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POINT OF VIEW

Teaching Experimental Instrumental Analytical Chemistry

Are we forming professionals, training operators or illuding students (and ourselves)?

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The term "science" refers to "any system of knowledge that is concerned with the physical world and its phenomena and that entails unbiased observations and systematic experimentation".[1] Therefore, laboratory courses are almost universally considered an integral and mandatory part of instruction on science and technology,[2] whatever the field or area of specialization. Consequently, undergraduate chemistry courses (and correlated specialties such as pharmaceutical sciences, biochemistry and some branches of engineering) always include practical disciplines, one of which is instrumental analytical chemistry. Despite being essential for these courses and part of the everyday routine of the faculty affiliated with analytical chemistry departments or programs, several aspects are far from being consensus among lecturers, students and the other people involved. Topics related to course syllabus, general approaches on the implementation and teaching of specific analytical techniques and experiments, their integration with other disciplines, and much more, are a matter of constant discussion and debate.

One aspect to be considered is the considerable change in the profile of students that has occurred in recent years. The teaching tools and didactic approaches that university professors and instructors aged > 40 years experienced in their own training are generally not suitable for the present-day undergraduate audience. With former generations, the usual sources of information were printed books and similar materials available in libraries, whereas students today have a greater affinity for consulting online sources,[3] which are not always reliable and often return a huge number of search results that require careful evaluation to select which information is relevant and/or reliable. Of course, the facility with which online sources of information are manipulated by our present pupils also has some important advantages: in particular, the near-instantaneous speed of information collection and the virtual accessibility to databases from anywhere on the planet. In addition, until the turn of the millennium, university students were more used to long lectures and experimental classes with relatively complex procedures that often took hours of careful manipulation and numerous laboratory operations (many of them repetitive and tedious). Specifically in the case of practical classes, many of today's students are relatively unaccustomed to experiments that require more than moderate manual skills (at least when compared to their colleagues of previous generations), which may also imply difficulty in organizing their time in the laboratory. Perhaps one of the biggest mistakes we make with our current students is that we consider them ill-prepared or less capable than our generation and attribute their difficulties to this simplistic, crude verdict – when perhaps the biggest problem is that, as educators, we are failing to cope with the rapid evolution in the characteristics and profiles of these young people. The type of change we need so that we can offer practical courses on instrumental analytical chemistry that are more appropriate and better suited for our students is not

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easy because, in addition to the demand that we change the vision of teaching and paradigms that we have considered as absolute since we entered our academic career, we are also confronted with practical reasons that make this type of change difficult. Laboratory classes demand a huge endeavor from technical and instructional staff and teaching assistants; furthermore, they are comparatively expensive, requiring space, fragile glassware, acquisition and maintenance of instruments, proper disposal of consumables and waste, as well as expenses on faculty salaries.[4] The revision of curricula and experimental procedures would impose additional pressure on the workload of the personnel involved and also on the reduced budget availability typical of most public and private universities and colleges (whether in Brazil or anywhere else on the planet).

Although there is no easy, direct and universal solution to the problems mentioned above, some alternatives can be tested and adopted with relative ease in most higher education courses on instrumental analytical chemistry. The workload of the experiments can be reduced, supplementing them or eventually even replacing some with practices carried out in virtual environments, which had an unexpected but necessary boost during the recent COVID-19 pandemic.[5] Several paid or free-to-use tools have been described for this purpose. For instance, Shallice *et al.*[6] describe a downloadable high-performance liquid chromatography simulator that emulates a basic automated liquid chromatography system capable of binary gradient operation. Similar software emulating other instrumental techniques exist, such as UV-Vis's spectrometry, electroanalytical techniques, etc., as stand-alone applications, full online resources or even as Excel spreadsheets. In addition to simulated experiments using virtual analytical instruments, other resources that can be used as a supplement to practical instrumental analysis classes are online video libraries, which have also proliferated after the recent period of restriction on face-to-face activities. A well-known example is the collection of the Royal Chemical Society,[7] which offers videos demonstrating basic principles and practical aspects of various instrumental techniques (from gas and liquid chromatography to nuclear magnetic resonance spectroscopy).

