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Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Science & Justice

journal homepage: www.elsevier.com/locate/scijus

Professional Practice Report

Teaching Forensic Entomology, Forensic Anthropology, and Haematology & Serology during the COVID-19 pandemic: Practical activities for distance learning

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ARTICLE INFO

Keywords:

Entomology
Anthropology
Hematology
Serology
Online learning
Forensic science education

ABSTRACT

As the COVID-19 pandemic upended college and university instruction throughout the world, instructors were hard-pressed to find suitable alternatives for practical activities typically carried out outside of classrooms—in laboratories, workshops, clinics, and in the field. In response to this unanticipated challenge, they relied on their ingenuity to achieve pre-pandemic goals under pandemic conditions that necessitated the shift to online teaching. The Forensic Science Undergraduate Program housed in the School of Medicine of the National Autonomous University of Mexico was not exempt from this educational upheaval but, due to its interdisciplinary nature, required creating and/or adopting a wide range of activities capable of training students to perform practical tasks associated with subject areas that span the natural and social sciences, the humanities, and the law. This report aims to describe the approaches undertaken in three subjects (Forensic Entomology, Forensic Anthropology, and Hematology & Serology) by interviewing instructors and examining their teaching materials. Also, through online surveys, students' reactions to these approaches were elicited to learn about their suitability and teaching potential. Instructor's experiences during the pandemic have proven to be a rich source of ingenious solutions, with implications well-beyond the current crisis, such as creating blended or fully online courses aimed at larger numbers of students, forensic and legal professionals, and even other instructors. The wide variety of forensic sciences offers the opportunity to innovate and improve the teaching and learning of science, particularly to the benefit of students that must combine their school tasks with professional and/or family duties.

1. Introduction

The Forensic Science Undergraduate Program (FSUP), hosted by the School of Medicine of the National Autonomous University of Mexico (UNAM), was created in response to mounting economic, social, and

political unrest due to high levels of violent crime—particularly that associated with the government's militarized response to the operations of drug cartels—and widespread impunity at both the local and federal levels [1,2]. As conceptualized by the FSUP mission statement and curriculum [3,4], the forensic scientist will be a professional capable of

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<https://doi.org/10.1016/j.scijus.2022.04.009>

Received 2 October 2021; Received in revised form 28 February 2022; Accepted 22 April 2022

Available online 26 April 2022

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understanding, explaining, and applying the theoretical and technical principles of a wide range of forensic disciplines, so as to perform key tasks such as 1) plan and coordinate a full criminal investigation; 2) manage the investigation of a crime scene and collect the evidence itself, if necessary; 3) ascertain the judicial relevance and supervise the technical quality of forensic reports; and 4) act as technical counsel to judges, prosecutors, defense attorneys, victims, or suspects. To prepare students to perform these tasks, the FSUP curriculum comprises subjects from areas such as physics, chemistry, biology, medicine, anthropology, criminalistics, psychology, research methods, statistics, bioethics, and the law.

Before the COVID-19 pandemic struck, it was almost impossible to imagine teaching forensic science to undergraduates without ready access to specialized training facilities, such as wet and dry laboratories, workshops, mock crime scenes, court rooms, outdoor areas, and libraries, as well as field trips and visits to forensic laboratories. In the FSUP, all these instructional resources had been used, to a larger or lesser extent, in the process of training successive generations of forensic scientists since the program's opening in 2013. Despite the abrupt suspension of in-person activities in universities across all of Mexico from mid-March 2020 to December 2021, instructors in the FSUP—especially those in charge of subjects that require students to perform many hands-on activities—devised ingenious alternatives to make up for the lack of access to the facilities the School of Medicine has built to serve the specific training needs of forensic scientists. These alternatives were targeted to a student population that, in large part, does not have high-speed, reliable internet access and does not own a desktop computer or laptop for personal use—having instead to share it with parents and/or siblings. Students also tend to lack a dedicated study space at home and suffer from both the discouraging prospects of not being able to take full advantage of the learning opportunities previously available in the company of their fellow students and the stresses owed to the disruption of their everyday lives, due to illness or loss of income, for example.

In contrast to traditional undergraduate programs focused on a single discipline, interdisciplinary programs offer educators the unique opportunity of sampling a wide range of teaching approaches to subjects of a widely varying nature and, hopefully, promote cross-fertilization among instructors about how to improve their own teaching. At a moment of uncertainty and openness to change, such as the one we are currently living through, it seems important to leave an account of the different responses to the educational challenge posed by the COVID-19 health crisis, as well as foster the exchange of ideas between instructors, administrators, and department heads with the aim of cementing the happy discoveries and leaving behind actions that do not represent best teaching practices.

Forensic Entomology—offered in the fall semester of 2020 to 34 students—and Forensic Anthropology and Hematology & Serology—both offered in the spring semester of 2021 to 35 students—drew our attention because of encouraging comments from some students: the instructors responsible seemed to have managed the no mean feat of adapting the design of their courses to a distance learning modality that, before the pandemic, had never been seriously considered viable for either the FSUP or the UNAM at large. (Entomology and anthropology happen to be two of the most attractive areas for students: 10% and 15%, respectively, of the undergraduate dissertations produced in the FSUP belong to those areas, only surpassed by law dissertations, with 25%.) Students reported feeling motivated despite 1) not being able to access the school's facilities, 2) interacting with instructors and their peers only online, and 3) investing additional time and effort to transform their living environments into spaces suitable for learning highly specialized skills. Apart from the anecdotal evidence of their success in adapting to the limitations imposed by the health restrictions, our interest in these subjects is motivated by their diverse disciplinary content within the biological sciences, the highly practical nature of their teaching, and the key roles they can play in the investigation of violent crime.

To prepare this report, instructors shared the course materials they

uploaded to their learning management system (LMS) and offered comments on their experience of preparing the course and teaching it, with particular emphasis in what they believed worked best and what did not work as intended. In what follows, we present an overview of the content and structure of the three courses, followed by a detailed discussion of the most salient activities that enabled instructors to achieve the learning outcomes specified for each despite the adverse conditions forced upon by the COVID-19 pandemic and the ensuing closure of universities. We then present the results of a survey that explored students' views of the practical activities. Finally, we discuss some of the areas of opportunity—identified from inputs provided by both students and instructors—and conclude our report with lessons learned from the experience, highlighting insights that can be drawn for other science subjects that rely on hands-on activities to develop students' technical proficiency.

2. Overall course design

Table 1 shows the course content and structure of Forensic Entomology, Forensic Anthropology, and Hematology & Serology, as they appear in their respective syllabi. In the case of the first two courses, this is the first time that students are exposed to topics of entomology and anthropology, therefore, an introduction of the field of study is part of the courses' curriculum. In the case of Hematology & Serology, students have previously completed the subjects of Cell Biology & Biochemistry, Genetics & Molecular Biology, Criminalistics, and Methods to Investigate Crime Scenes, from which instructors draw to present the properties, behavior, and identification of biological fluids for forensic purposes. In all three, there is a noticeable focus on covering principles and methods aimed at preparing students to participate in forensic casework. Forensic Entomology and Forensic Anthropology situate their subjects in the context of Mexico, since the country is considered a biodiversity hotspot [5] and its population boasts great genetic, ethnic, and cultural diversity [6]—factors that might be relevant when conducting entomological or anthropological forensic inquiries. **Table 2** lists course objectives for the three subjects, as stated in their respective syllabi.

Table 3 offers a summary of the types of teaching activities that comprised the coursework of each subject. The three adopted a roughly modular structure where, for each topic, students 1) read preparatory materials (textbook chapters or extracts, journal articles, manuals or protocols) or watch an introductory video; 2) participate in a live lecture or receive instruction from a tutorial prepared by the instructors themselves or available online, and 3) carry out a practical activity, a product of which is then assessed. At the end of the course, individual topics were then integrated in a final project. Clearly, from the amount of practical work on evidence, instructors are committed to developing students' skill set through a series of activities that run the gamut from actively developing an understanding of the topics—concept mapping, making diagrams, drafting decision trees—to learning how to perform technical procedures—in the field or the laboratory—and critically appraising forensic reports. The profile of the forensic scientist as scientific supervisor of criminal inquiries, crime scene investigator, and technical counsel to the judiciary appears to be well served by these activities.

