Incorporation of Analytical Chemistry in the Undergraduate Curriculum: Examples from Different Regions of the World

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Introduction

The International Union of Pure and Applied Chemists (IUPAC) has funded an initiative that is reviewing the status of analytical chemistry education throughout the world [1]. This initiative grew out of anecdotal evidence that suggests there has been an erosion of analytical chemistry and consequently its professional status. This includes situations where required instructional hours in analytical chemistry have been reduced, where groups carrying out analytical research have been eliminated, and individuals not formally trained in analytical chemistry have been hired to teach analytical chemistry courses. Some feel that analytical chemistry is increasingly perceived as a service function. Also, the ease with which many instruments can be used has created a mistaken belief that there is a reduced need for highly trained analytical chemists in some industrial organizations. A study group of 34 individuals representing 22 countries has undertaken the review. Questions for the study group to examine include whether, in academia, the health of analytical chemistry, proportion of professorships, funding for and quality of analytical chemistry education have declined over the past few decades. Additionally, the group will explore the extent to which some industrial organizations no longer feel the need for highly trained analytical specialists.

The sub-committee tasked with examining the educational environment began its work with the idea of conducting a survey of academic analytical scientists throughout the world. However, in attempting to construct a useful survey instrument on analytical chemistry in the bachelor's curriculum, the sub-committee soon realized that different parts of the world use different terminologies and had markedly different curricular systems, which may even vary between institutions in the same country. Some have entire courses, modules or units wholly devoted to analytical chemistry whereas others have analytical topics dispersed throughout offerings that cover more than one subfield of chemistry. Some have lectures combined with a simultaneous laboratory component whereas others separate lectures and laboratory experiences. Some systems have programs where students specialize in analytical chemistry and therefore receive a much richer experience than students who specialize in other areas of chemistry. Creating one survey that could accommodate the range of possibilities and result in data suitable to compare across different systems has been challenging.

The sub-committee thought it would be useful to provide the community with an overview of how analytical chemistry is incorporated into several different curricula throughout the world. Those included herein are not meant to cover all the different systems but provide a range of approaches that can generate reflection and conversation about effective ways of including analytical chemistry in the curriculum.

Comparison of Different Educational Systems

Tables 1 and 2 provide general characteristics of the university systems and specific characteristics of the analytical component of the bachelor's degree, respectively, for the countries described in this report. Prior reports in this education series have provided overviews of analytical chemistry education in Japan [2], China [3] and Russia [4]. While all the countries described herein have some form of a national accreditation process, and three have optional accreditation processes in chemistry, all these systems give chemistry programs considerable latitude in the requirements for a chemistry major.

Programs have the flexibility to offer separate analytical chemistry courses/modules/units or to distribute the coverage of analytical and other areas of chemistry into interdisciplinary offerings. Similarly, analytical chemistry laboratories/practicals may be separate offerings or distributed into interdisciplinary laboratories. Analytical chemistry lectures and laboratories are mostly taught as separate courses in Peru, South Africa and the United States. In Germany, and the United Kingdom, many

institutions have separate lectures and labs while many others distribute the coverage. Australia is unique in mostly having separate analytical lectures but distributed laboratories. In all but Germany, students mostly take the analytical laboratory simultaneous with the lecture instead of during a subsequent term. In courses emphasizing instrumental techniques, where the numbers of each instrument are limited, simultaneous lecture and laboratory often means that students are conducting experiments using instrumental methods that have not yet been covered in the lecture.

While all the countries have a system with two semesters a year, institutions have some flexibility with the number of weeks in a semester. In Australia, Germany, South Africa and the United Kingdom, students can obtain a bachelor's degree with three years of study. Four and five years is needed in the United States and Peru, respectively. Students in Australia and South Africa can earn a bachelor's degree with Honours by completing a fourth year of study. The way countries count credits varies widely among those represented herein. In some countries, students are expected to complete other academic experiences or continue self-study in times between the formal terms, whereas in others, students are free to pursue any activities of their choosing.

