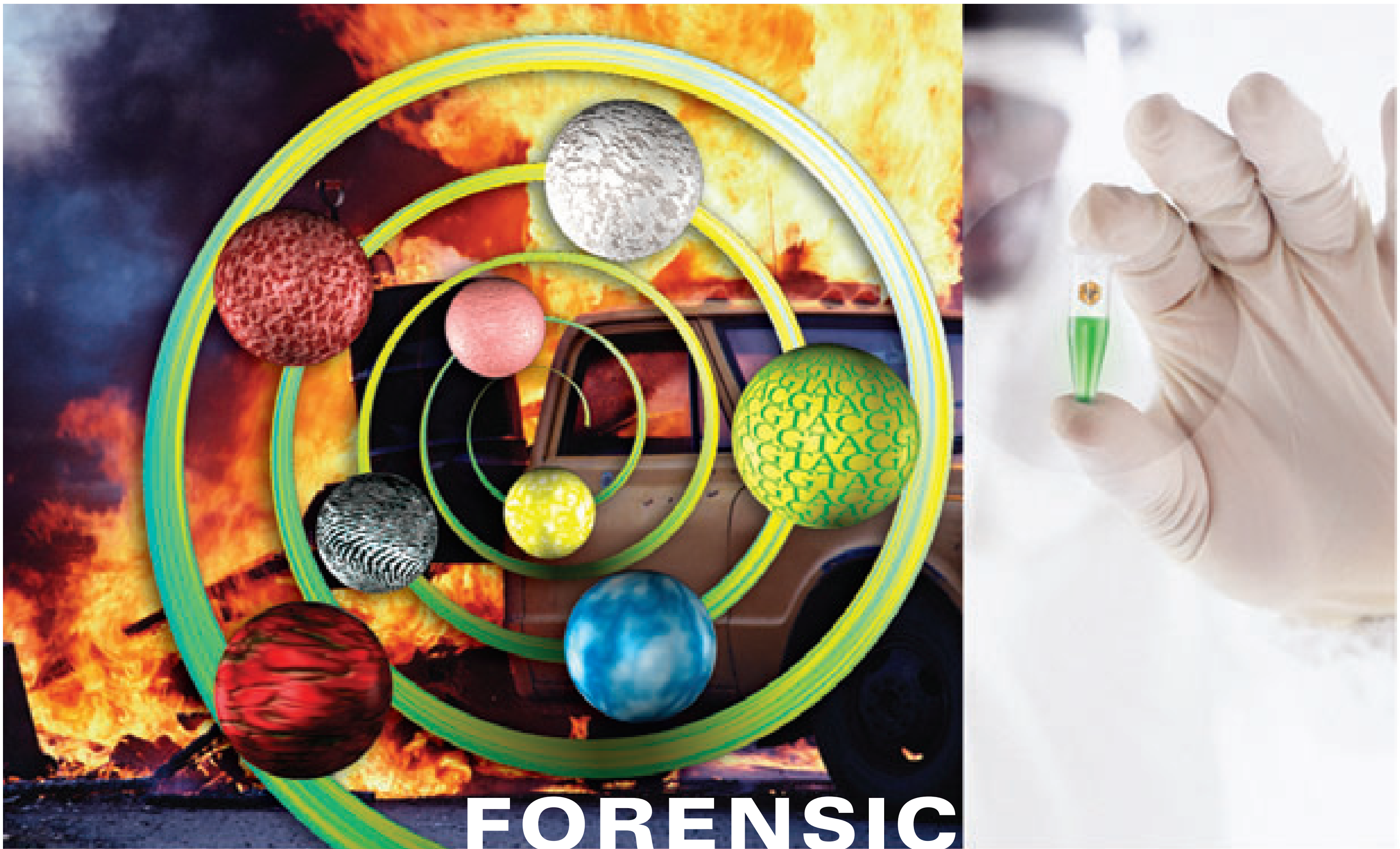

FORENSIC Chemistry Education

News reports and popular TV shows have spurred interest in this career option for chemists.

