Laboratory Curriculum for a Survey of Forensic Chemistry

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Abstract: This paper describes a laboratory curriculum for a one-semester forensic chemistry survey course with options that could be adapted to a two-semester course. Students are instructed in drug chemistry, toxicology, explosives analysis, arson examination, pattern evidence, and trace evidence analysis. Each week, students are instructed on a new method, instrument, or technique using known standards and unknown compounds or materials. Student writeups include short abstracts, laboratory notebook pages, data table(s), graph(s), and chart(s). A simulated case or capstone laboratory concludes the course. Learning how the instruments work, which to choose, setting to apply, how to apply them to the analysis of physical evidence, and concise reporting of data and findings is the focus of this course, and a description of the instructor's curriculum modules and weekly activities is the focus of this paper.

Keywords: forensic science, laboratory instruction, teaching methods, simulated case, instrumental analysis, chromatography, spectroscopy, microscopy, trace evidence, drug chemistry, toxicology, pattern evidence, arson examination, explosives analysis, inks, questioned documents

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Introduction

Forensic chemistry is the application of chemistry to answer questions in legal cases. Forensic chemists analyze physical evidence submitted to the crime laboratory using color tests, microscopy, spectroscopy, and chromatography. Laboratory instruction in forensic chemistry is essential for students to develop hands-on laboratory skills and gain experience safely collecting, documenting, and interpreting data, working with standards, and developing critical thinking, problem-solving, data analysis, and writing skills. Laboratory-based instruction supports and augments theory introduced in the lecture portion of the coursework. The accreditation standards set forth by the Forensic Science Education Programs Accreditation Commission (FEPAC) require "in-person, hands-on laboratory experiences" (FEPAC 2024) (1). Some forensic science survey courses cover crime scene investigation, fingerprint, firearm, toolmark, tread, sole, toxicology, entomology, odontology, anthropology, serology, and DNA typing in addition to drug, ink, and trace analysis. As we have separate courses focused on crime scene investigation, anthropology, serology, death analysis, toxicology, microscopy, weapons of mass destruction (WMD), fingerprint analysis, and firearms analysis, the focus of the forensic chemistry laboratory curriculum described herein is more narrow in scope and focuses on trace, materials, and drug analysis.

The textbooks available for teaching forensic chemistry include Investigating Chemistry: Introductory Chemistry From A Forensic Science Perspective, 4th ed. (2), Introduction to Forensic Chemistry (3), and Forensic Chemistry, 3rd ed. (4). The textbooks target different audiences ranging from introductory chemistry students to forensic chemistry majors to advanced analytical chemistry students. The textbooks introduce and cover the theory of the methods and approaches, but laboratory exposure and experience are essential for practice and to develop competency and confidence with the methods and data analysis. There are many laboratory manuals for forensic science. The Basics of Investigating Forensic Science: A Laboratory Manual, 2nd Edition is a recent one (5). Many instructors have developed their own manual or course materials for their lecture and laboratory instruction.

Instructors tailor their courses to their institutions, curriculum, major requirements, laboratory equipment, prior training and interests, and research programs for course-based research courses. The focus of this paper is to provide new instructors inspiration and a modular framework for laboratory instrument and technique instruction and application connected to a forensic chemistry survey course.

Laboratory modules

In a forensic chemistry survey course focused on criminalistics, drug and trace analysis, the curriculum is

composed of five modules. The laboratory modules include 1) safety and essential laboratory skills, 2) controlled substances and drug analysis, 3) trace evidence analysis, 4) arson and explosives analysis, and 5) inks and pigments questioned documents analysis.

There are many topics and approaches to forensic chemistry laboratory instruction that meets both the FEPAC standard and practice with typical analyses that are performed in public forensic laboratories. Laboratory instruction options within each of the modules are listed in **TABLE 1**. Due to the length of a 5-to-15-week instructional period of most university summer and academic year semesters and varying instrumental and instructional resources at different institutions, instructors need to select laboratory experiments that support the content and breadth of the theoretical instruction in a forensic chemistry survey course. Some of the laboratory instruction can be combined in one laboratory period depending upon allotted time. When only one instrument is available, a rotating approach can be used. In the laboratory, we discuss and use standards from American Society for Testing and Materials (ASTM), Cerilliant, Cayman Chemical, National Institutes of Standards and Technology (NIST), Thermo Fisher Scientific, Sigma, and Carolina Biological.