Programs have considerable flexibility in how much analytical chemistry is required for the bachelor's degree. That is reflected in the considerable range in numbers for items in Table 2 such as the required analytical courses/modules, required analytical laboratories/practicals, the number of credit hours and the number of lecture and laboratory hours in analytical chemistry. In compiling these numbers, we either tried to represent the most common situation in our country or the typical range of requirements that exists across institutions in our country. Even with ranges included in the table, there are likely outliers at the institutional and individual student level in each case. The length and structure of analytical chemistry laboratories also vary considerably among institutions. Some laboratories meet for three hours a week whereas others meet for six. In some cases, students take the laboratory in a separate, shorter term where they can devote many hours a week to the laboratory. In countries where a distributed approach to teaching analytical chemistry is common, it is difficult to determine the range of hours of analytical chemistry experience students get over the degree.

Australia

Chemistry is taught in 22 of the 41 universities in Australia. Most offer a major/specialization in chemistry (not specifically analytical chemistry) through a three-year Bachelor of Science (BSc) degree program. There are also universities offering bachelor's degrees in biotechnology, environmental science, forensic science, and medical science in which chemistry is an integral component. Students meeting the requirements can pursue an additional year of study to gain a BS with Honours (BSc (Hons.)). Performance in the BSc (Hons.) program determines whether a student can proceed directly to a PhD program. In recent years, several universities have replaced the BSH with a two-year Master of Science by Research.

Most universities run on a two-semester system over the February-June and July-November periods, each lasting 12-13 weeks. First year students intending to major in chemistry will typically take two units covering fundamental aspects of inorganic, organic and physical chemistry, supported by other science disciplines (biology, geology, mathematics, physics, statistics, etc.) of the student's choice. In years 2 and 3, respectively, students take one unit of analytical chemistry in addition to advanced offerings in the three chemistry subfields mentioned above.

Topics covered in analytical chemistry commonly include statistical treatment of chemical data, chromatographic separations, spectroscopic techniques, and electrochemical detection. The third-year

analytical chemistry unit focusses more on analytical instrument-based techniques. In many universities, third year students have the flexibility to include more units in a subfield that appeals to them. In general, for each unit, students are required to attend 2-3 hours of lecture per week, accompanied by a one-hour tutorial and/or a one-hour workshop per week. In some universities, there is an associated laboratory component with each unit, while others offer laboratory work covering all chemistry subfields as a separate unit. The laboratory component is usually a 3-4-hour session held every other week. Laboratory safety and risk assessments of reagents used are a compulsory component of all pre-laboratory work. As indicated in Table 2, there are variations in lecture and laboratory hours among universities, which vary with the number of credits allocated to an analytical chemistry unit. The credits and contact hours are influenced by several considerations including the timetable of laboratory sessions, the availability of laboratory space and instrumentation, and whether the lab session accompanies the lecture or is taught as a separate unit.

Laboratory work in analytical chemistry is designed for students to gain hands-on experience operating major analytical instruments, applying those techniques to the analysis of real-life samples, and troubleshooting any problems that arise when executing a method. Students analyze results using statistical methods and interpret their results. Students acquire communication skills through preparation of laboratory reports and group oral presentations. In some universities, there are opportunities for third year students to conduct a project related to real-life analytical chemistry problems and/or to earn credits through internships at local or international industrial organizations. Experiences gained through these types of activities are generally expected by prospective employers in chemical industry in Australia. Assessments usually include a formal examination, (online or paper) assignments, laboratory work, and if appropriate, a project report.

An additional Honours year is mostly to prepare students for higher degree research work. Students pursuing Honours complete fewer units of study and devote a substantial amount of time to a research project under academic supervision during the year. Accordingly, there is an opportunity for an Honours student to opt for a research project in analytical chemistry. Honours students usually present their research in a department seminar series and write a mini thesis by the end of the year. The quality of the mini thesis and performance in a thesis defense usually constitute two-thirds of the assessment for Honours students.