To organize the assigned coursework and run the class, instructors relied on the LMS of Google Classroom, and the videoconferencing platform Zoom for holding and recording live sessions. Free access, compatibility with available computing equipment, and ease of use were among the main reasons behind the choice of these tools. These—or similar—online management and communication platforms seem to be common enough resources used in response to the COVID-19 lockdown [7], even in the specific context of forensic science education [8–12]. As we will see, each team of instructors added specific digital tools to achieve their learning outcomes, such as online databases, open access software, free simulators, and YouTube videos and tutorials.

Table 1

Course content and structure of Forensic Entomology, Forensic Anthropology, and Hematology & Serology as taught in the Undergraduate Programme of Forensic Science at UNAM.

Topic	Forensic Entomology	Forensic Anthropology	Hematology & Serology
1	Introduction to forensic entomology • Definition of forensic entomology • Main fields of forensic entomology • History of forensic entomology • Forensic entomology in Mexico	The anthropological context in forensic cases • The comprehensive study of human beings • The main branches of anthropology • The anthropology report in forensic science	Saliva • Presumptive tests: principles, relevance, limitations • Confirmatory tests: principles, relevance, limitations
2	Morphology and ecology of arthropods • Recognition of arthropods with emphasis on insects • External morphology and function of insects • Internal morphology and function of insects	Human biological, psychological, and sociocultural diversity • Human diversity from an evolutionary perspective • Variability across ontogeny and growth • Sexual dimorphism throughout life	Semen and sex crimes • Detection of semen with alternate light sources (UV) • Acid phosphatase presumptive test • Microscopic examination of spermatic cells: Christmas-tree stain • P30 confirmatory test • Sex crimes investigation process • Male reproductive system • Anatomy • Cytology • Physiology • Pathology
3	Life cycles of insects • Metamorphosis and ecdysis • Types of metamorphoses • Types of immature states	Introduction to forensic anthropology • General forensic anthropology protocol • <i>Antemortem</i> and <i>postmortem</i> information • The role of forensic archaeology • Near-surface geophysical methods • Forensic taphonomy • Excavation and archaeological recording methods	Blood sample analysis • Composition and functions of blood tissue • Role of the haemo group and porphyrin structure • Hemoglobin and haemo group derivatives • Immune system and immunoassays • Antigens and antibodies • The antigen-antibody reaction • ABO blood types and subgroups • Indirect typing of dried blood • Presumptive tests for the identification of blood: luminol, Bluestar, Adler, and Kastle-Meyer • Confirmative tests: Teichmann, Takayama, Hematrace
4	Insect orders • Principles of taxonomy and classification • Taxonomy and classification of representative insect groups with	Human identification from bone remains • Forensic anthropology laboratory protocol • Introduction to forensic osteology	Bloodstain pattern analysis • Point of convergence, area of origin, angle of impact • Flight characteristics of blood spatter • Bloodstain pattern analysis

Table 1 (continued)

Topic	Forensic Entomology	Forensic Anthropology	Hematology & Serology
	emphasis on their forensic relevance • Ecology of insect groups relevant to forensic entomology	• Biological profile estimation • General aspects of sex estimation • Generalities of age-at-death estimation • Age-at-death estimation: epiphyses ossification • Patterns of skeletal degeneration processes • Ancestry estimation from skeletal remains • Stature estimation • Individual skeletal variation • Skeletal variation related to cultural practices • Markers of occupational stress • Pathological conditions • Trauma analysis • Complementary methods: forensic radiology	• The Bevel and Gardner system
5	Classification and recognition of Diptera and Coleoptera of medicolegal relevance • Morphology and classification of the main groups in Diptera and Coleoptera • Relevant aspects of their life cycle and ecology • Diptera families of forensic and medicolegal relevance: Calliphoridae, Sarcophagidae, Muscidae, and Fanniidae, among others • Coleoptera families of forensic and medicolegal relevance: Dermestidae, Silphidae, and Staphylinidae, among others	Forensic facial recognition • Forensic sketches and craniofacial reconstruction • Forensic DNA phenotyping • Facial Identification Scientific Working Group protocol • FISWG protocol: morphoscopy • FISWG protocol: geometric morphometrics	Genetics • Role of biological fluids in forensic identification • Methods for DNA extraction • Quantification, amplification, and detection of DNA • The forensic role of genetic profiling
6	Cadaveric decomposition and medicolegal entomology • Thanatology and <i>postmortem</i> interval (PMI) estimation • Classification of cadaveric phenomena • Early cadaveric phenomena	The praxis of forensic anthropology • Forensic anthropology report • Forensic anthropology teams in Latin America • Forensic anthropology in Mexico	Criminalistics • Processing the crime scene • Collection and packaging of biological samples • Transfer, chain of custody, and storage of evidence • Structure of technical reports and opinions

(continued on next page)

Table 1 (continued)

Topic	Forensic Entomology	Forensic Anthropology	Hematology & Serology
	<ul style="list-style-type: none"> Late cadaveric phenomena Preservative and destructive cadaveric phenomena PMI calculated from the arthropod community Outdoor and autopsy sampling for medicolegal purposes Description of the cadaver and the crime scene Description and sampling of entomological fauna in the crime scene 		

Table 2

Course objectives of Forensic Entomology, Forensic Anthropology, and Hematology & Serology as stated in their syllabi.

Forensic Entomology	Forensic Anthropology	Hematology & Serology
<ol style="list-style-type: none"> Understand basic concepts of forensic entomology, as well as their applications Identify techniques with which to sample insects in forensic cases Analyze entomological data as forensic evidence 	<ol style="list-style-type: none"> Identify elements for the forensic study—somatologic and/or osteologic—of live individuals, cadavers, and bone remains as constituents of the human identification process in a forensic context Learn methods and techniques to identify live or dead individuals involved in legal issues by means of physical characteristics of each Learn methods and techniques to estimate variables such as age, sex, height, and ancestry from human skeletal remains 	<ol style="list-style-type: none"> Systematically and rigorously identify traces in the crime scene Systematically and rigorously collect samples in the crime scene Characterize blood and its constituents Distinguish human blood from that of other animal species Identify and characterize body fluids Identify dried blood and its immunological features Apply the above learning outcomes to the study of forensic cases

Already, Table 3 offers a glimpse of how instructors dealt with the challenge of students not having access to the school’s facilities for practical work. Chiefly, they resorted to three main approaches: 1) creating take-home kits for students to perform laboratory procedures and field sampling; 2) digitizing materials, particularly arthropod specimens, bone remains, and bloodstain patterns, and 3) using free analytic software. In the next sections of this report, we will delve in more detail into the implementation of these approaches and discuss their outcomes, limitations, and avenues for development.

3. Development and use of take-home kits

Instructors of Forensic Entomology and Hematology & Serology created take-home kits aimed at developing skills that, under normal circumstances, are acquired and exercised in field work and laboratories. Kits combined specialized equipment and materials provided by

Table 3

Teaching activities implemented in Forensic Entomology, Forensic Anthropology, and Hematology & Serology as taught in the undergraduate programme of forensic science at UNAM.

Type of activity	Forensic Entomology	Forensic Anthropology	Hematology & Serology
Lectures	<ul style="list-style-type: none"> Live and recorded sessions Instructor-made video tutorials, YouTube videos PowerPoint presentations 	<ul style="list-style-type: none"> Instructor-made video tutorials PowerPoint presentations 	<ul style="list-style-type: none"> Live and recorded sessions PowerPoint presentations YouTube videos, Netflix shows
Readings	<ul style="list-style-type: none"> Guide on how to write a scientific report Textbooks and manuals Journal articles 	<ul style="list-style-type: none"> Textbook chapters Journal articles Search protocols Statutory law 	<ul style="list-style-type: none"> Chain of custody forms Test protocols and/or manuals CSI protocols and/or manuals Textbook extracts and chapters Journal articles
Practical work	<ul style="list-style-type: none"> Take-home laboratory/field kit At-home laboratory/field worksheets Reports of results Written assignments Concept mapping Diagramming Glossary compilation Letter soup exercise Group discussions Student-made videos Student presentations Online PMI calculation Protocol proposal 	<ul style="list-style-type: none"> At-home laboratory activities At-home laboratory worksheets Reports of results Written assignments Reading reports Diagramming, scene sketching Analysis of digitized images Online searches Free statistical software (R) Online and instructor- or student-compiled databases Image analysis software Online sex estimation O-nline ancestry estimation Enquiry proposal 	<ul style="list-style-type: none"> Take-home laboratory kit At-home laboratory worksheets Reports of results Written assignments Decision tree diagramming Infographic creation Analysis of digitized images Blood typing simulator Student-compiled database Forensic report critical review Case file critical review Student presentations Student questions forum
Assessment	<ul style="list-style-type: none"> Multiple-choice questions Open-ended questions Rubrics Self-assessment Peer assessment 	<ul style="list-style-type: none"> Multiple-choice questions Open-ended questions Guidelines/checklists 	<ul style="list-style-type: none"> Multiple-choice questions Open-ended questions Rubrics Model answers Diagnostic assessment Self-assessment

instructors with everyday objects and substances readily available in most people’s homes, hardware stores, local markets, or supermarkets. (With some notable exceptions, like a stereoscopic digital microscope students had to purchase from online vendors for around US\$ 20.) The design of the kits factored in the role of its components in achieving the learning outcomes of the course; the inventory of equipment and materials available in the laboratory warehouses of the FSUP; the cost of the objects and substances that students would need to purchase; the feasibility of operating the equipment and/or materials at home, and of safely disposing of any chemical or biological waste; the protective equipment available to students, and the limitations they might

experience due to space—or other—restrictions while working from home.