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Was a crime committed, and if so, who committed it? What is the evidence that links the individual with the event? When and where did the crime take place? What happened, and how did it happen? What is the significance of the physical evidence? Forensic scientists must answer some, if not all, of these questions. Improvements in selectivity and detection limits of analytical methods have led to progress in the forensic analysis of a variety of evidence, including drugs and explosives, as well as material transferred from the criminal to the victim or the crime scene. In the context of terrorism, *Analytical Chemistry* has recently showcased forensic chemistry applications that can be used to prevent catastrophic events by detecting explosives and biohazards (*1*, *2*).

Several specific scientific developments in the mid-1980s and their application in widely publicized cases, combined with recent popular television shows, have focused a great deal of attention on forensic science. This exposure has increased undergraduate and graduate students' interest in forensic chemistry, and many colleges and universities in the United States, the United Kingdom, and Australia have developed new academic programs. A recent survey of academic institutions revealed that more than 90 U.S. colleges and universities claim to offer a program of study in forensic science (*3*). Much of this growth has occurred during the past 10–15 years.

A problem of numbers

In 1985, Sir Alec Jeffreys first introduced the now widely used technique of DNA fingerprinting, which can link DNA found at a crime scene with a suspect (*4*). Equally important were the advances in biochemistry and analytical chemistry, including Kary Mullis's development in that same year of

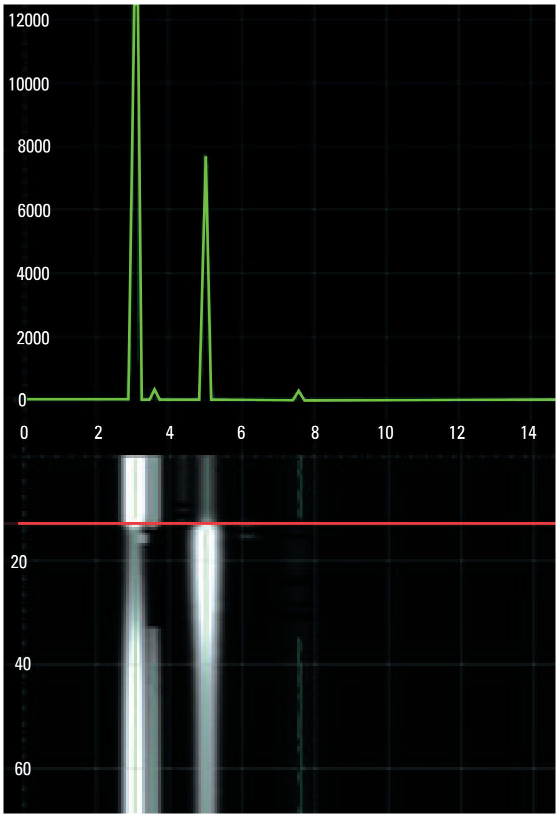
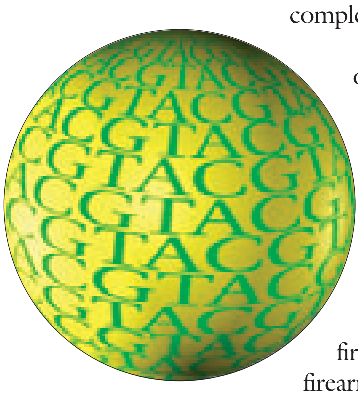


FIGURE 1. (top) Plasmagram with peaks for a dopant and a 4-NT standard and (bottom) a 2-D plot of the IMS signal vs time (ms) after sample introduction.

PCR, which amplifies small amounts of DNA (*5*). DNA typing tools have since been widely accepted by the courts and successfully used as powerful evidence in many criminal trials to prosecute guilty persons. The PCR amplification technique has also been used to exonerate 153 jailed individuals (as of November 2004) through postconviction DNA testing of evidence (Innocence Project, www.innocenceproject.org). Erroneous eyewitness testimony is generally the cause of wrongful convictions (*6*). The PCR technique is so sensitive that, in addition to the usual requirement of maintaining the chain of custody of the evidence, great care must be taken to avoid sample contamination.