Many universities gain accreditation for their chemistry program through The Royal Australian Chemical Institute (RACI) [5], although this is not a compulsory requirement for a university to offer a program. Currently, 19 of 22 universities that offer a chemistry program are accredited by RACI. Accreditations are based on materials presented to a panel that demonstrate a set of chemistry threshold learning outcomes (understanding chemistry; scientific knowledge; inquiry, problem solving and critical thinking; communication; personal and social responsibility), followed by assessments by a visiting panel to the university. In recent years, all higher education research institutions in Australia must satisfy the general content and assessment requirements for each unit of study as guided by the Tertiary Education Quality and Standards Agency of the Australian Government [6].

Germany

Analytical chemistry is included in the bachelor's curriculum of chemistry, food chemistry, biochemistry and business chemistry at German Universities and in a large variety of chemical and chemistry-related studies at Universities of Applied Sciences. Universities have a stronger focus on research activities including PhD studies. Universities of Applied Sciences are more focused on education with limited opportunities to carry out research and PhD studies. At Universities, 98% of students obtaining a

bachelor's degree in chemistry or a related subject pursue a master's study afterwards, and 86% of the students obtaining a university master's degree proceed with a PhD. At Universities of Applied Sciences, 68% of students obtaining a BSc proceed with a master study. Of these, just some 20% start a PhD project [7].

Study programs must be accredited and re-accredited regularly [8]. This is carried out by several agencies authorized by the German Accreditation Council [9]. This national accreditation system demands several structural requirements. However, the content of study programs is decided by the universities themselves. Due to the German constitution, governmental influence on this is very limited [10]. Chemical societies such as the German Chemical Society (GDCh) or German Society for Biochemistry and Molecular Biology (GBM) only indirectly influence study programs – either by their members as part of university faculty or by publishing recommendations. There is currently no system in which chemical societies provide approval for chemistry programs.

With the Bologna process and the creation of a joint European Higher Education Area, the German system changed from the diploma to the new bachelor/master system. With that, scientific societies gave their recommendations for the introduction of the renewed chemistry programs. Regarding analytical chemistry, *Eurocurriculum II for Analytical Chemistry* gave a valuable basis for strengthening analytical chemistry in the reformed curricula demanding at least 15 credit points [11]. GDCh also gives regularly updated recommendations for bachelor programs in chemistry at Universities with the latest one dating from 2021 [12]. However, GDCh statements do not contain any recommendation in terms of credit points for the chemical subfields. For the last two decades, analytical chemistry has become an approved subfield of chemistry in these statements. Before that, analytical chemistry had mostly been incorporated into either inorganic or physical chemistry courses.

To obtain a bachelor's degree in chemistry at Universities in Germany predominantly takes three years, (i.e. six semesters). A six-term program yields 180 credit points. There is a winter and a summer term, both comprising normally 14 to 15 weeks. The time between the terms is often used for laboratory courses, which may also have a seminar component. While laboratory courses running during the term mostly occur in the afternoon, laboratory courses between the terms often run in the morning and afternoon. One credit point involves a workload of 25 to 30 hours, which includes formal lecture and laboratory time in the presence of an instructor and time the student spends out of class in self-study.

A chemistry major is predominantly set-up in such a way that the first four terms include chemistry basics (general chemistry, mathematics, physics, inorganic and organic chemistry, physical chemistry, analytical chemistry, biochemistry, theoretical chemistry). There are at least two subfields per term. The last two terms are often devoted to advanced topics in mostly inorganic, organic and physical chemistry.