The contents of the take-home kits for Forensic Entomology and Hematology & Serology are shown in Table 4 and Table 5, respectively. Although UNAM is a publicly funded university that does not charge tuition fees and operates under tight budgets, it is worth noting the substantial level of financial support—in the form of specialized equipment and materials—that it managed to provide to students enrolled in these subjects. However, students still had to invest time and money to continue their training under the financial strains caused by an—already weak—economy reeling from the pandemic. This fact imposes important restrictions on the extent to which practical activities can be effectively transferred from schools to homes in the future.

In the case of the Forensic Entomology course, the take-home kit was used to train students in a) how to search for arthropod specimens in the field and build traps with which to capture them, while at the same time gaining familiarity with their different habitats; b) how to preserve and fix specimens for microscopic study in the laboratory, and c) how to identify—from a morphological standpoint and with the aid of taxonomic keys—arthropod orders, insect groups, and life-cycle states of forensic significance. To collect specimens, students set traps in nearby parks, in the street outside their homes, in their gardens and rooftops, and even in their pantries! Of considerable educational benefit is the fact that instructors taught students how to build specialized forensic equipment from commonplace objects, a definite plus in a country where forensic services—particularly at the local level—tend to be critically under-funded. One drawback of this approach lies in the fact that city-dwelling populations are different from those of rural and wild areas, so some insect groups of forensic and medicolegal interest cannot be caught and examined by students living in urban areas. Fig. 1 shows part of the process of building and setting the traps, as well as analyses carried out by students.

In Hematology & Serology, the take-home kit was used to a) identify saliva in either chewed gum or a cigarette butt; b) identify semen in a problem specimen; c) determine students' own ABO blood type; d) verify the presence of blood by means of a confirmatory test, and e) study the flight behavior of blood by measuring angles of impact, describing the shape of stains produced by dropping it from different heights, observing the effect of different surfaces on stains, and calculating points of convergence. To carry out these latter activities, instructors shared with students a recipe to prepare synthetic blood, since it was not possible to procure a large enough amount of commercial synthetic blood for all of them and neither was it desirable—for technical, security, and ethical concerns—for them to draw more than a few drops of their own. Unfortunately, the patterns produced by the homemade substitute did not match the behavior of true blood. Despite this setback, students—intrigued by the differences between the expected and observed behaviors—decided to examine and document these differences to practice their ability to interpret actual bloodstain patterns. Students, also by their own initiative, carried out a statistical analysis of the differences between patterns produced by true and synthetic bloods, reporting their results in a national conference poster [13]. In all these practical activities, students performed the steps of the testing procedures and interpreted the results based on their understanding of the principles upon which the tests operate, with the expectation that they will be able to execute them in real scenarios and critically assess the quality of bloodstain pattern reports. Figs. 2 and 3 show some of the tests performed by students and the materials used. After the term was over, the Hematology & Serology instructors organized—with institutional authorization and in compliance with social distancing guidelines—a capstone practical activity in the FSUP's crime scene house where students could put into practice some of the skills acquired and developed through the activities performed at home with the aid of the kit.

Even though the team of instructors in charge of the course of Forensic Anthropology did not prepare a take-home kit, they created and implemented a practical activity in which students had to acquire,

Table 4
Contents of the take-home kit for FForensic EEntomology.

Provided by instructors	Provided by students
Arthropod collection and preservation methods	
	<ul style="list-style-type: none"> • Insect net (handmade) • Bite trap (handmade) • Bite pitfall trap (handmade) • Flight intercept trap (handmade) • 1.5 L PET bottle • 600 mL PET bottle • 600 mL bottle with 96% (v/v) ethanol • 2 m standard wire • 4 m general purpose cord • Small garden shovel • Funnel • Sieve • 250 mL plastic cups • 500 mL Ziploc bags • White sheet • Light source • Yellow plastic dish • Dissecting forceps • Brush • 50 mL containers with 96% (v/v) ethanol • Vellum labels • Cardstock for labels • Pencil • Thermometer and hygrometer smartphone app • Watch • GPS smartphone app • Smartphone camera
Identification of different arthropod orders	
<ul style="list-style-type: none"> • Insect specimens • Plastic Petri dish 	<ul style="list-style-type: none"> • Stereoscopic digital microscope • Tray • Brush • Container with 96% (v/v) ethanol • Magnifying glass • Collected insect specimens
Preservation, fixing, and taxonomic identification of Diptera larval states	
<ul style="list-style-type: none"> • 10% (w/v) potassium hydroxide • Fixed larval specimens • Synthetic resin for fixing larval specimens • Cup for holding test tube • Larvae preserved in 70–96% (v/v) ethanol • Plastic Pasteur pipette • Petri dish • 3 mL syringe • Flat-bottom test tube • Microscope slides and slide covers • Taxonomic keys 	<ul style="list-style-type: none"> • Stereoscopic digital microscope • Collected larvae specimens • Dissecting forceps • Dissecting needles • Taxonomic keys chosen by student • Permanent marker • Adhesive labels • Scissors • Mechanical pencil
Preservation, fixing, and taxonomic identification of Calliphoridae adult states	
<ul style="list-style-type: none"> • Diptera adult specimens • Entomological pins • Entomological forceps • Petri dish • Specimen box • Polyfoam slab • 1.5 mL Eppendorf tubes 	<ul style="list-style-type: none"> • Stereoscopic digital microscope • Adhesive labels • Dissecting forceps • Dissecting needles • Thin brush • Taxonomic keys chosen by student • Diptera specimens • Smartphone camera
Preservation, fixing and taxonomic identification of Coleoptera adult states	
<ul style="list-style-type: none"> • Insect forceps • Fixed and preserved specimens 	<ul style="list-style-type: none"> • Magnifying glass • Smartphone camera • Collected specimens • Taxonomic keys chosen by student

Table 5
Contents of the take-home kit for and HHematology & SSerology.

Provided by instructors	Provided by students
Biological fluids of forensic interest: saliva <ul style="list-style-type: none"> • Petri dish with 1% (w/v) agar, starch, and Lugol's iodine • SALigAE test • Problem specimen for testing (chewed gum or cigarette butt) • Cotton swab 	<ul style="list-style-type: none"> • Permanent marker • Saline solution
Forensic identification of semen in sex crimes: confirmatory P30 test <ul style="list-style-type: none"> • Problem specimen for testing • P30 test with buffer 	<ul style="list-style-type: none"> • Permanent marker • 1% (v/v) sodium hypochlorite solution
Blood group typing <ul style="list-style-type: none"> • Wood toothpicks • A, B, AB, D anti-serums • Microscope slides • Lancets • Capillary tube 	<ul style="list-style-type: none"> • Permanent marker • 1% (v/v) sodium hypochlorite solution
Forensic identification of human blood by presumptive and confirmatory tests <ul style="list-style-type: none"> • Hematrace tests with buffer • Problem specimen for testing • Cotton swab 	<ul style="list-style-type: none"> • Scissors • Ethanol • Cotton balls • Permanent marker • 1% (v/v) sodium hypochlorite solution
Bloodstain pattern analysis <ul style="list-style-type: none"> • Plastic Pasteur pipette • Artificial blood 	<ul style="list-style-type: none"> • Protractor • Measuring tape • Permanent marker

from a butcher, fragments of the cranium and of long bones of a pig (*Sus scrofa domestica*) and expose them to the elements in their home's rooftop, protected by wire mesh. On a weekly basis, they photographically recorded the taphonomic changes that took place, together with the weather conditions during the observation period. Fig. 4 shows a sample of the bone fragments students exposed as part of the practical activity.