Concise, accurate, and specific writing is an essential skill in forensic science. Initial instruction on writing short (ca. 150 word American Chemical Society conference abstract length or 250 word *Journal of Forensic Sciences* abstract length) structured abstracts is given in the first week of the course. Students are asked to practice their research and writing skills through a historical research assignment. Each student finds and retrieves a pre-1923 (or slightly newer) newspaper or journal article relating to a forensic case or application of forensic science analysis. Topics may include toxicology, drug analysis, microscopy of materials, and analysis of poisons, or another relevant topic related to forensic investigation and death analysis. After reading the articles, the students are assigned to write a structured abstract for the article including an introductory statement of purpose, method(s) employed and data collected, specific results and interpretation of the data, and conclusion or impact statement. The citation is required to be provided in a standardized format with all details. The format of the abstract is the same used thereafter for reporting on the results in the weekly laboratory experiments and the practice reading and writing about data as well as providing exposure to the history of forensic laboratory science provides a scaffold for success in the laboratory portion of the course.

TABLE 1 *Laboratory modules for a forensic chemistry survey course (*currently used).*

MODULE 1: SAFETY AND ESSENTIAL LABORATORY SKILLS
-Safety and PPE*
-Pipetting accuracy and precision*
-Making reagents: solutions and dilutions*
MODULE 2: CONTROLLED SUBSTANCES AND DRUG ANALYSIS
-Color tests for controlled substances (drugs)*
-Drawing drug structures using software*
-TLC of drugs*
-ALS of medicine packaging
-UV-Vis spectroscopy of drugs*
-ATR FTIR spectroscopy of drugs*
-Raman spectroscopy of drugs*
-C18 reverse phase column liquid chromatography of drugs
-GC-MS of drugs*
-NMR spectroscopy of drugs*
MODULE 3: TRACE EVIDENCE ANALYSIS
-Stereomicroscopy of torn items / pattern analysis*
-Stereomicroscopy of botanical and crystalline materials*
-Koehler illumination, compound light microscopy, and comparison microscopy of hair & fibers, crystalline materials, dust, pollen, and pathogens*
-ALS of rocks and minerals*
-Fluorescence microscopy of fibers & glitter trace evidence*
-ATR FTIR spectroscopy of fibers and plastics polymers*
MODULE 4: ARSON AND EXPLOSIVES ANALYSIS
-Color tests for explosives*
-GC-MS of accelerants / arson analysis*
-ATR FTIR spectroscopy of explosives
-SEM of gunshot residue (GSR)
MODULE 5: INKS AND PIGMENTS QUESTIONED DOCUMENTS ANALYSIS
-UV-Vis spectroscopy of dyes*
-C18 reverse phase column liquid chromatography of dyes*
-ATR FTIR spectroscopy of paint
-Raman spectroscopy of inorganic pigments and dyes*
CAPSTONE LABS
-ALS, TLC, UV-Vis Spectroscopy and ATR FTIR spectroscopy of inks*
-Mock crime scene case*

Laboratory instruction

Since the laboratory instruction must fit in the scheduled defined, time-limited sessions, the content and skills must be divided. Typically, laboratory sessions range from 2 to 4 hours per session once or twice per week depending upon the course and the length of the term. In a traditional semester-long course, there are 14 to 15 weeks of class meetings followed by a week of final exams. The forensic chemistry laboratory at Towson

University consists of weekly 2-hour sessions for 14 weeks and complements a weekly 2-hour course lecture.

Each week, students are instructed on a new method, instrument, or technique using known standards and unknown compounds or materials. The laboratory module exercises addressed in the laboratory instruction are starred. Brief descriptions of each laboratory follow. The students are required to submit short abstracts each week following the laboratory experiment as well as their laboratory notebook pages, data table(s), graph(s), and chart(s). The students are instructed to include the goal or purpose of the laboratory session, background, method(s), data collected, brief statement of results and conclusion. As in forensic case reporting, opinion statements of how well they liked the laboratory are to be avoided.