Many programs offer an introductory laboratory course of analytical chemistry in the first term, which is often mainly devoted to wet-chemical techniques (gravimetry, titrations etc.). At some Universities, this belongs to the general chemistry education and is not classified as analytical chemistry. Advanced instrumental analytical techniques (spectroscopy, chromatography and separations, mass spectrometry, electroanalysis, etc.) are then often part of the second, third or fourth term. In nearly all programs, the lectures are delivered before students learn the practical aspects of analytical chemistry in a later laboratory course. Elective offerings in analytical chemistry are possible at some institutions, but they are few.

Students in Germany take at least one one-term lecture (2 hours per week) and one laboratory course (often four weeks, typically 25-30 hours per week) in analytical chemistry as part of the requirements of a bachelor's degree. The wide range of lecture and lab course hours in Table 2 arises from the fact that analytical chemistry is often limited to one lecture combined with one subsequent laboratory course, mostly given during one term. However, some institutions require a second analytical chemistry lecture and laboratory courses that mostly cover advanced topics. Therefore, as curricula are quite different at different institutions, credit points in analytical chemistry also differ a lot. However, as stated earlier in this section, the number of credits relates to the amount of workload carried out by the students. At least ten credit points of analytical chemistry can be found in nearly every chemistry curriculum. At Universities with a professorship in analytical chemistry, the counting of credit points is often much stricter than at Universities where analytical chemistry is taught by inorganic, organic or physical chemists. At the latter Universities, the amount of analytical chemistry in the curriculum is sometimes overestimated.

Peru

Peruvian universities offer bachelor's degrees in chemistry, pharmaceutical chemistry and biochemistry. According to the National Superintendence of Higher Education (Superintendencia Nacional de Educación Superior Universitaria - SUNEDU) in Peru, there are 7 chemistry programs and 15 universities offer pharmacy and biochemistry [13]. In all cases, a reform of the Peruvian university system in 2015 established minimum standards and created SUNEDU to oversee the quality of services provided by universities. The University Law [14,15] requires that all undergraduate programs have a minimum of 200 credits, a minimum of five years, and two semesters per year that are at least 16 weeks long. A credit has been defined as 16 lecture hours or 32 laboratory/practical hours in a semester. In Peru, students usually begin their college degree at the age of 17, which accounts for the five years needed to complete a bachelor's degree. Chemistry programs in the country do not have a particular agency that certifies bachelor's degrees in chemistry. Currently, some programs are accredited by different international agencies, such as the National Council for Chemistry Teaching and Professional Practice A.C. [16], the Interinstitutional Committee of Higher Education Evaluation from Mexico [17], or the Accreditation Board for Engineering and Technology [18], among others.

Undergraduate science students spend their first 2-4 semesters studying calculus, physics, and general chemistry through a combination of lectures and laboratory sessions. Chemistry majors spend the next 6 semesters studying organic, inorganic, physical, analytical, biochemistry, and other areas related to chemistry. In most chemistry programs, students are required to take 3-4 lecture courses in analytical chemistry (for a total of 9-16 credits, and 144-256 hours), which are associated with 3-4 laboratory courses (for a total of 6-8 credits, and 192-256 hours). The number of courses and hours per week changes from one university program to another, but in almost all case students take a 3-4 credit lecture course along with a 2-credit laboratory course each semester during their third and fourth year. Topics covered in these courses include qualitative and quantitative analysis in the second and third year, and instrumental analysis in the third and fourth year. In addition, students may have the opportunity to take some elective courses to further specialize in some analytical chemistry topics (e.g., X-ray detection methods, surface analysis) or to enhance their analytical chemistry skills in some applied topics (e.g., applied electrochemistry, environmental analysis). In most programs, courses focus on the principles, applications, and limitations of different analytical techniques. Laboratory courses focus on providing hands-on experience with different instruments, implementing different analytical methods, sample treatment, data processing, troubleshooting, and developing professional skills such as communication, teamwork and problem solving. In some cases, students spend their fifth year working on a research project, which may or may not be related to an analytical chemistry topic, to gain further experience.