4. Digitization of teaching materials

All three subjects digitized teaching materials to make them accessible to students, notwithstanding the COVID-19 higher education lockdown. In the case of Forensic Entomology, instructors digitally photographed diverse arthropod specimens in detail so that their morphological features could be visually examined, without it being necessary for students to capture them personally and/or have access to microscopic equipment and materials at home. In Forensic Anthropology, four skeletons from the osteological collection housed by the FSUP were photographed in full: students could examine all four sets of bones in their computers at home—instead of just the one, as was the case in the laboratory before the pandemic due to time constraints. For their part, the team in charge of teaching the Hematology & Serology course was able to produce and record different bloodstain patterns with which to test students' understanding; additionally, they prepared a set of digital case files documenting the processing of a mock crime scene that students could analyze critically to apply their knowledge of the proper procedures. In all instances, the range of teaching materials—and the learning opportunities they offer—was substantially increased by virtue of digital photography and cloud-sharing technology through the LMS. This strategy proved to be both straightforward and relatively inexpensive to put into practice, but it did require a considerable time investment on the part of instructors, depending on the amount of

materials to be photographed.

Instructors' efforts uncovered some limitations of this approach. Prominent among them is the fact that some properties cannot be conveyed solely by visual means. For example, students in Forensic Anthropology could not successfully distinguish between human and animal bones, because their photographs were unable to convey physical properties such as texture and 3D shapes. (Students had not experienced this difficulty when examining bone fragments in the laboratory.) Similarly, students in Forensic Entomology could not identify all the morphological structures that instructors expected them to find in the photographs. In the case of bloodstain pattern analysis, spatial relationships can be difficult—if not impossible—to capture at their actual scale, and students cannot explore the three-dimensional relationships that exist in actual spaces. Importantly, only focusing on images as teaching resources loses sight of the processes that produce them: students need to learn how to use the microscopes, cameras, and measuring equipment that help to document forensic traces.

5. Use of free online software

Instructors in Forensic Anthropology made the most use of free online software in practical activities that students could complete at home. To identify patterns of sexual dimorphism in humans, students made use of the R software environment for statistical computing and graphics (<https://www.r-project.org>) that they previously had learned to use in the courses of Forensic Statistics I and II. For estimating an individual's sex based on morphological traits of the skull and pelvis, they used the free interactive program MorphoPASSE Database (<https://www.morphopasse.com>) and the DSP: Diagnose Sexuelle Probabiliste (<https://osteomics.com/DSP/>), also a free software that estimates sex from data on hip-bone measurements from around the world. Finally, to estimate the biogeographical ancestry of a person whose identity is unknown, students resorted to three tools: cranExplr, a database that allows users to see how cranial measurements influence the probability of belonging to a particular ancestral group (<https://joao.shinyapps.io/cranExplr/>); 3D-ID, a software based on geometric morphometrics that, by allowing users to input spatial coordinates of an anatomical specimen, produces an estimate of ancestral affiliation and sex (<https://www.3d-id.org>), and AncesTrees, a program that takes cranio-metric variables and—through an algorithm that runs randomized decision trees—estimates an individual's ancestry (<https://osteomics.com/AncesTrees/>).

In Forensic Entomology, as part of the sixth and last topic (see Table 1), students were directed to the vCalc time of death calculator that produces an estimate of the *postmortem* interval from data about body temperature and ambient air temperature (<https://www.vcalc.com/wiki/Time+of+Death>), while in Hematology & Serology the Shakshat Virtual Laboratory from the Indian Institute of Technology Guwahati (<https://www.iitg.ac.in/cseweb/vlab/anthropology/Experiments/BloodGroup/index.html>) was suggested as an aid in verifying the results of blood typing reactions.

To train students in how to use the take-home kits and carry out on their own the practical activities described above, instructors implemented a variety of methods: 1) sharing freely available instruction manuals and instructional videos—authored by universities, manufacturers, or law-enforcement agencies—or creating them tailor-made to the nature of the activities and the needs of students; 2) eliciting and answering student questions through message boards embedded in the LMS; 3) scheduling synchronous class sessions in which to demonstrate procedures and troubleshoot problems; 4) preparing Excel spreadsheets that directed students to the data they needed to collect, and 5) posting detailed inventories of the contents of the kits, specifying the role of each item. In Forensic Entomology, instructors found Flipgrid (<https://info.flipgrid.com>) quite useful as a live annotation tool with which to train students—interactively and in a stepwise manner—in the identification of features of different arthropod specimens, for instance, adult Diptera.

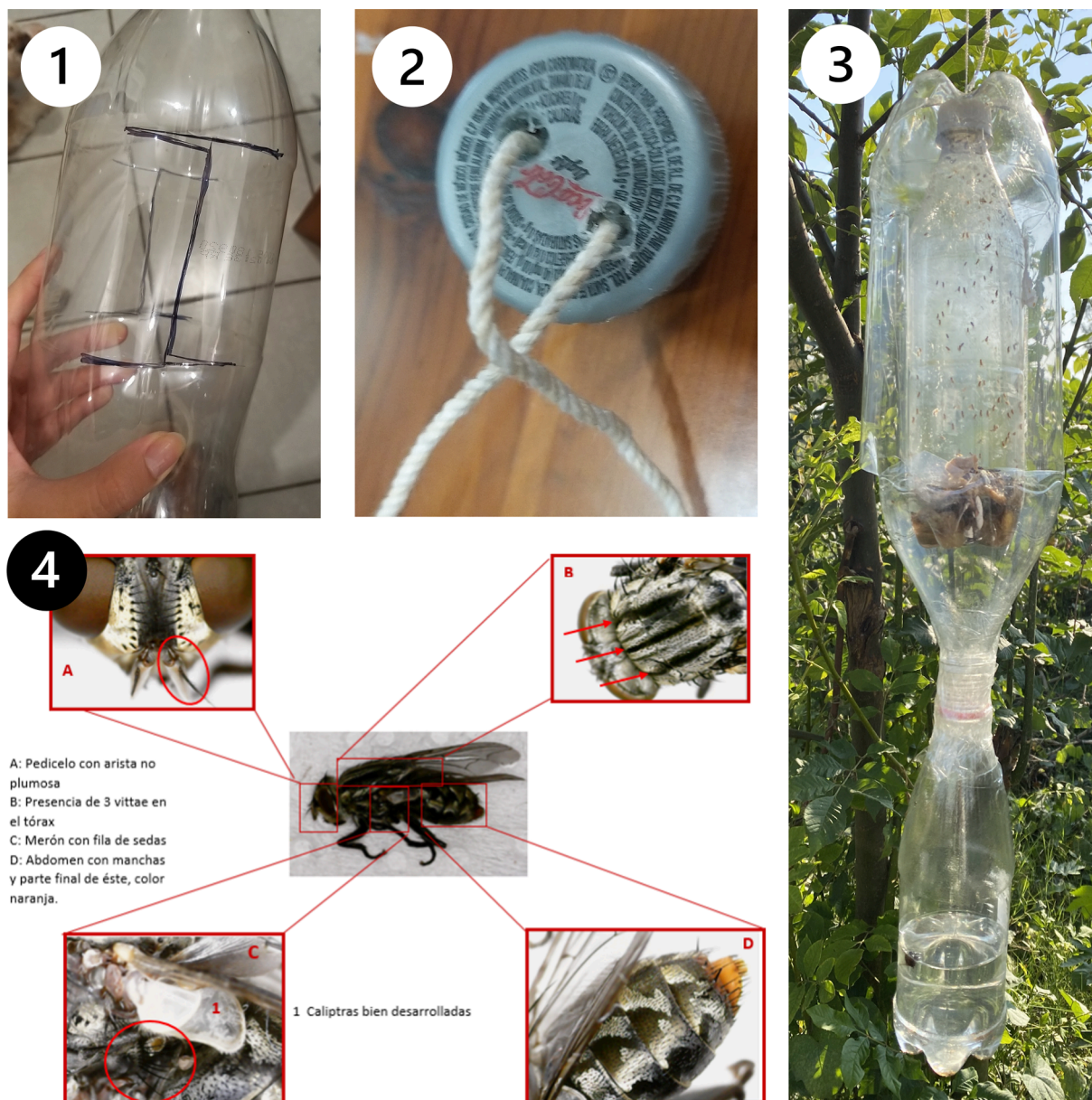


Fig. 1. Examples of student work with the Forensic Entomology take-home kit. (1) Preparing the outer casing of the trap from a soft drink PET bottle; (2) attaching cord to the bottle cap from which the trap will hang; (3) trap set in a tree; (4) analysis performed on a collected specimen, extracted from a student report.