The vast majority of chemical analyses performed in U.S. forensic laboratories are routine identifications of controlled substances. In addition to federal forensic laboratories, ~200 state and local laboratories conducted ~1.2 million drug analysis cases in 2002 (*7*). A case may include multiple exhibits; therefore, a better estimate of the number of analyses conducted is ~875,000 items of drug evidence chemically identified during the first half of 2003 by state and local forensic laboratories (*7*). This estimate does not include the number of drug identifications in body fluids and tissues that are normally conducted in toxicology laboratories.

According to a recent report on forensic laboratory staffing, state and local laboratories in the northeastern United States, which has 51 million residents, employed only ~850 forensic scientists in 2001 (*8*). The authors of the report estimate that the number of scientists actually needed to staff this area of the country is double that level, given the backlog of unexamined cases and the increasing case submissions. They and others conclude that "an additional 10,000 new forensic scientists are needed nationwide over the next decade to address the expanding case backlog" and to allow case examinations to be completed within a 30-day period (*8*, *9*).



These staffing estimates include all operational areas: drug analysis; fiber, hair, paint, glass, adhesive tape, soil, and building materials comparisons; fire debris and explosives analyses; gunshot residue analysis; headlight and filament examinations; serological and DNA typings; bloodstain and gunpowder pattern interpretations; firearms and toolmark identifications; firearm operability; projectile and casing comparisons; footwear and tire impression comparisons; forged documents and author authentication; breath, blood alcohol, and urine analyses; drug identifications in biological fluids and tissues; fingerprint and latent identification and comparison; computer and data recovery; and voiceprint analysis.

Federal forensic laboratories have received an increase in resources in recent years, for example, new facilities at the U.S. Federal Bureau of Investigation (FBI) and a new research facility at the U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF). However, state and local laboratories have not all received the necessary funding to meet the law-enforcement community's growing demands for forensic services.

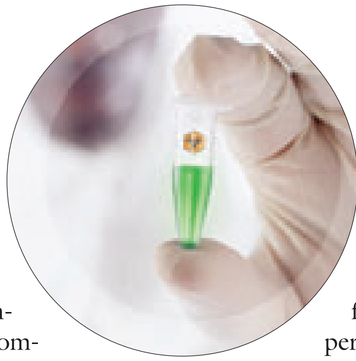
Education

Surveys of laboratory directors and others who employ forensic scientists have indicated that they have a preference for applicants with a B.S. in chemistry or biochemistry, followed by biology and forensic science degrees, with a substantial number of chemistry and other natural science courses (*10–12*). Although the minimum educational level has traditionally been a B.S., graduate degrees such as an M.S. in forensic science are now preferred for entry into the field and are expected for career advancement (*13*).

The development of graduate programs in forensic chemistry and biology will require an investment in research infrastructure by universities and external funding sources, such as the National Institute of Justice (NIJ), which is the research arm of the U.S. Department of Justice. Although NIJ has seen a marked increase in its research budget, the majority of its funding to academic institutions has been congressionally directed. Additional funding sources are needed.

The Technical Working Group on Education and Training in Forensic Science (TWGED) was sponsored by NIJ and commissioned to develop consensus guidelines for academic programs in forensic science. The group, composed of 50 practitioners, laboratory directors, forensic science educators, and others, has drafted a document entitled *Education and Training in Forensic Science: A Guide for Forensic Science Laboratories, Educational Institutions, and Students* (http://nij.ncjrs.org/publications/pubs_db.asp). The guide is intended to assist academic institutions planning to offer new programs or revising their curricula. It contains sections on qualifications for a career in forensic science, undergraduate and graduate curricula, training and continuing education, and careers outside the traditional crime lab.