After graduating, these students may spend additional time completing their research project, writing a thesis and defending it in front of an evaluation committee, their advisor and other members of the university. In this way, someone with a bachelor's in chemistry obtains their Licentiate in Chemistry, a professional title that allows them to register with the national society of chemists.

Organic, inorganic, and physical chemistry courses may include some complementary activities to reinforce concepts related to NMR, molecular and atomic spectroscopy, mass spectrometry, chromatography, and electrochemistry and their application in various areas of chemistry. However, a limitation in several programs has been access to state-of-the-art instrumentation or proper maintenance to perform some hands-on experiments in instrumental analysis. In addition, most faculty members teaching these other courses are not primarily trained as analytical chemists and it is not clear if students are properly trained in topics such as sampling, interferences, matrices, calibration, validation, and troubleshooting with the various instrumental methods. When instruments are accessible, they most often use them as a tool to complete a set protocol. Perhaps the only chance for a student to gain a deep understanding of an instrument is to use it in a research thesis project.

South Africa (SA)

In South Africa, three-year bachelor's degrees in chemistry (BSc Chemistry) are offered by higher education institutions. This may be followed by a one-year chemistry Honours degree, a one-year (minimum timeframe) chemistry masters degree (MSc), and finally by a three-year (minimum) PhD. The Council for Higher Education (CHE) in South Africa accredits these degree programs according to the Higher Education Act [19]. The registration of degrees is governed by the South African Qualifications Authority (SAQA), [20] and must meet the requirements detailed in the National Qualifications Framework Act (NQF) [21].

The total number of credits for a BSc Chemistry degree is typically 360-400, which translates to 3600-4000 notional hours over the course of the degree. These notional hours include contact time comprised of both lectures (for the chemistry component this is generally four to five hours per week including a tutorial) and laboratory practical sessions (typically one three-hour session per week for chemistry in the first year and two three-hour sessions in second and third year), as well as additional time students require to work on the module, such as self-study and completion of assignments and practical reports. The academic year is commonly divided into two semesters running from February to June and July to November, or four quarters with each quarter being seven weeks long.

General chemistry typically accounts for 30 of the 120 credits in the first year of the BSc degree, with physics and mathematics core modules similarly accounting for 30 credits each. The two semester-based first year general chemistry modules (or one year-long module) introduce the subfields of chemistry, including analytical chemistry. Further credits are taken in an elective that supports a second major. Those offered differ between institutions; examples include applied chemistry, biochemistry, physics, geology, mathematics, geography and plant science. The first year may include fundamental modules (having a small number of credits) to enhance the chance of academic success of students by developing competencies in areas such as academic orientation, computer literacy, and language and study skills.

In the second and third years of the BSc Chemistry degree, institutions usually offer modules dedicated to the four subfields of chemistry (analytical, organic, inorganic and physical) either in quarter or semester format. Chemistry accounts for 40-44 of the 120-132 credits for the second year of the degree, with the remaining credits allocated to elective modules. The second-year analytical chemistry module (for example 12 credits, with 5 lectures per week for a quarter module) tends to cover more traditional

and fundamental aspects of the field, with concurrent titration (wet chemistry) based laboratory practical sessions. A similar structure is followed for the third year of the undergraduate degree with chemistry accounting for half of the credits. The analytical chemistry learning outcomes (for example totaling 18 credits) relate to instrumental analytical techniques such as chromatography, mass spectrometry, optical molecular spectroscopy, optical atomic spectroscopy, electrochemical methods and surface analysis. The theory and laboratory practical components are run concurrently in most cases (as one module) and are well aligned to facilitate holistic learning. Laboratory sessions run between 3-6 hours each (depending on whether one or two sessions are completed per week and on whether a greater number of notional hours for a laboratory practical need to be allocated to interpretation of data and report writing), with six sessions per analytical chemistry module.

