet the current professional situation [5].

Problem solving in analytical chemistry covers the total analytical path of sample processing from the sample source through laboratory and further on to the customer. The four fundamental steps are sampling, digestion, measurement, and data analysis. Collection of samples in the right proportions of course requires some knowledge of basic mathematical methods and statistical methods and, as such, the subject is linked directly to data analysis. Digestion requires basic chemical skills that allow extraction of analyte without significant loss. The subject of measurement includes all known laboratory equipment devised to quantify the analyte and to simultaneously suppress possible interferences. Data analysis is based on fundamentals of statistics and may include areas of chemometrics and graphical data interpretation. Furthermore, data analysis has to promote concepts of quality assurance and optimization that are compulsory skills for a professional analytical chemist.

ECTN recommends modules of a minimum size of 5 credits (i.e., the analytical chemistry curriculum may be split into 3 modules). This may help to distribute the teaching load over more than one semester. It should be remembered that each separate module has to be completed by an examination. The more modules that are established for the minimum education in analytical chemistry, the more examinations have to be supervised. It is, however, recommended to certify the completion of analytical chemistry education by only one final mark instead of a number of assessments of less impact to the BSc certificate.

Depending upon the profile of each university, the number of credits allocated to analytical chemistry during general education may be above the basic 15 credits; however, in cases where specialized courses in analytical chemistry are offered, the number of credits must be higher than the basic 15 credits.

Recommendations for the BSc level (Chemistry Eurobachelor)

The following recommendations aim at the protection of the educational standards achieved by the leading chemistry departments. "Eurocurriculum II for Analytical Chemistry" should exhibit sufficient flexibility to offer incentives to these departments. It should comply with the requirements of the Bologna Process and help to put the Chemistry Eurobachelor into practice. Moreover, "Eurocurriculum II for Analytical Chemistry" should help to form effective teaching networks and to develop intensive international teamwork among the corresponding chairs.

The interdisciplinary character of analytical chemistry has already been emphasized. Contemporary demands of analytical skills of every chemist are far beyond a first-semester level of wet chemistry experience. Moreover, basic knowledge in a number of chemical topics is needed before the modules of analytical chemistry should be taught. With respect to these and other considerations, we combined the compulsory and semi-optional modules of the ECTN proposal into a complex called "Basic Modules". It comprises General and Inorganic Chemistry, Organic Chemistry, Physical Chemistry, Analytical Chemistry, Macromolecular Chemistry, Chemical Technology, Theoretical Chemistry, Chemoinformatics, Biochemistry, Physics, Mathematics. These basic modules constitute the bulk of the chemistry BSc curriculum. Within this bulk framework, the modules of analytical chemistry could be pooled in only one semester. Our model assumes a distribution over two semesters in order to distribute the teaching load (Fig. 1).

A few considerations have to be made before the 15 credits for analytical chemistry can be allocated to the various basic topics. A fundamental assumption concerns the ratio of hours spent by the students in practicals and lectures (seminars are not taken into consideration here). Our concept proposes twice as many hours spent in practicals than in lectures. (These hours are usually called "contact hours" and should not be confused with "workload hours" for students.) For simplicity, our recommendation focuses merely on lectures and practicals. Seminars can easily be incorporated at the expense of lectures or lab exercises.

It was clearly expressed in the ECTN proposal, that "... the total workload involved in a 1-hour lecture is different than that involved in 1 hour of practical work". We assumed the following workload factors for students:

– lectures 3
– practicals 1

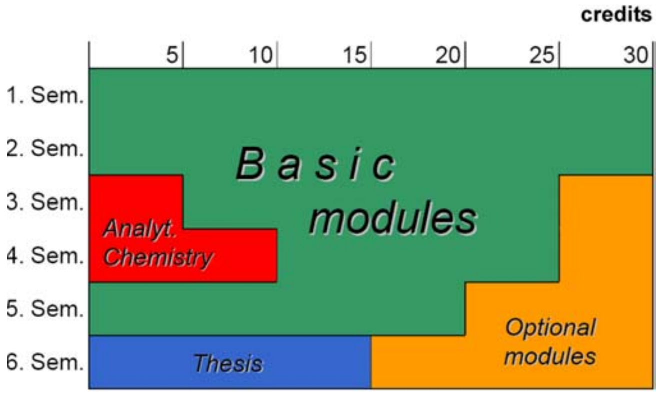

Fig. 1 Model placement of the compulsory basic parts of "Eurocurriculum II for Analytical Chemistry" in a Chemistry Eurobachelor environment

From the ratio of hours to be spent in lectures and practicals (1:2) and the workload factors for lectures and practicals (3:1) we obtain the credit ratio between lectures and practicals (3:2).

The ECTN proposal assumes that the "European average for the total student workload per year is close to 1,500 hours". This results in a total workload for students of 750 h per semester, corresponding to 25 h workload per credit. Because of the differences in lengths of the semester across Europe, a further breakdown to weekly workload may add confusion. For this reason, we restrict our considerations to the semester level.

The above considerations are necessary in order to transform credits into contact (teaching) hours according to:

$$\text{contact hours} = \frac{\text{number of credits} \times 25\text{h}}{\text{workload factor}}$$

For a chemistry module of 5 credits we obtain:

– lectures: 3 credits=25 contact (teaching) hours
– practicals: 2 credits=50 contact (teaching) hours

This results for the basic education in analytical chemistry for the BSc level (15 credits or 3 modules) in 75 h lectures (9 credits) and 150 h practicals (6 credits).