For their part, instructors in Forensic Anthropology discovered that recording video tutorials aimed at providing step-by-step guidance on how to use the programs listed above allowed students to learn how to use them at their own pace—rewatching or skipping parts of the videos—and, in the process, saved class time for discussions or troubleshooting. Finally, in Hematology & Serology the teaching team organized live “unboxing” sessions to familiarize students with the items in the kits, focusing on how to use them and in which activities to do so.

6. Students views about the activities

To find out students’ views about the practical activities implemented in response to the shift to an online mode of learning motivated by COVID-19, we prepared and distributed—via Google Forms—a survey among the students that enrolled in the Forensic Entomology, Forensic Anthropology, and Hematology & Serology courses. The survey asked students, first, to rank their degree of satisfaction with the three types of practical activities in a five-point Likert-type scale, from

unsatisfied to completely satisfied. Next, they were asked to indicate which activities had contributed the most towards achieving the course objectives (as stated in Table 2). Finally, they were offered the opportunity to write down comments related to difficulties they had experienced while completing the activities, how could they be improved upon, and which ones might be worth keeping when face-to-face teaching is resumed.

All students enrolled in the LMS of each of the three courses were invited to participate in the survey: 34 in Forensic Entomology, 35 in Forensic Anthropology, and 35 in Hematology & Serology. The survey was anonymous, but respondents were offered the chance to participate in the draw of one out of seven US\$ 12 gift cards. 18 responses were received for Forensic Entomology, 21 for Forensic Anthropology, and 20 for Hematology and Serology. (Response rates of 53, 60, and 57 per cent, respectively.)

Figure 5 presents students’ degree of satisfaction with the at-home practical activities. For the most part, satisfaction appears to be quite high: taken together, the completely and very satisfied categories ranged

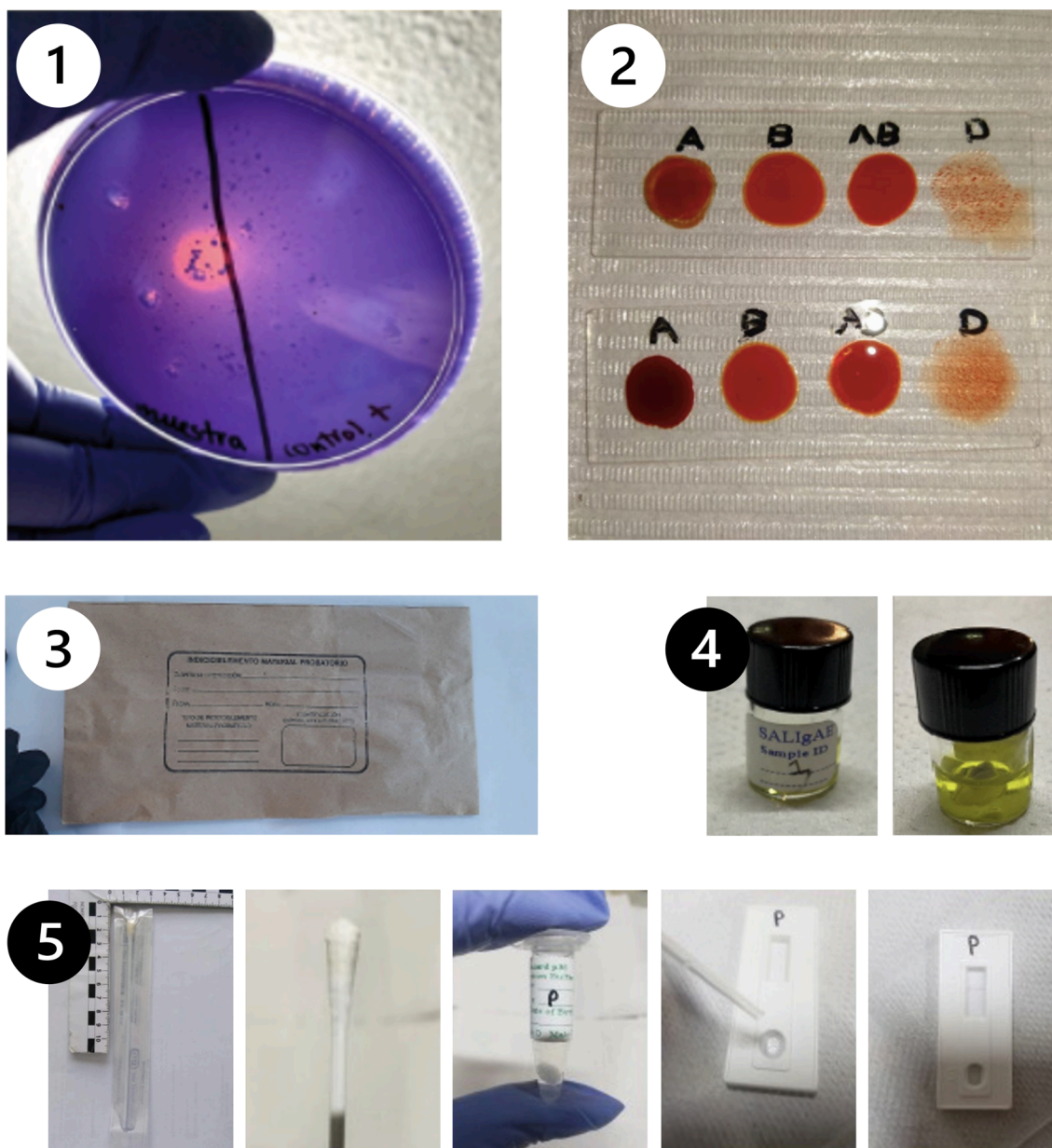


Fig. 2. Examples of student work with the Hematology & Serology take-home kit. (1) Backlit Petri dish with 1% (w/v) agar, starch, and Lugol's iodine for saliva identification (haloes indicate positive results); (2) blood typing results that show agglutination with anti-D serum (students drew blood from their fingertips); (3) paper envelope where biological samples were enclosed, with chain of custody label; (4) SALigAE test indicating presence of saliva by the change in coloring; (5) the sequence of five images illustrates the process students followed in analyzing of a cotton swab with a semen sample, starting with the photographic registration of the swab and its packaging, incubating the tip of the swab inside an Eppendorf tube with buffer solution, applying a drop of the supernatant to the sample well of the P30 test device.

from almost 67 per cent (for the taphonomy at-home practical, first of the central columns in Fig. 5) to 100 per cent (for the take-home Hematology & Serology kit, first of the right-hand columns in Fig. 5). Comments in the survey helped explain why some activities left students less satisfied than others. In the case of the taphonomy practical, problems included difficulties identifying taphonomic changes—especially at the beginning—due to lack of experience and knowledge; insufficient time—a single term—to observe more stages of the process; struggles to control the conditions of exposure; lack of regular sessions dedicated to discussing the changes observed; unavailability of adequate spaces for the activity; and resistance from family members or neighbors.

Other important sources of dissatisfaction—specific to the activities—included problems downloading, installing, or running some of the software required by instructors, specifically that used for

anthropological analyses and for configuring the microscope; these problems arose largely from—or were compounded by—faulty or low-speed internet connections, technical incompatibilities, and/or old equipment with limited working memory. Digital images, for their part, did not always allow students to manipulate them easily with available image-editing tools, examine some angles of objects or traces, appreciate subtle structures, and/or develop a sense of scale. In the Forensic Entomology kit some specimens were damaged during transport, and the resin for fixing arthropod specimens dried up and had to be substituted with nail polish.