Completion of certain undergraduate analytical chemistry modules may be a requirement for other degrees, such as a BSc Biochemistry. Some institutions do not offer discrete analytical chemistry modules to BSc Chemistry undergraduate students, but rather embed aspects of the material within interdisciplinary chemistry offerings and laboratory practicals dedicated to a range of subfields of chemistry. It should be noted that aside from these BSc qualifications, a three-year diploma in analytical chemistry is offered by Universities of Technology in South Africa, which are dedicated to training analytical chemists and technologists.

BSc Chemistry graduates may enroll for a one-year BSc Honours degree (BSc Hons) in chemistry. Entry to the BSc Hons is usually competitive, with institution-specific minimum grade point averages (GPA) required for the chemistry modules of the BSc degree. The curriculum of the BSc Hons (Chemistry) degree includes advanced analytical chemistry modules to build depth of understanding and to expand on content coverage. In addition, a research project for at least 25% of the total credits is completed by students that may have a clear focus on analytical chemistry or may include use of analytical techniques (for example employing mass spectrometry to identify synthesized organic compounds). A BSc Hons qualification is required for entry to the MSc program and for registration as a Professional Natural Scientist with the South African Council for Natural Scientific Professions (SACNASP).

United Kingdom (UK)

The inclusion of analytical chemistry in the bachelor's curriculum within the UK occurs in two different approaches. At some institutions, aspects of analytical chemistry are embedded into organic, inorganic, and physical chemistry modules. At others, analytical chemistry is taught in discrete modules. The Royal Society of Chemistry (RSC) is responsible for accreditation of chemistry degrees within the UK [22] but will also allow chemistry programs throughout the world to apply for RSC accreditation. There are specific requirements for the depth and breadth of chemistry that must be present for accreditation. One key criterion for accreditation is that students in bachelor's programs spend at least 300 hours, and students on integrated master's programs 400 hours, in the practical laboratory across the entirety of a program. Alongside this most chemistry degrees in the UK will align with the Quality Assurance Agency (QAA) subject Benchmark Statement for Chemistry [23]. This framework describes the nature of study and the academic standards expected of chemistry graduates.

Students within the UK need three years to complete a bachelor's degree (BSc) or can take four years to complete an integrated master's degree (MChem and MSci). Integrated master's degrees may have alterative options in the third year such as study abroad or placement in industry. Most universities have two semesters that are typically 15-17 weeks long. Students attend both semesters and usually take between 4-5 modules in each. Modules cover a single topic (e.g. analytical chemistry) and focus on practical and transferable skills. Modules range from 10 to 30 credits, in which 10 credits involve 20-30

contact hours over the semester. Students taking 4-5 modules will spend between 10-15 hours in lectures and 3-6 hours in laboratory classes per week. The bachelor's degree requires 360 credits. Classification of the degree is mainly based on the latter years of the degree program. The varying number of lecture (60-120) and laboratory (30-60) hours of analytical chemistry reported in Table 2 are due to the differences in course structure at different institutions and the extent of analytical chemistry each includes relative to other areas of chemistry.

The RSC does not directly stipulate the chemistry content for accredited degrees but expects that the main subfields of chemistry (organic, inorganic, physical, and analytical) are provided at appropriate points within the program. However, the QAA Benchmark Statement for Chemistry stipulates that analytical chemistry graduates should be able to "explain the theoretical basis and limitations of a range of classical and instrumental analytical techniques, undertake practical analyses and measurement and communicate the outcomes using appropriate terminology and mathematical or graphical notation". Laboratory sessions on analytical chemistry focus on measurement and instrumentation and are either embedded in organic, inorganic, and physical chemistry or taught separately. In the final year of all degree programs, students undertake an extended project in any aspect of chemical sciences.