Safety and Personal Protective Equipment: Students are instructed on the location and use of all safety equipment (e.g., exits, chemical fume hood, fire blanket, eyewash, sinks, fire extinguisher) in the laboratory and university-specific laboratory code of conduct policies. Students must take and pass the department's online safety training module and quiz prior to continuing with the laboratory instruction. All students must wear clothing that covers their skin from torso to toe. Crocs, open back, and open toed shoes are prohibited. Hair must be tied back, and goggles must be worn when wet laboratory experiments are being conducted. Students are instructed each week on the safe handling and disposal of the chemicals and when nitrile gloves should be worn, or materials should be prepared in the chemical safety hood.

Pipetting Accuracy and Precision: The students are instructed on proper and accurate use of a micropipette and balance and the terms accuracy and precision. They are instructed to record the volume and mass of ten replicates of 100 µL of water or dyed water and compute the average and standard deviation with the correct number of significant figures. Students also pipette 10 replicates of 10 µL on parafilm and report their qualitative observations of accuracy and precision. They must state in their abstracts the definitions of accuracy and precision and tabulate and attach their quantitative data and computations. Students also collect data on the relationship between mass and volume by creating a graph with a linear least-squares best fit line and line equation and R^2 to compute density of the liquid (e.g., water pipetted sequentially 5 times into the same container) and report on the accuracy of the tools comparing to literature values.

Making Reagents: Solutions and Dilutions: Students are instructed to make serial dilutions (from 1:10 to 1:1,000,000) of a liquid (e.g., grape soda, dyes) that is used in a laboratory later in the semester and a solution from a solid salt (weigh 1 mg and dissolve in 1.000mL) using a balance, micropipettes, weigh paper, and tubes. The students report the goal, the method they used, what they observed while making the solutions and solubility, and at what dilution the colored solutions are no longer visible to the eye.

Color Tests for Drugs: The students are instructed to test selected drugs or drug-like compounds with selected color tests. The tests include Marquis, Nitric Acid, Nitric-Sulfuric, Ferric chloride, Liebermann, Mandelin, Mecke, and Ferric hydroxamate. The analytes include white powders including salicylic acid, acetaminophen, quinine sulfate, Excedrin, aspirin, ibuprofen, diphenhydramine, procaine, and lidocaine hydrochloride but others can be substituted. Controlled substances can be used instead of cutting agents if the lab has a Drug Enforcement Agency (DEA) controlled substances license. In the lecture, the students are instructed about the expected results with each compound and the chemical reactions. A negative control is performed to compare with the color of the test with the samples. The students are instructed to report their observations with each test and a decision tree flow chart that could be used to differentiate each substance based upon their results.

Drawing Structures using Software: The students are instructed to use Biovia Draw (free software download, https://www.3ds.com/products/biovia/draw) or another available structure program (e.g., subscription ChemDraw, https://revvitysignals.com/ or free ChemSketch, https://www.acdlabs.com/products/chemsketch/) to create the structures of four drug molecules: ethanol, caffeine, lidocaine and diphenhydramine. These drug compounds and cutting agents are discussed in lecture and are used in subsequent labs. The students turn in their structures in lieu of an abstract and other data for this session.

TLC of Drugs: The students are instructed on the use of thin layer chromatography (TLC) solid and mobile phases and how to analyze the results. The students use plastic plate coated with silica. The line of origin is marked with a pencil and 1-2 mg of the analytes dissolved in methanol solvent are spotted with microcapillary tubes. The analytes include the legal substances caffeine, aspirin and Excedrin or salicylic acid, acetylsalicylic acid, and aspirin. The plates are placed in TLC chambers or beakers with watch glasses with mobile phase in the chemical safety hood. The mobile phase used consists of 6.5 mL acetate, 3.0 mL hexanes, and 0.5 mL acetic acid or for a more nonpolar solution 5.0 mL of hexanes and 5.0 mL of ethyl acetate. The drugs are detected using color tests, iodine fuming or a light source at 254 nm. The solvent is run three quarters of the way up the plate. The students measure the distance travelled by the analyte and solvent front and compute the retention factor (Rf) value for each

drug. Based on the distance traveled, the students indicate which drug is most to least polar and compare the results to the structures and provide interpretation of their results.