Several students also suggested that live online instruction would have benefitted their understanding of how to analyze both bloodstain patterns and taphonomic changes. Inadequate or adverse conditions at home hindered tasks such as using pig bones for the taphonomy

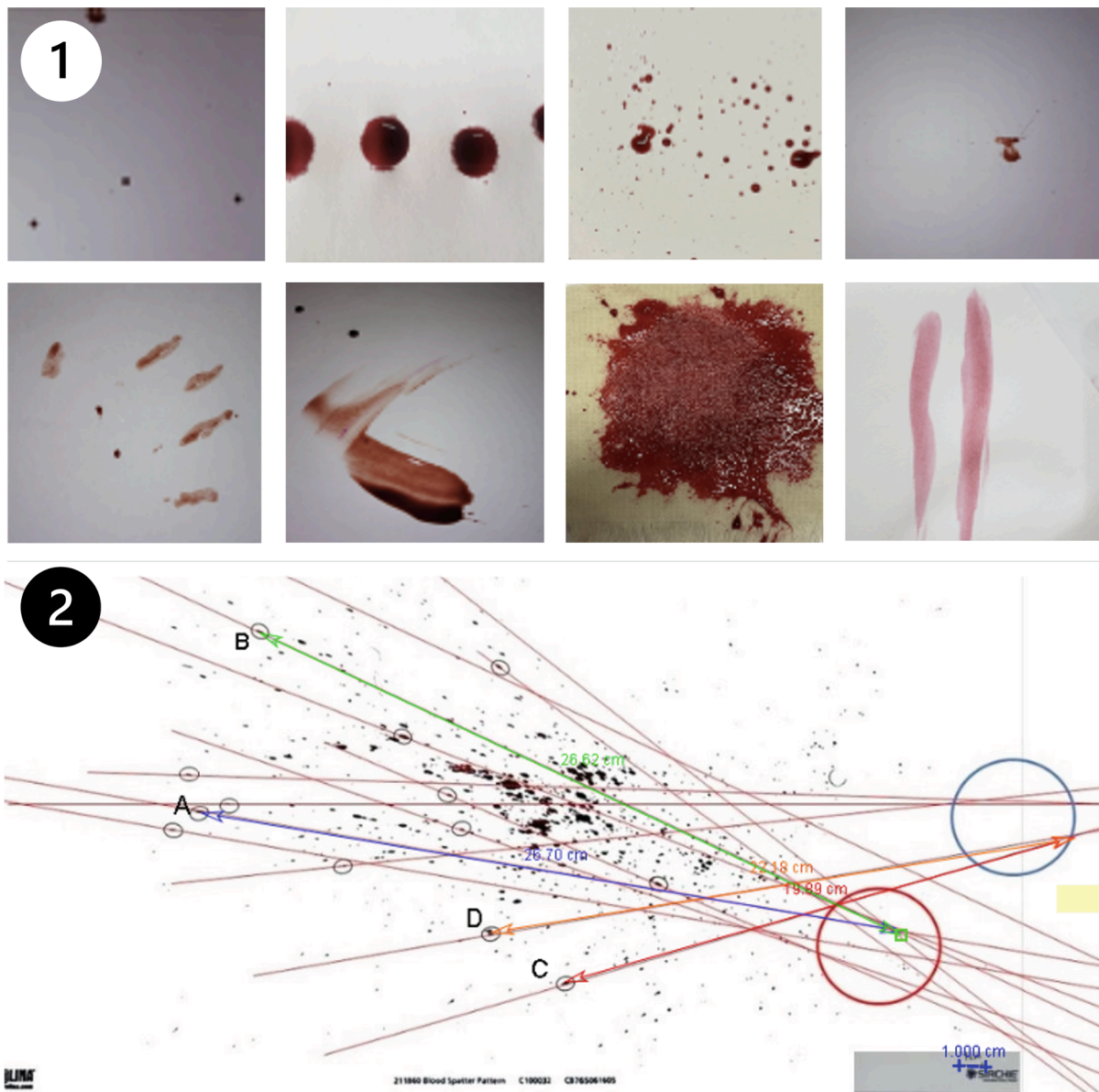


Fig. 3. Examples of student work with a home-made blood substitute and bloodstain pattern analysis. (1) The pictures on the top half illustrate the different patterns produced by students using the blood substitute, attempting to replicate Bevel and Gardner's classification scheme; (2) the bottom half shows the analysis performed by students on blood spatter digital images provided by the instructors.

practical, placing the bite traps in communal areas, and collecting sufficiently diverse arthropod specimens. (A couple of students cited facing some opposition from family members or neighbors.) More generally, some students complained of heavy workloads; tight schedules; difficulties coordinating teamwork; lack of regular feedback from—and interactions with—instructors; and few face-to-face synchronous class sessions. Fortunately, very few students in the courses saw their performance affected by COVID-19 or recovery from it, or mental health issues. (Students, however, might not have felt confident enough to disclose health-related issues, despite the survey being anonymous.)

Regarding the alignment of the course objectives with the practical activities, by the students' own estimation some of them clearly align with the learning outcomes intended by instructors. For example, in Forensic Entomology (Fig. 6) most respondents agreed that the take-home kits helped them to understand the basic concepts of the discipline—as well as their application—and identify techniques for sampling insects, but not how to analyze entomological data as forensic evidence, which was not the purpose of the activity. Reasonably good

alignment can also be seen in the cases of Forensic Anthropology (Fig. 7) and Hematology & Serology (Fig. 8). Some activities contribute to the achievement of more than one objective—for example, the second one of Forensic Anthropology—whereas others are intimately associated to just one—i.e., the fourth one of Hematology & Serology. Given the sizeable investment of time, effort, and resources needed for planning and running practical activities—from both instructors and students—it seems wise to devise activities that can accomplish more than one learning outcome.

Some activities appear to have been, overall, less effective than others: in Forensic Entomology, for instance, only between six and eleven respondents (33 and 61 per cent, respectively) believed that the take-home kit, the use of digital images of specimens, and the *postmortem* interval calculator contributed to achieving either the second or third objectives of the course (Fig. 6, central and right-hand columns). This behavior is only apparent for these activities; in all remaining cases, at least one of the activities clearly aligned with an objective.

Responses were somewhat mixed over whether to keep the practical



Fig. 4. Examples of student work with pig bone fragments for their taphonomy at-home practical. Currently, the fragments are kept in the rooftop of the FSUP main building, and their changes continue to be recorded for future use.

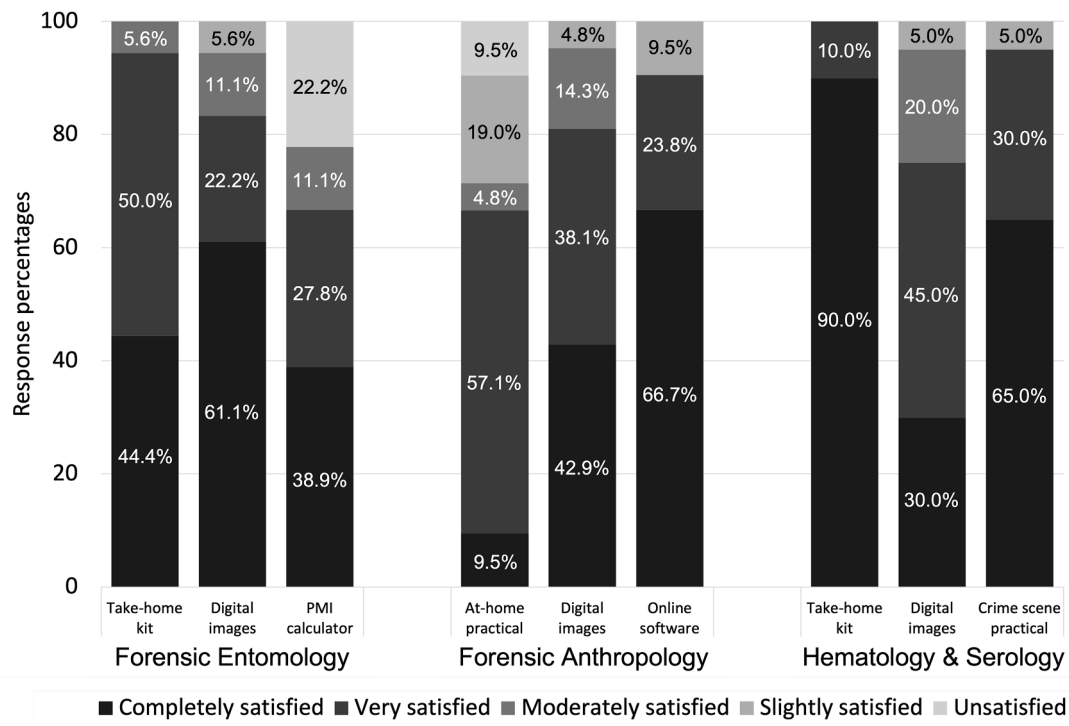


Fig. 5. Degree of student satisfaction with the at-home practical activities implemented in response to the COVID-19 health crisis. Percentages are based on the number of respondents to the survey.