Students in most chemistry programs take organic, inorganic, and physical chemistry each year, building year upon year. Analytical chemistry is either introduced in year one or in later years depending on whether it involves a stand-alone module or is embedded into other chemistry subfields. This can equate to approximately 10 to 25 % of the degree content in an average bachelor's degree. In the final year of the degree, students can often take optional specialized modules in analytical chemistry. Many alterative degree programs such as pharmaceutical chemistry and forensic science provide a much wider extent of analytical chemistry and within the UK there are some bachelor's degrees solely focused on analytical chemistry.

United States (US)

The inclusion of analytical chemistry in the bachelor's curriculum in the US discussed herein is what occurs at most institutions. There are regional accreditation entities that create certain country-wide expectations, but these do not force every institution in the country into a single curricular structure (e.g., one mandatory length for each semester of study). The American Chemical Society (ACS) operates a program that approves chemistry programs to offer certified bachelor's degrees [24], although all chemistry majors in an approved program do not need to pursue the certified degree. There are about 700 ACS-approved chemistry programs. The ACS approval program has requirements for the certified degree but does not constrain programs to a single curricular approach.

Students in the US typically need four years to obtain a bachelor's degree. Most institutions have a fall and spring semester, each of which is typically 15-17 weeks long. Students usually attend both semesters and take 4-5 courses in each. Courses mostly cover a single discrete topic (e.g., analytical chemistry) and are typically 3-4 credits depending on how many hours they meet and whether they have an associated laboratory. Bachelor's degrees require around 120 credits.

ACS-approved programs must offer one lecture course equivalent in each of the five subfields of chemistry (analytical, biological, inorganic, organic and physical). In most programs, the classroom portion of these courses meets three hours a week, which typically corresponds to three credits. Students completing a certified degree must take one lecture course equivalent in each of the five subfields, and one 3-4 hour/week laboratory experience in four of the five subfields. ACS approved programs must provide undergraduates hands-on use of an NMR spectrometer and have

instrumentation in four of the five following areas: 1) optical molecular spectroscopy, 2) optical atomic spectroscopy, 3) mass spectrometry, 4) chromatography and separations, and 5) electrochemistry. While some programs have integrated laboratories (e.g., synthesis bridging organic and inorganic, measurement bridging analytical and physical) that are often taught at the upper level, most courses have an associated laboratory component that students take simultaneously with the lecture.

Students in most chemistry programs take two semesters of general chemistry lecture and laboratory in their first year and two semesters of organic chemistry lecture and laboratory in their second year. Physical chemistry lecture and laboratory is often taken in the third year. Analytical and inorganic courses are often taken in the second through fourth year depending on whether they are introductory or advanced and whether they have prerequisites. Many programs offer an introductory quantitative analysis course taken by second- and third-year students and an instrumental analysis course taken by third- or fourth-year students [25]. Many programs offer alternative degree tracks (e.g., biochemistry) that may not require any analytical chemistry lectures or laboratories.

While programs can distribute the coverage of a subfield among multiple courses, this is uncommon. TJW served for eight years on the committee that oversees the ACS approval program. Analytical chemistry was the only subfield that some programs taught in a distributed manner. In many of these cases, most of the analytical component of the curriculum was distributed among laboratory rather than lecture offerings. The rationale for distributed coverage was that other areas of chemistry inherently perform chemical analysis procedures in the completion of experiments. However, these programs often had no faculty members who were primarily trained as analytical chemists and it was a challenge to determine if many topics that would be expected in dedicated analytical courses (e.g., sampling, interferences, matrix effects, limit of detection, dynamic range, calibration, validation, and troubleshooting) were included. Also, instrumental methods were mostly used as tools to complete measurements, and it was doubtful that students were exposed to the entirety of the analytical process as described in an ACS supplement [26].