ALS of Medicine Packaging: Counterfeit medicines pose threats to consumer health. Authentic packaging and pills have unique and characteristic print, color, and shape characteristics. Prescription pill books and identifier applications can be used to evaluate color, shape, and markings. An alternate light source (ALS) is used to evaluate the fluorescent properties of the ink and dyes used in the pills and packaging. Students report their observations at each wavelength with each colored goggles or filter used. Counterfeit and authentic packaging can be compared, if available, and the results tabulated and interpreted.

UV-Vis Spectroscopy of Drugs: A NanoDrop ultraviolet-visible (UV-Vis) spectrophotometer with direct microliter application or an Agilent 8453 UV-Vis spectrophotometer with a 1 mL quartz cuvette is used as the instrument. The students learn how UV-Vis spectrometers can be used as detectors for liquid chromatography and for quantitation of an unknown. The analytes in this course include diphenhydramine (Benadryl), acetylsalicylic acid, salicylic acid, naproxen, and/or caffeine. The students are instructed to weigh 5 mg of a substance and dissolve it in 1 mL of distilled water and then make 3-5 dilutions serially with a final volume of 1 mL each. Scans are recorded from 190-800 nm to determine the absorption maxima. At the λ_{max}, the absorbance is recorded for each dilution and an unknown provided by the instructor with a concentration in the range of the standards and detection limit of the instrument. The students predict which compounds will absorb at the longest and shortest wavelengths based on their structures and report on their results and if their hypothesis was correct. Using standards prepared at 5, 1, 0.2 mg/mL of diphenhydramine detecting absorbance at 257 nm, students are able to quantify diphenhydramine in a 25 mL Benadryl capsule in which the powder was removed and dissolved in 10 mL of water. Students construct Beer's Law absorbance versus concentration graphs and display the best fit line equation for the serial dilution standards and determine the concentration of the unknown, capsule or tablet using the graph assessing the accuracy of the label. Internal calibration standards could be added to the analytes. As the focus is the absorption fingerprint and determining the λ_{max} and the spectrometer is not coupled to an high performance liquid chromatography (HPLC) instrument or liquid chromatography (LC) instrument, they have not been included. Internal calibration standards and HPLC with a UV-Vis detector are used in a subsequent course.

ATR FTIR Spectroscopy of Drugs: Drugs and starting materials including caffeine, salicylic acid, naproxen, lidocaine, procaine, and acetaminophen are used as samples, air as a blank, and spectra are collected and analyzed using attenuated total reflectance (ATR) Fourier transform infrared (FTIR) spectrophotometer (Thermo Nicolet iS10 with ATR accessory). A small amount of the material is transferred to the diamond surface. The range is set to scan 4000 to 400 reciprocal centimeters using a 0.929 cm^{-1} spacing and displaying Percent Transmittance (%T). Sixteen scans are recorded. The library is searched to identify the compounds. The results are compared to the Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG) and National Institute of Standards and Technology (NIST) spectra. Spectra are saved as .csv files and replotted in stack plots in a graphing program such as Microsoft Excel. Students are instructed to assign the major peaks for the for the stretches using a correlation chart with a focus >1500 cm^{-1} and explain in their abstracts how the spectra can be used to differentiate each substance by specifying peaks.

Raman Spectroscopy of Drugs: Raman spectra are recorded using a portable dual laser Raman spectrophotometer (Rigaku Progeny X2) calibrated with benzonitrile. The background is collected without sample and the cover on prior to sample analysis. The samples include salicylic acid, acetylsalicylic acid, caffeine, procaine, and naproxen, and are loaded to glass vials that fit the holder. Alternatively, the probe can be directed at the sample without the holder. The laser was set to 785 nm (as opposed to 1064 nm). Scattering efficiency is higher at 785 nm. The laser power was set at 200 mW and the data was recorded for 1000 ms for 1 and 30 scans. The library was searched for each sample using the library default settings; the library settings were changed to demonstrate to the students the effects of the settings on the library hits. The data was saved as .csv files and plotted in stacked plots using Microsoft Excel. Students were instructed to label the peaks using a correlation chart and explain in their abstracts how the spectra can be used to differentiate each substance by specifying peaks.