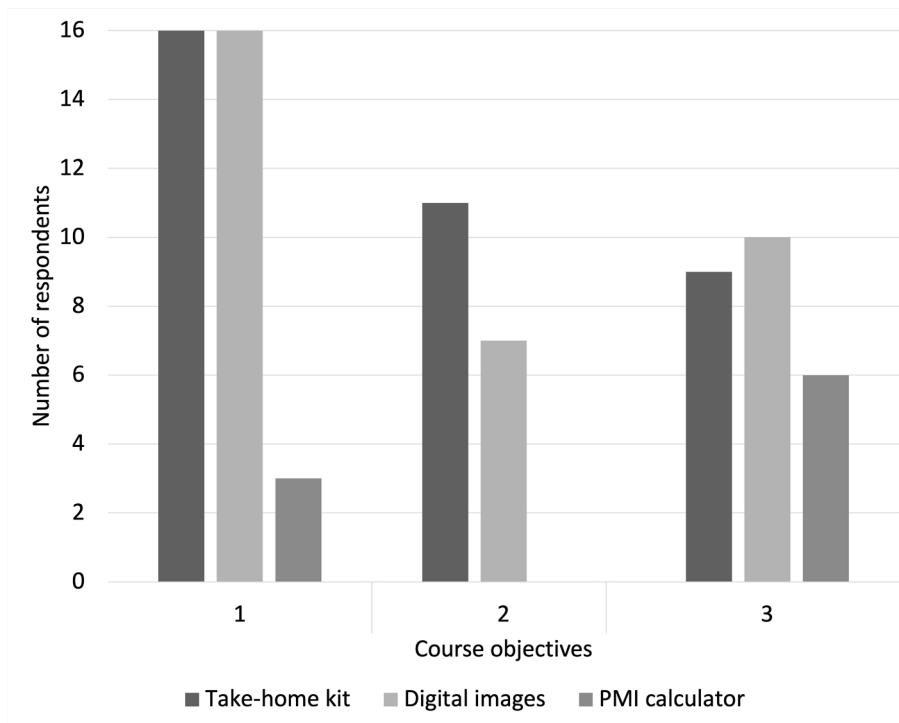


Fig. 6. Students' views about which of the three activities implemented in Forensic Entomology in response to school closures contributed to achieving each of the course's objectives ($n = 18$): (1) understand basic concepts of forensic entomology, as well as their applications; (2) identify techniques with which to sample insects in forensic cases; (3) analyze entomological data as forensic evidence.

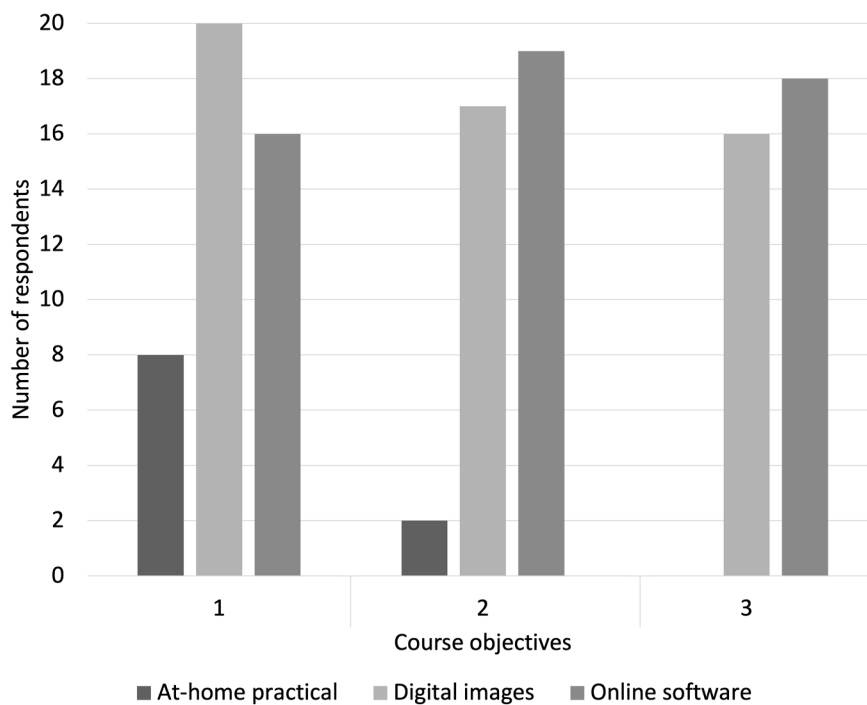


Fig. 7. Students' views about which of the three activities implemented in Forensic Anthropology in response to school closures contributed to achieving each of the course's objectives ($n = 21$): (1) identify elements for the forensic study—somatologic and/or osteologic—of live individuals, cadavers, and bone remains as constituents of the human identification process in a forensic context; (2) learn methods and techniques to identify live or dead individuals involved in legal issues by means of physical characteristics of each; (3) learn methods and techniques to estimate variables such as age, sex, height, and ancestry from human skeletal remains.

activities when normal face-to-face teaching resumes. Several students enjoyed the activities and expressed their appreciation of efforts to provide practical instruction despite the adverse conditions. Accordingly, they recognized their pedagogical value and agreed that at-home activities could represent worthwhile additions to in-person coursework, but in a supplementary capacity. A minority of students stated in

no uncertain terms that the activities would be better if they could be carried out in the FSUP's laboratories, open spaces, or crime scene house.

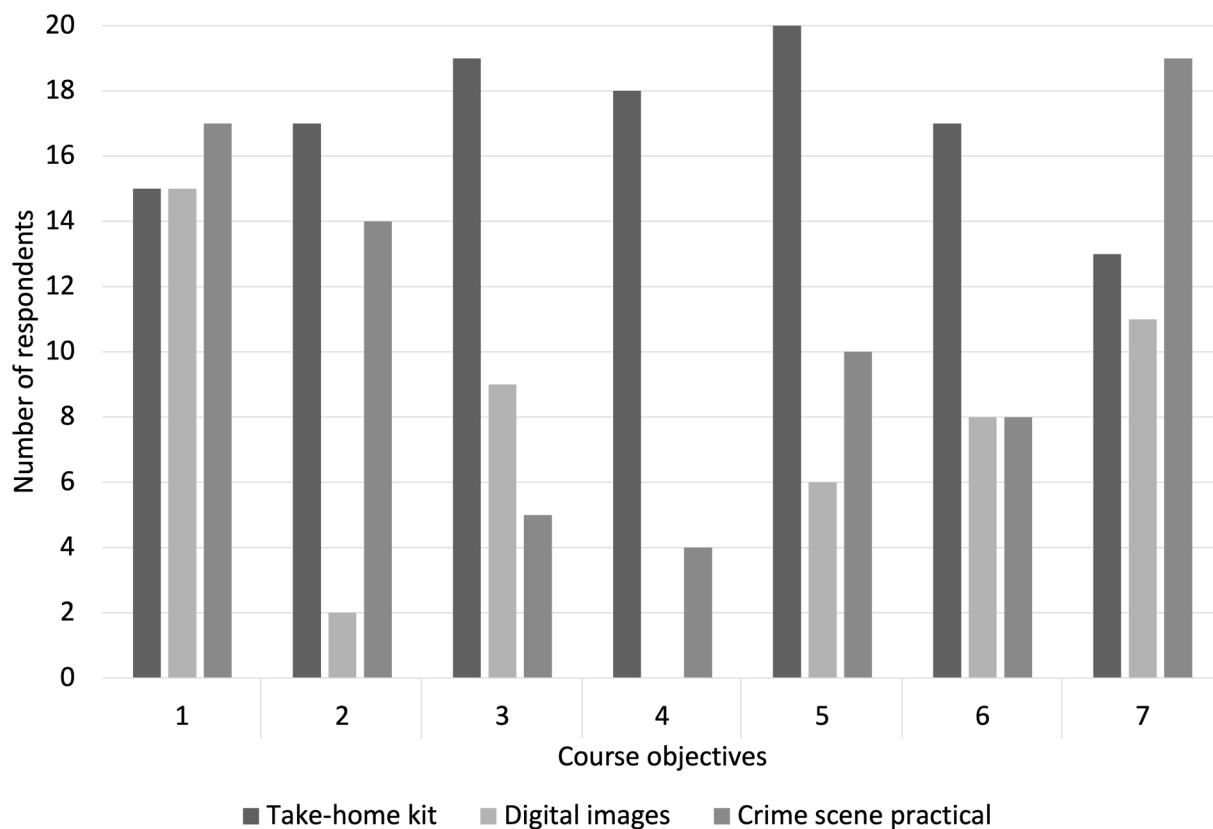


Fig. 8. Students' views about which of the three activities implemented in Hematology & Serology in response to school closures contributed to achieving each of the course's objectives ($n = 20$): (1) systematically and rigorously identify traces in the crime scene; (2) systematically and rigorously collect samples in the crime scene; (3) characterize blood and its constituents; (4) distinguish human blood from that of other animal species; (5) identify and characterize body fluids; (6) identify dried blood and its immunological features; (7) apply the above learning outcomes to the study of forensic cases.