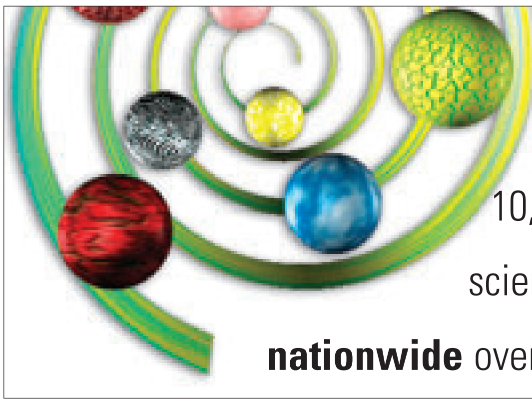
The American Academy of Forensic Sciences (AAFS) formed a group in late 2001 to continue the work of the TWGED by



organizing the first accreditation mechanism for academic programs in forensic science. The commission is composed of five lab directors and practitioners, five educators, and one public member. The stated mission of the Forensic Science Education Programs Accreditation Commission (FEPAC) is to "maintain and enhance the quality of forensic science education through a formal evaluation and recognition of college-level academic programs. The primary function of the commission is to develop and maintain standards and to administer an accreditation program that recognizes and distinguishes high-quality undergraduate and graduate forensic science programs."

FEPAC has adopted the TWGED guidelines in the development of its accreditation criteria, conducted a pilot accreditation of six institutions during 2003, and considered the applications of five more institutions in 2004. FEPAC, through a grant from NIJ and additional support from AAFS, will consider applications for accreditation of academic programs in 2005 and beyond. Additional information on the FEPAC organization, including the accreditation standards, minutes of the commission meetings, and application forms, are available (www.aafs.org).

Central to the development of graduate education in any profession is research activity. Universities with graduate programs have tremendous opportunities to apply analytical chemistry to forensic science problems.



A recent **report concludes** that 10,000 new **forensic** scientists **are needed nationwide** over the **next** decade.

Ignitable liquid residues and explosives

The identification of controlled substances and ignitable liquid residues (ILR; the term used to describe compounds or mixtures that "accelerate" a fire) is routinely performed by GC/MS. Tandem MS has facilitated the analysis of fire debris evidence, especially when the analyte concentrations are very low and/or when the sample contains interfering species not entirely resolved by chromatography (*14*). These more sensitive and selective methods can result in the reporting of evidence that might otherwise go unnoticed. In an arson investigation, the detection of gasoline components—even at extremely low concentrations—in the living room of a house or in an office lobby, absent a good explanation, may lead to the conclusion that the fire was set intentionally. The selectivity of MS/MS allows for the unambiguous isolation of the target analytes from pyrolyzates, which can interfere and possibly coelute and may be present in relatively large concentrations. Improvements in extraction methods, including solid-phase microextraction (SPME), can also assist in the detection of small quantities of ILR evidence (*15–17*).

Common explosives include aliphatic nitrates, aromatic nitrates, nitrate esters, nitramines, and inorganic salts. Ion mobility spectrometry (IMS) has been successfully applied to the field analysis and detection of a wide variety of analytes of forensic interest, including drugs and explosives. About 10,000 IMS instruments have been installed for civilian security purposes and many more for military use, including those deployed as handheld devices (*18*, *19*). These instruments provide fast and inexpensive presumptive testing of explosive particles from surface swabs. About 10 million such IMS analyses are performed every year (*18*).

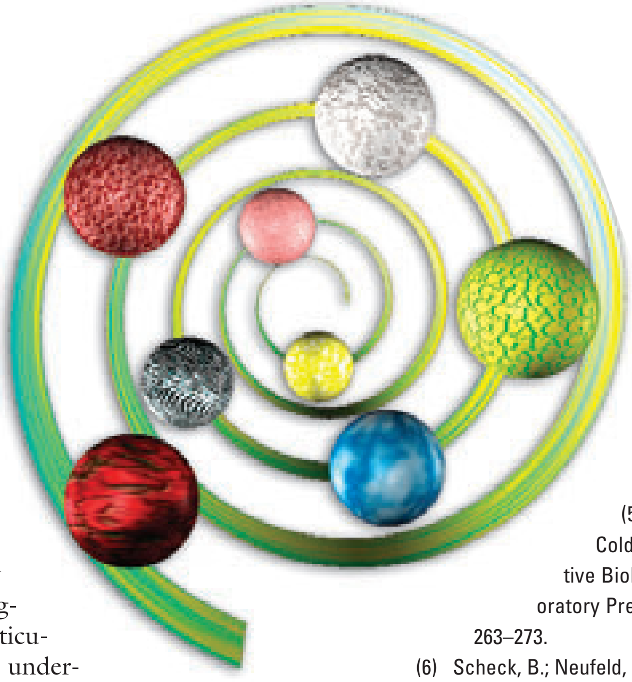
Combining SPME with IMS has the potential to enhance the analysis of the volatile components characteristic of drugs and explosives (*20–23*). Such a device could replace trained dogs for fast, simple, and inexpensive screening for explosives and narcotics in large spaces, such as the cargo hold of an airplane. One set of compounds of particular interest is the organic taggants, whose addition to high-explosive formulations has been required since 1998. The taggant 4-nitrotoluene (4-NT) can be concentrated on a carboxen/divinylbenzene/polydimethylsiloxane SPME fiber with a 1-min extraction to produce a response on an IMS instrument (Figure 1).