C18 Reverse Phase Column Chromatography: Students separate grape soda or Kool-Aid samples using reverse phase C18 column liquid chromatography using syringes. The C18 filter column (Supelco) is fitted on a 5 mL syringe. This laboratory is a fast, inexpensive and visual approach to reverse phase LC. The syringe is washed with isopropyl alcohol and water. A 1 mL sample is loaded to the column (one is selected either by the student or instructor). The sample is separated and eluted using four prepared 10 mL isopropanol solutions applied sequentially: 0% (distilled water), 5%, 25%, and 70%. Fractions are collected in the tubes. Students report on the identification of the stationary and mobile phase, analyte,

research on dyes polarity and their hypothesis on which will elute first, their observations and results and conclusions.

GC-MS of Drugs: Students are instructed in the use of a gas chromatography mass spectrometry (GC-MS) instrument, specifically an Agilent 7890A GC coupled to an Agilent 5975C mass spec detector (MSD). The samples include 1 mg of caffeine, diphenhydramine, lidocaine, and a mixture of the three drugs in 1 mL of methanol prepared in a chemical fume hold and placed in a 1 mL GC vial with a Teflon cap. Methanol was run before and after the samples. Students are instructed on file paths and creating sequence and method files. The drugs are injected at 265 °C in splitless mode and the temperature program begins with a hold at 50 °C for 1 min, a ramp from 50 to 280 °C at 30 °C/min, and a final hold for 7 min at 280 °C for a 13.9 min run. Data is collected after a 4 min solvent delay. The injection syringe is washed 4 times preinjection and 4 times postinjection with methanol. Prior to sample loading, the syringe is washed three times with sample, and the sample is pumped twice and injected. The instrument is set to scan mode and the elution profiles are compared for the analytes. The mass spectra for peaks are viewed and component materials compared to the library. The results are tabulated and compared, and the students reported if the elution profile and library hits were as expected based on the structures and boiling points from the literature and SWGDRUG data. The diphenhydramine isomers are resolved and impurities in samples are detected. To complete the runs, the samples were loaded on an autosampler and the data was provided to the students using the learning management system (LMS).

NMR Spectroscopy of Drugs: Students are instructed on the use of a nuclear magnetic resonance (NMR) spectrometer (JEOL 400 MHz is used) to analyze drugs including analytes used in previous weeks or different analytes. Students assign the ^{1}H NMR spectra to each proton or functional group in a unique environment for each drug using the chemical shift, peak splitting, and J coupling. The samples are recorded at 10 mg/mL in deuterated water solvent. The results are compared to SWGDRUG spectra. The samples include new psychoactive substances (NPS) and other substances that can be obtained from Cayman Chemical that are not controlled as well as drug and drug-like substances from Sigma and Thermo Fisher as in previous labs. If an NMR instrument is not available, SWGDRUG monograph spectra are substituted for analysis and assignment.

Stereomicroscopy of Torn Items / Pattern Analysis: Students are instructed to use a stereomicroscope to analyze the individualizing fracture edge and class morphological characteristics of samples including sets of torn tape samples (e.g., duct tape, scotch tape, masking or laboratory tape). Students report the magnification used and their sketches, observations and characteristics that can be used to identify the items, their assignments of which ends match and percent accuracy for each set.

Stereomicroscopy of Botanical and Crystalline Materials: Students are instructed to use a stereomicroscope to analyze the morphological and color features of samples including plant (e.g., coffee, tea, spices, tobacco, marijuana (if DEA licensed) and crystalline (e.g., table salt, sugar) material. Students report the magnification used and their sketches, observations and characteristics that can be used to identify the items.

