Brazilian Journal of Analytical Chemistry
2022, Volume 9, Issue 35, pp 5-6
doi: 10.30744/brjac.2179-3425.point-of-view.ecarrilho.N35

POINT OF VIEW

Analytical and Bioanalytical Chemistry
It is time we innovate

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It is time we innovate from the bottom up! From the analytical chemistry curriculum to the approach we take in teaching it. From the problems we are set to solve to the opportunities we create. Innovation and entrepreneurship are two words that are the "hype of the moment", indeed! But this is for the greater good! Modern societies and highly developed countries invest heavily in education and science and have open economies, with little or no bureaucracy to start a business or create a company. Startups, spin-offs, investors, and profit are words that should be in the minds of young analytical and bioanalytical chemists. Profit, contrary to what our Judaic-Christian religious background has stamped in our subconscious, is not a bad word. It is not a sin!

But let's start from the bottom; let's see how we can improve the way analytical chemistry is taught and what are the changes necessary to bring it to the 21st century. That is right! We are two decades deep into the 21st century, and we still teach our students with the same content and the same way as in the first half of the 20th century, if not earlier!

Is there still a place for the classical analytical march of cations and anions in this scenario?

Of course! Chemical and ionic equilibria in solution, acid-base and complexation reactions are examples of the most fundamental knowledge necessary in analytical and bioanalytical chemistry. It is not a case of not having these formatted as a mandatory course for chemists, but we need to review the methods, the content, and the hours invested in these classics. For example, dozens of cations and anions are separated, identified, and quantified in capillary electrophoresis (CE) experiments, instead of the eight-hour-long class for spot testing, titrations, and precipitations. Let alone running this CE experiment on a microfluidic platform! OK, so is this descriptive analytical chemistry important for the students? Why not present Fritz Feigl's spot tests on the new platform of paper-based microfluidics? These are two simple examples for new and innovative analytical chemistry teaching.

We, analytical and bioanalytical chemists, are passionate and believe it is the most critical discipline in the undergraduate chemistry degree, to the point that Peter Kissinger from Purdue University once said, "three things in life are certain: death, taxes, and the need for analytical chemistry," and that "the importance of analytical chemistry is not arguable!" Unfortunately, this is not the case in some of the most prestigious chemistry departments globally, where analytical chemistry is seen as a service. If this is the case, then we do a pretty good job. Out of 113 Nobel Prizes in Chemistry awarded to date, about a dozen can be directly linked to analytical chemistry fundamentals, instrumentation or methods, and about six others awarded with the Nobel in Physics. Therefore, the contribution of analytical and bioanalytical chemistry to the advancement of chemical sciences is clear. Curiously enough, about half of the chemistry prizes are associated with biochemistry and biomolecules; thus, reinforcing the central role of bioanalytical chemistry

Cite: Carrilho, E. Analytical and Bioanalytical Chemistry – *It is time we innovate*. *Braz. J. Anal. Chem.*, 2022, *9* (35), pp 5-6. http://dx.doi.org/10.30744/brjac.2179-3425.point-of-view.ecarrilho.N35

as the analytical chemistry for life sciences rather than the analyses of small molecules in biofluids.

We now live in a multi- and interdisciplinary time within a complex and integrated world. For example, the SARS-CoV-2 pandemics have shown the values of understanding virology, immunology, epidemiology, physics, statistics, biochemistry, pharmacology, vaccines, and, most importantly, diagnostics! The state-of-the-art Next Generation Sequencing (NGS) is an analytical tool that provides the forefront information on virus sequence and identity, the presence of mutations, and the design of probes for diagnostic tests. The first diagnostics came from quantitative real-time PCR (polymerase chain reaction), the gold standard method. Lateral flow (LF) rapid test diagnostics kicked in afterwards, and became a massive testing tool for antibody search. Later, LF tests against the antigen (the virus) became available. Where did Brazil rank in contributing to fighting the pandemics? Brazil sequenced the virus in just a couple of weeks, started to produce a couple of vaccines, and made alternative molecular diagnostics to PCR. The three major science funding agencies in Brazil, CAPES, CNPq, and FAPESP, quickly invested a fair amount of money and became one of the top producers of papers. So, one might say Brazil is very well-structured? Unfortunately, it is quite the opposite. All the chemicals and instrument supplies are imported. We designed molecular tests, but don't produce the reagents for the synthesis of oligonucleotides; we isolated the virus, but don't produce the disposable material for safely handling it; we made antibodies for rapid tests, but don't produce the membranes needed for LF; we developed biosensors to detect the virus, but we don't have a company producing them. Brazilian science and industry have become entirely dependent on imports.

It is time we innovate and teach modern analytical and bioanalytical chemistry early on in student courses. It is time we innovate and teach the students how to create jobs instead of seeking employment. It is time we innovate and add entrepreneurship in the curriculum of all undergraduate courses, especially in the chemistry degree.

Emanuel Carrilho, FRSC, is a Full Professor at the University of São Paulo (USP) with a Master's degree in Analytical Chemistry from USP (1990) with focus in instrumentation for supercritical fluid chromatography, and a Ph.D. from Northeastern University, Boston, USA (1997) in bioanalytical chemistry, helping in the development of DNA sequencing technologies that led to the sequencing of the Human Genome Project. Later, (2007-2009) he spent a sabbatical leave at Harvard University in the Whitesides Group, working on the emergence of microfluidic paper-based analytical devices (μPAD) and wax-printing. The Carrilho group, or BioMicS – Bioanalytical, Microfabrication, and Separations Group, develops new bioanalytical methods and instrumentation covering the broad aspects of genomics, proteomics, and metabolomics for human health, applied cell and microbiology in microfluidic platforms like organs-on-a-chip, searching for biomarkers for cancer, rare, and neglected diseases. Dr. Carrilho has supervised over 60 graduate students and a dozen of post-docs, has published about 200 papers with 9,000 citations, and an *h* index of 41. CV