Outcomes of a recent survey on analytical chemistry instruction within the US were recently published [25]. In the survey, 97% of respondents indicated that their major required at least one course in analytical chemistry; 66% reported that more than one course was required. Over 75% of these courses were titled Quantitative Analysis (or similar), Analytical Chemistry, or Instrumental Analysis. Over 80% of the courses included a laboratory component. About a third of survey respondents were in programs that offered more than two analytical courses, giving students the possibility of obtaining additional experience in analytical chemistry beyond degree requirements. Data from this survey indicates that typical bachelor's chemistry majors in the US will have 4-8 credits of analytical chemistry, which correlates with 45-90 hours of classroom and 45-120 hours of laboratory instruction.

Concluding Comments

The wide ranges for the items in Table 2 indicate that students finish their bachelor's degrees with highly variable backgrounds in analytical chemistry. The number of required courses and hours may often depend on the degree to which analytical chemistry faculty members can influence the requirements for the major. Also, there are instances in each country where the analytical courses or laboratories are not necessarily taught by faculty trained in analytical chemistry. Finally, some graduates may have more theoretical than hands-on practical experience in analytical chemistry, particularly when resources are constrained, thereby limiting the availability of instrumentation for undergraduate laboratory education. Employers wishing to hire bachelor's degree recipients with analytical chemistry experience cannot

assume that all graduates have uniform skills and background and need to carefully consider the nature of experiences a student has had. Many institutions throughout the countries represented herein do offer additional courses in analytical chemistry that often cover special topics, meaning that students with an interest in analytical chemistry can often gain extra experience in the field.

Two goals of the IUPAC study are to determine whether the inclusion of analytical chemistry in the bachelor's curriculum has changed over time and whether those teaching analytical chemistry are primarily trained in that area. Understanding the different terms used in different countries (e.g., courses/modules, laboratories/practicals) and the different ways that analytical chemistry is incorporated into the curriculum (e.g., separate versus distributed courses) will help the committee devise a survey instrument that will provide more useful data. Information from the survey of the form reported in this article on longitudinal trends for inclusion of analytical chemistry in the curriculum will help the IUPAC study group determine whether analytical chemistry receives proper inclusion in the bachelor's degree or whether changes are recommended. If changes are recommended, the study group will provide constructive suggestions for suitable interventions.

Table 1. General Characteristics of the University System

	Australia	Germany[a]	Peru	SA	UK	USA
National accreditation process	Yes	Yes	Yes	Yes	Yes	Yes
Chemistry accreditation process -Mandatory (M) or optional (O)	Yes – O	No	No	No	Yes – O	Yes – O
Years to bachelor's degree	3	3	5	3	3	4
Credits for bachelor's degree	80-300	180	200	360-400	360	120
Semesters per year	2	2	2	2	2	2
Weeks per semester	12-13	14-15	16	14	15-17	15-17

[a]Situation for Universities only

Table 2. Specific Characteristics of Analytical Component of the Bachelor's Degree

	Australia	Germany[a]	Peru	SA	UK	US
Mostly separate courses (SC) Mostly distributed coverage (DC) Both common (BC) – university dependent	SC	BC	SC	SC	BC	SC
Mostly separate labs (SL) Mostly distributed labs (DL) Both common (BC) – university dependent	BC	BC	SL	SL	BC	SL
Labs simultaneously with (SW) lecture or subsequent term (ST)	SW	ST	SW	SW	SW	SW
Required courses or modules	2	1-2	3-4	2[b]	-	1-2
Required labs or practicals	2	1-2	2-3	2[b]	-	1-2
Total credits for degree	12-25	10-20	3-8	30[b]	30-90[b]	4-8
Total lecture hours for degree	72-104	45-120	144-256	70[b]	60-120[b]	45-90
Total lab hours for degree	36-48	75-145	192-256	36-72[b]	30-60[b]	45-120
Specialization option – Extra courses	Yes	Rarely	Yes	Yes	Yes	Yes

[a]Situation for Universities only
[b]Only applies to programs with separate analytical chemistry courses or modules

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Declarations
Conflict of interest The authors declare no competing interests.

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