Koehler Illumination, Compound Light Microscopy, and Comparison Microscopy of Hair & Fibers and Pathogens: Leica compound light microscopes (CLM) and a comparison microscope are used by the students to evaluate and compare trace evidence materials including fifteen items from dust, pollen, hairs, fibers, and pathogens from Carolina Biological (e.g., human hair, animal fiber, natural and synthetic fibers, bacteria slides of potential bioterrorism agents and foodborne pathogens, dust, and pollen) using Brightfield microscopy. Students make sketches and tabulate their observations and magnification used including the tip, shaft, root, cortex, cuticle, and medulla for natural hairs and explain specific features and approaches that can be used to differentiate each fiber. Polarizing microscopy can be used to extend the lesson.

ALS of Rocks and Minerals: A Crime Source mini Crime Scope alternate light source (ALS) is used to evaluate rocks and minerals of known source obtained from Carolina or a geologist. Students are instructed to tabulate and report the fluorescence of samples using the ALS at the different wavelengths (e.g., 300-400 nm, 415 nm, 455 nm, 515 nm, 535 nm, etc.) and different colored goggles as filters and explain how the materials can be differentiated.

Fluorescence Microscopy of Fibers & Glitter Trace Evidence: Students are instructed in the use of a fluorescence microscope including the DAPI, FITC, and TRITC filters. We use an Eclipse 100 LV Polarizing Fluorescent Microscope. The samples include blue, pink, and gold pearl glitter, and red, green and yellow fibers. were observed with the DAPI, FITC, and TRITC filters. Students record the fluorescence and observations with each filter and tabulate their observations and explain for the materials can be differentiated.

ATR FTIR Spectroscopy of Fibers and Plastics Polymers: Samples include trace evidence plastics from each recycling code (e.g., polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride

(PVC), low density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS) from household and commercial items. Additional samples include trace fibers (e.g., nylon, Dacron, polyester) when the composition is known and not known but a library is available. The spectra are collected and analyzed using the ATR FTIR spectrophotometer as previously described. A plastic or fiber material is applied with pressure to the diamond surface. The library is searched to identify the compounds. Spectra are saved as .csv files and replotted in stack plots in a graphing program such as Microsoft Excel. Students are instructed to assign the major peaks for the aliphatic, phenyl, carboxylate, and chlorine group stretches using a correlation chart. Students reports on differentiation using the instrument versus visually for the fibers and fabrics and the polymers.

Color Tests for Explosives: The students are instructed to test known and unknown simulated explosives samples using a commercial nitrate test and/or Griess test. A dilute solution of barium and lead nitrate solution can be used. A negative control is performed to compare the color of the test with the samples. The students are instructed to report their observations and interpret the results.

GC-MS of Accelerants / Arson Analysis: Students are instructed in the use of a GC-MS instrument as previously described. The students are instructed to read ASTM E1618. The samples include 1 µL of hexanes, lighter fluid, gasoline or diesel fuel in 1 mL of methanol prepared in a chemical fume hold and placed in a 1 mL GC vial with a Teflon cap. The temperature program used begins with a hold at 50 °C for 1 min, and continues with a ramp from 50 to 280 °C at 15 °C/min, and a final hold for 5 min at 280 °C for a total of 21 min. The injection syringe is washed 4 times preinjection and 4 times postinjection with methanol. Prior to sample loading, the syringe is washed twice with sample, and the sample is pumped twice and injected. The instrument is set to scan mode and the elution profiles were compared for the analytes. The mass spectra for several peaks are viewed and component materials compared. The results are tabulated and compared to the ASTM standard and unknown ignitable fluids are classified as light, medium and heavy.

ATR FTIR Spectroscopy of Explosives: Nitrates and perchlorates including ammonium nitrate, potassium nitrate, sodium nitrate, potassium perchlorate, sodium perchlorate are collected and analyzed using the ATR FTIR spectrophotometer. A small amount of the material is transferred to the diamond surface. The range is set to scan 4000 to 400 reciprocal centimeters using a 0.929 cm^{-1} spacing and displaying %T. The instrument is blanked with air. The library is searched to identify the compounds. Spectra are saved as .csv files and replotted in stack plots in a graphing program such as Microsoft Excel. Students are instructed to assign the major peaks for the N-H, N=O, and N-O stretches using a correlation table and explain how to differentiate the compounds tested.