In addition to possible inadequacies due to changes in the profile of typical students currently entering higher education courses in chemistry and related sciences, the evolution of analytical instrumentation, its scope of application and the practical demands imposed on analytical methods that future professionals will apply also pressure us to make changes in the programs of experimental disciplines of instrumental analytical chemistry and in the way we teach the associated techniques. Until the turn of the millennium, the typical program of experimental disciplines of instrumental analytical chemistry in most of the curricula in Brazil and many other countries comprised sequences of isolated experiments using analytical techniques such as gas or liquid chromatography, UV-Vis absorption spectrometry, atomic emission/emission spectrophotometry, etc., with samples and procedures that required relatively simple and quick preparation (usually only sample dissolution, decomposition or extraction). However, due to the natural evolution of analytical instrumentation, the equipment that future professionals will typically find in academic and industrial research laboratories after their impending graduation is very different from that previously employed in the teaching laboratories where their instructors learned analytical chemistry (typically, much simpler equipment that required careful attention and reasonable practical skills from users and operators). The contemporary analytical instruments are much less transparent to the user in their operation; however, as a rule, they incorporate extensive automation and/or mechanization resources, complete control of operation by software and greater operational robustness. From a didactic point of view, modern equipment certainly does not provide students with the same understanding and insight of the basic operational principles of the associated techniques as the instruments of previous generations. However, considering the typical profile of today's students, it possibly would not be advantageous to use those simpler analytical platforms exhaustively merely for didactic purposes. For example, until the turn of the millennium, one of the main demands for students in gas chromatography didactic experiments was to improve and master the manual injection of samples using micro syringes. Today, this didactic approach seems to be preposterous, considering that chromatographs without automatic sample injection are becoming increasingly rare in industrial and even in academic environments. The result is that students are sometimes subjected to tedious laboratory sessions and often completely lose their focus on what would be fundamental in that practical class. In addition, the present demand is increasingly for professionals to be trained to interpret data and propose solutions based on the information gained and not to act as mere operators of laboratory equipment. Thus, it seems to us that we should increasingly design experiments for undergraduate students that incorporate all stages of the analytical process, with particular attention to sampling and sample preparation (taking advantage of features of modern instruments that allow processing more samples in less time and whose operation is less dependent of user ability and manual dexterity) as well as the interpretation and understanding of the analytical data produced.

Regarding the above-mentioned focus on the interpretation and understanding of analytical data, it is interesting to note that in 2004, when the Analytical Chemistry Division of the Federation of European Chemical Societies (FECS) established the curricular guidelines to be observed in the analytical chemistry disciplines taught in universities of the European Community (the so-called “Eurocurriculum II”),[8] four basic pillars of education in analytical chemistry were defined: Spectroscopy; Chromatography; Chemical Sensors; and Chemometrics and Computer-Based Analytical Chemistry. Thus, it was recognized that in modern analytical chemistry the processing and interpretation of data, as well as its transformation into useful information about the chemical systems studied, is on a par with the three traditional subdivisions of analytical chemistry (spectroscopic and spectrometric techniques, chromatographic techniques and electroanalytical techniques). Although it is important to emphasize that these considerations apply to courses in the European Community, they can be contemplated in the training of chemists anywhere else on the world. Also, they reinforce the indication that the education of analytical chemists should place an increasing emphasis on aspects related to information generation/manipulation and interpretation and not merely on the direct operational aspects of analytical methods and protocols already established.

The discussion so far does not pretend to cover all the relevant points whose evaluation would perhaps be necessary for a comprehensive and exhaustive debate of the current status of college/University courses on instrumental analytical chemistry, as well as the possible alternatives and paths to follow. In addition, this text of course echoes the author’s personal opinions and idiosyncrasies, without any pretense at being an absolute expression of the truth (if indeed one exists on this matter). In fact, any discussion of these topics is, by their nature, highly controversial and heavily influenced by the background and area of expertise of those involved. However, we have the firm conviction that the community needs to continuously discuss the education and professional development in analytical chemistry, with emphasis on areas where changes can occur very quickly, always keeping an open mind and a willingness to review supposedly untouchable concepts (and, of course, remembering that its focus should always be on the students).

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