Materials characterization

Glass and automotive paint are common types of trace evidence found at crime scenes, especially hit-and-run accidents (*24*). Examiners measure the physical and optical properties of glass, such as color, thickness, and refractive index (RI), to determine whether an association exists between, for example, glass found at the scene of a hit-and-run accident and a broken windshield on a suspect automobile. Industry-wide improvements in quality control during glass manufacturing have made RI less informative as a comparison tool because many glasses now have very similar RI values.

Elemental analysis of glass is now commonly performed with inductively coupled plasma (ICP) optical emission spectrometry, ICPMS, X-ray fluorescence, or scanning electron microscopy; ICP provides better detection limits and discrimination power than other elemental techniques (*25–27*). An ICP mass spectrometer and a laser ablation (LA) sample introduction system used together offer the advantages of minimum removal of sample by LA and the excellent sensitivity and precision of ICPMS (*28–30*). Compared with conventional acid digestion methods for glass analysis, LA reduces costly and time-consuming sample preparation and minimizes contamination.

When the elemental profile of a glass fragment found at the scene of a crime is compared with that of a fragment from a suspected source of origin, the method's sensitivity and precision must be good enough to differentiate between sources. If two fragments have matching profiles, one can infer that the glass samples originated from the same manufacturer (*28*). Chemometrics has become a necessary part of the decision-making process. For example, a multivariate comparison of the trace metals in the glass is necessary to determine whether the glass fragments can be distinguished by a particular analytical method. A thorough understanding of the chemistry of the materials analyzed and the variation of the analytes in a population is also required.



These advances are a few examples of the impact that analytical chemistry is having on forensic casework. Other examples are sample sourcing techniques that use stable-isotope-ratio MS for the analysis of explosives, drugs of abuse, soils, and microbes, and fast atom bombardment and laser desorption/ionization MS methods for the direct analysis of inks and dyes in document examinations (*31*; www.forensic-isotopes.rdg.ac.uk; www.nitecrime.eu.com).

Conclusion

Analytical chemistry has improved the quality of forensic evidence in real criminal cases. Although television shows have glamorized the profession and attracted the attention of the public and prospective students, many forensic laboratories remain understaffed and underfunded, particularly at the state and local levels. Formal programs in forensic chemistry and forensic science education are expanding to meet these staffing needs, and a mechanism now exists to recognize programs that meet minimum curriculum standards. The training programs that choose to undergo accreditation will undoubtedly benefit from the process of self-evaluation and eventually will produce better-prepared graduates and future leaders in the forensic science profession.

J. Perr, A. Hobbs, S. Montero, and T. Trejos are graduate students whose work on the analysis of explosives, paint, and glass is discussed.

José R. Almirall is the director of the forensic science graduate program and an associate professor at Florida International University. His research interests include developing and applying analytical chemistry tools to enhance the value of scientific evidence in legal disputes. These tools include LA-ICPMS and laser-induced breakdown spectroscopy for the elemental characterization of materials and GC/MS, GC/MS/MS, and ion mobility spectrometry for the characterization of organic compounds. Address correspondence to Almirall at Department of Chemistry and Biochemistry, Florida International University, University Park, Miami, FL 33199 (almirall@fiu.edu).

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