SEM of Gunshot Residue (GSR): Gunshot residue from spent cartridge cases can be recovered by swabbing and dissolving in water acidified with nitric acid. These can be analyzed using a scanning electron microscope (SEM) for metals including Ba, Ca, Sn, Pb, and Si and the particle sizes and dimerization / complex formation.

UV-Vis Spectroscopy of Dyes: A NanoDrop UV-Vis spectrophotometer with direct microliter application or an Agilent 8453 UV-Vis spectrophotometer with a quartz cuvette is used as the instrument. A visible spectrometer can alternatively be used as the dyes absorb in the visible range of the spectrum. The students learn how spectrometers can be used as detectors and for quantitation of an unknown. The analytes can include red and green food coloring dyes or lab dyes. The students are instructed to dilute 1 µL in 1 mL of distilled water and then make 5 dilutions serially with a final volume of 1 mL each. Scans are recorded from 190-800 nm to determine the absorption maxima. At the λ_{max}, the absorbance is recorded for each dilution and an unknown provided by the instructor with a concentration in the range of the diluted stock dye and detection limit of the instrument. The students predict which dye component compounds will absorb at the longest and shortest wavelengths based on their structures and report on their results and if their hypothesis was correct. Students construct Beer's Law plots and display the line equation for the serial dilution standards and determine the concentration of an unknown using the graph.

ATR FTIR Spectroscopy of Paint: Car paint swatches or nail polish swatches are collected and analyzed using an ATR FTIR spectrophotometer. The colored portion of the swatch is placed facing the diamond surface. The range is set to scan 4000 to 400 reciprocal centimeters using a 0.929 cm^{-1} spacing and displaying %T. The instrument is blanked with air and 16 scans are recorded. The library is searched to identify the materials if a library is available. Spectra are saved as .csv files and replotted in stack plots in a graphing program such as Microsoft Excel. Students are instructed to assign the major peaks for the stretches using a correlation chart and specify how the evidence can be differentiated.

Raman Spectroscopy of Inorganic Pigments and Dyes: The students conducted the exercise and report as before for drugs but recorded spectra of inorganic pigments and dyes. The samples include sodium nitroprusside, alum

(carmine) lake, bromophenol blue, indigo, and phenolphthalein.

ALS, TLC, UV-Vis Spectroscopy, and ATR FTIR Spectroscopy of Inks: In this capstone lab, students present their results and report a process that could be used to differential three inks from pens or markers of their choosing of different colors or manufacturers using ATR FTIR spectroscopy, ALS, UV-Vis spectroscopy, and TLC as previously used earlier in the semester. The TLC is performed with a mobile phase consisting of 3.5 mL ethanol, 6.5 mL ethyl acetate, and 3.0 mL of distilled water (or another solution approved by the instructor based on a literature search) and the inks were dissolved in diluted isopropanol prior to loading using microcapillary tubes.

Mock Crime Scene Case: Several of the methods and principles are integrated in a simulated case that may be used. The methods include stereomicroscopy, ALS, compound light microscopy, ballistics microscope, and nitrate color test. This case (Appendix) has been used as a stand-alone activity for out-of-school engagement with high school students as well as college students.

Reflection

Students gain experience on a variety of instruments and handling diverse types of materials encountered by forensic labs. One highly relevant instrument that is not taught due to time is the use of an HPLC. Its use is taught in subsequent forensic and instrumental analysis courses. Similarly, modules on latent prints, firearms, and toolmark investigative techniques that previously was a part of this course has been moved to stand-alone courses on these topics. The laboratory instruction has fluctuated over the years depending on the instructor, available instrumentation, available materials for analysis, desired level, and number of enrolled students. Most times, analytes are kept consistent for several labs for direct comparison of the results and techniques later in the semester. This also reduces costs. The materials selected are relatively low cost and not controlled substances thus minimizing risks of using controlled substances, gaining DEA authorization and being subject to reporting requirements. In addition, household materials and personal products like nail polish are used, when possible, to simulate the types of samples that graduates may encounter in evidence. Controlled substances may be substituted for the uncontrolled cutting agent and drug-like compounds if the laboratory possesses a drug license from the DEA or similar outside the United States.