Content of the mandatory part of "Eurocurriculum II for Analytical Chemistry"

The four pillars of analytical chemistry [4], namely, spectroscopy, chromatography, chemical sensors, chemometrics, are found again in "Eurocurriculum II". Merely the number of credits allocated to them as well as the relationship between the areas had to be changed. There has never been any doubt about the affiliation of these fields to the compulsory basic education. Discussions arose about the impact of atomic spectroscopy versus mass spectrometry for practically working analytical chemists nowadays in terms of whether the former is still more important than the latter. The answer obviously depended

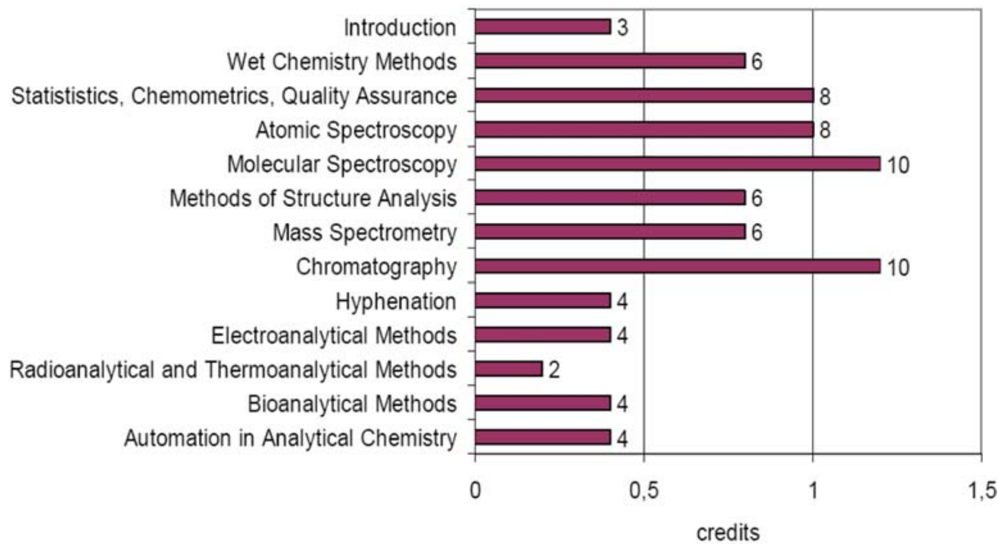

Fig. 2 Recommended content of the compulsory basic parts of "Eurocurriculum II for Analytical Chemistry" (*inset* lecture hours)

upon the profile of the institution and of the person, respectively.

The chapter "Equilibria" has totally been omitted from "Eurocurriculum II" (Fig. 2). This chapter belongs to general chemistry. It was replaced by the chapter "Wet Chemistry Methods", which covers such important fields as sampling, digestion, and sample preparation. This chapter may also incorporate areas like titrations or kinetic methods.

More emphasis has now been placed on the chapter "Statistics, Chemometrics, Quality Assurance" because of its importance for problem solving in analytical chemistry. It is assumed that basic statistics has already been taught in the mathematics modules. This chapter builds on existing knowledge and deals only with dedicated statistical applications in analytical chemistry. The chapter includes topics like accreditation, traceability, reference materials, method validation, and sampling strategy.

Structural analysis is still too often related purely to organic matter, hence taught in organic chemistry and sometimes reduced merely to the discussion of NMR spectra. Or course, fundamentals of structural analysis are a matter of analytical chemistry. The multi-method approach has to be taught here, whereas any dedicated method of structure elucidation might be offered by chairs or institutes with a dominating synthetic orientation. Sometimes it is metaphorically said the task of analytical chemistry is the production of valid numbers. If this were true, the field of analytical chemistry would be diminished to quantitative analyses. In fact, the task of analytical chemistry is the elaboration of yes/no answers (detected/not detected or identified/not identified). Such answers can only be achieved if the compulsory basic modules comprise both qualitative and quantitative aspects of analytical chemistry.

Electroanalytical methods are widely used in routine analytical chemistry. It is assumed that the basics of electrochemistry have already been taught in courses of physical chemistry. The analytical part therefore concentrates on practical application with a corresponding allocation of credits for this part.

Radioanalytical exercises may be offered by only a few departments across Europe. Nevertheless, radioanalytical methods are of particular importance. A Chemistry Eurobachelor should have at least a very basic understanding of opportunities and challenges particular to radioanalytical methods. A similar situation exists for thermoanalytical methods, which are of considerable relevance in polymer chemistry.

Bioanalytical methods play an increasing role in our professional life. It is assumed that the basics have already been taught in courses of biochemistry. The analytical part therefore concentrates on practical application. All of us have heard about substantial errors caused by application of biological principles but disregarding analytical fundamentals. It is our duty to improve the situation by providing basic insights into this important application area.

Automated analytical instruments are penetrating into all fields of social and of economic importance (e.g., clinical or environmental chemistry). These types of instruments will be operated by employees with a Bachelor degree. The topic therefore has to be included in the compulsory modules.

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