In vertically integrated programs, students may receive instruction in forensic-related topics (e.g., determination of caffeine in coffee, analysis of acetaminophen, detection of drugs on money, etc.) in quantitative analysis, organic chemistry, and instrumental analysis courses. The survey course in our program enrolls biology and criminal justice students who may not have taken quantitative and instrumental analysis and had the opportunity to build on those courses as well as the chemistry students.

The students have reported that they like the short frequent abstract assignments as opposed to writing full weekly laboratory reports. The goal of the weekly writing practice is to improve the students' writing in succinct reports; the abstracts and analysis improve over the course of the semester. Students also develop data handling and analysis skills that are useful for their research projects and future jobs. While the students are required to keep dated notes, data, spectra, graphs and laboratory notebooks, paper or electronic notebooks are accepted. While students consider the course challenging, especially due to the breadth of material, many students have communicated that it was one of the most useful courses they have taken and that they especially enjoy the laboratory component.

Conclusion

Laboratory instruction in forensic chemistry may vary from institution to institution; however, the central tenets will remain the same. The students should receive safe, appropriate, and in-person instruction in forensic chemistry that develops skills graduates will use as practitioners in forensic labs. The laboratory activities described in this paper cover the range of topics in most forensic chemistry survey courses and prepare students to use an array of instruments prior to engaging in independent or course-based research experiences (which we offer in other courses). The modules or activities could also be employed by faculty teaching an elective or advanced chemistry course seeking to include forensic topics or analytes.

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Appendix

Mock Crime Scene Case Scenario:

A body was recovered from a remote area. Foreign fibers were recovered from the victim's clothing. Rocks and mud were found in the victim's shoes. The victim was bound with tape. Cartridge cases were found nearby.

Suspect 1: Suspect one met the victim online through a gaming site. White duct tape, muddy tools, a wool rug, and a 9mm firearm were found in the suspect's shed.

Suspect 2: Suspect two is an ex of the victim. White duct tape, muddy tools, a cotton blanket, and a rifle were found in the suspect's car.

Assignment:

Your job as the forensic scientist is to analyze the evidence that was recovered from the crime scene and compare it to the evidence found in suspect one's shed and suspect two's car to determine who cannot be eliminated for which DNA testing should be conducted.

Stereomicroscopy

· Use the stereoscope to examine the torn edges of the tape evidence.

· Record and draw observations (e.g., color, shape, pattern, edges, etc.) on your report sheet.

· Report which torn tape edge recovered from the suspects matches the tape evidence recovered from the crime scene.

· You may need to adjust the focus of the stereomicroscope to better view the evidence.

Compound Light Microscopy

· Use the compound light microscope to examine the fiber evidence.

· Record and draw observations (e.g., color, central and surface features, tip, root, etc.) on your report sheet.

· Report which fiber recovered from the suspects "matches" the fiber evidence recovered from the crime scene.

· You may need to adjust the focus of the microscope to better view the evidence.

Ballistic Scope

· Use the ballistic microscope to compare the cartridge casing found at the crime scene to cartridge casings recovered from the suspects' firearms.

· Record and draw observations (e.g., manufacturers' headstamp label on casing, impressions, etc.) on your report sheet.

· Report which cartridge casing recovered from the suspects matches the cartridge casing evidence recovered from the crime scene.

· You may need to adjust the focus of the microscope to better view the evidence.

Alternate Light Source (ALS)

· Use the ALS to examine rocks/soil recovered from the crime scene.

· Record observations (e.g., if fluorescence is observed, goggles worn, wavelength used on ALS, and color observed under the ALS) on your report sheet.

· Report which rock sample recovered from the suspects match the evidence that was recovered from the crime scene.

Chemical Test – Nitrate Test strips

· Pipet a drop of the dirty water sample to the test strip to determine if nitrates are present.

· If a color is present, compare to the color results on the bottle and assign the result as positive and quantity.

· If no color change occurs, then the test is negative.

· Record the reagents used and observations/results (e.g., color change and if that indicates a positive or negative result and quantity) on your report sheet.