7. Instructors views about the activities

Despite the sudden and unforeseen circumstances that forced them to adapt their courses to a mode of teaching traditionally seen as ill-suited to the development of technical proficiency, and bereft of specialized teaching facilities, instructors discovered that many of the learning outcomes of their subjects could be achieved by other means—as described in this report. Digital images of specimens, samples, traces, and other materials—for example, digital case files for critical review—are resources that they would keep in subsequent courses, whether online or in-person. Instructors in the Forensic Anthropology course are even now preparing 3D models and tomographs of pieces from their osteological collection to enrich the analysis students can perform. Likewise, at-home activities are being kept, with some adjustments. Students are now given the option to expose other materials—apart from pig bone fragments—such as wood and paper in response to a vegan-motivated reticence to work with animal remains. In Forensic Entomology, students still sample arthropods from their immediate surroundings, but more emphasis is placed on understanding the ecological context where organisms are found, rather than on collecting a diversity of specimens of forensic relevance that not all students could find in their vicinity. Finally, also in Forensic Anthropology, specialized software remains a feature of the course, with the addition of an app—developed by a Mexican MSc student of physical anthropology and computing [14]—that can be installed and ran in a smartphone to determine the biological profile of skeletal remains (<https://sites.google.com/view/osteolab>).

Notwithstanding the above, instructors remain convinced that in-person, hands-on practical work is necessary for training competent forensic scientists—for both practical and pedagogical reasons. As the instructors of Hematology & Serology pointed out, preparing individual

take-home kits incurs in additional costs—of time and money—for both institutions and students themselves that might not be sustainable in the long run. Furthermore, students' circumstances outside of school vary so much that standardizing instruction and offering equivalent opportunities to all becomes very hard indeed. From differences in equipment and internet access to different environments and living arrangements, it cannot be taken for granted that students will be able to make the most of the teaching experiences. Finally, based on their observations of instances of student performance, some instructors believe that remedial action—in the form of additional courses—might be warranted to supplement distance learning and correct perceived shortcomings. They fear that, otherwise, students might be left with the impression that they did not develop the skills expected of a forensic scientist.

8. Discussion

None of the three main approaches trialed by instructors of Forensic Entomology, Forensic Anthropology, and Hematology & Serology is entirely without precedent as a response to COVID-19 school lockdowns. Londino-Smolar and Hansel [15] purchased and customized commercial kits that included various forensic science laboratory activities, adapting them to the topics and learning outcomes of a Forensic Science course, whereas Miller [16] reported on the use commercial drone kits for the teaching of digital forensics. In contrast with Londino-Smolar and Hansel's [15] approach, instructors in the FSUP tailor-made their take-home kits to address the learning outcomes of their courses, without the need to set aside unnecessary materials. Furthermore, as was the case in Forensic Entomology, students not only managed to use the items in the kit and perform the assigned tasks at home, but also learned how to construct some of the equipment they needed, furthering a greater understanding of how they work.

As regards the digitization of teaching materials, instructors in various forensic disciplines have relied upon three-dimensional images of bullets and cartridge casings, footwear, and casts [15]; radiographs and pictures of pathological features found in autopsies [8], and illustrations filmed with a document camera [17]. The published literature on forensic science education in response to the pandemic offers some encouraging ideas that can improve the use of digital images and exploit them to their full potential, for example, by preparing 360-degree photographs of different outdoor locations or spaces and items in a laboratory to create virtual tours [15], interactive 3D models [18], or immersive virtual reality scenarios [19]. In the case of the digital teaching materials of Forensic Entomology and Forensic Anthropology, what may set them apart is the quality of the digitized specimens: they come from entomological and osteological forensic collections that are currently being built in the FSUP for research purposes. Using them in education brings students closer to the research carried on by the academic staff of the FSUP, while also increasing the versatility of the material.

Well before lockdown, virtual laboratories, online simulations, calculators, and databases were a staple of science courses, especially given their accessibility and ease of use, and the high costs associated with laboratory work that not always has clear pedagogical benefits [20]. One notable example is FauxDIS DNA Database—inspired by the Combined DNA Index System (CODIS) database—that currently contains 151 DNA profiles that allow students to investigate mock crimes [21]. During the pandemic, Labster virtual lab simulation (<https://www.labster.com>) was embedded in modules dedicated to laboratory safety, biosafety, solution preparation, pipetting, antibodies, and ELISA within a course of Body Fluid Analysis aimed at undergraduates of a Bachelor of Science degree in Forensic Chemistry, and in courses of Forensic Molecular Biochemistry and Forensic Serology for students in a Master of Science in Forensic Science degree [22]. Instructors have also built their own interactive virtual laboratories, using nothing more than PowerPoint, to train students in the identification of blood and semen [9]. What seems noteworthy about the use made of simulators and databases in Forensic Anthropology at the FSUP is the fact that, even though they allow students to work from home, and thus are particularly adequate for our current situation, they are not really substitutes for practical, hands-on work in laboratories or the field. Rather, they make a unique contribution to students' training that might be well worth keeping even after normal, in person teaching resumes, to offer students richer learning experiences.

Despite positive responses from students and high levels of performance, there are serious limitations to sustaining indefinitely an online, distance learning approach. Chief among them—as some instructors of the FSUP pointed out—is the undeniable reality that there are some skills that cannot be effectively developed without access to specialized facilities, equipment, and materials. For example, students can only stage so many crime scenes in their rooms, and then only of low complexity. Arthropod populations vary widely geographically, especially in such a biodiverse country as Mexico, and its desirable for students to observe first-hand those variations and be aware of their implications for forensic cases. Anthropological digs cannot be carried out outside of the FSUP's grounds, say, in local parks or nature reserves. Biological fluids need to be handled and disposed of in accordance with technically and legally sound safety measures that are unlikely to be met in students' homes. Instructors lamented not being able to provide immediate feedback to students, like the one they could offer when closely supervising students' practical work over their shoulders. Under the current lockdown, many—if not most—students do not work in the ideal conditions that schools can provide. And in the approaches reviewed in this report, online learning implied an additional financial burden on students.

Instructors acknowledged that shifting to online learning demanded of them more care, ingenuity, and labor than preparing for normal, face-to-face teaching, with its corresponding increase in stress. They also felt

responsible for having to motivate students to participate in and make the most of the new activities, while at the same time allaying their fears that they may be receiving a subpar education. At a time like this, when teaching staffs face new responsibilities for which there has been no time to prepare, it is crucial that department heads pay close attention to needs and anxieties, so they can, in their turn, support students.

One unforeseen consequence of the shift to online learning has been the recognition that, without denying the importance of technical proficiency for forensic work, preparing the future generations of forensic scientists requires helping students to achieve a broad, interdisciplinary mindset, as well as providing them with ample opportunity to develop strong research, leadership, communication, and critical skills. Because only armed with these attributes can they hope to fulfil their roles as coordinators of criminal inquiries, crime scene investigators, and technical counsel to the judiciary, victims, and suspects.

Concerning the future of teaching at the FSUP, it seems to be the case that some of the approaches adopted in response to the pandemic constitute good teaching practices and merit inclusion in instructors' teaching toolboxes. Furthermore, the realization has dawned that not all courses need to be conducted in person all the time: some, like Forensic Entomology, Forensic Anthropology, and Hematology & Serology will still require students to spend large amount of time at school, whereas other subjects can adopt a hybrid or blended mode of instruction, and still others a completely online course of work. In a very important sense, COVID-19 has collapsed the distinction between the classroom as the place where students learn theory and the laboratory as the space for developing skills. Reorganizing timetables to accord more on-site time to those subjects that require it to fulfil their learning outcomes, and less to those that do not, could allow an increase in enrolment numbers, as well as a more diverse student body, for example, with students that must combine their school tasks with professional and/or family duties.

9. Conclusions

Rising to the challenge of transforming higher education to cope with the COVID-19 pandemic, students and their families, instructors, administrators, and department heads—and the institutions they form a part of—have shown great resilience and adaptability to change. In the case of the FSUP, instructors' resourceful responses to the unfortunate and unprecedented circumstances that have stopped students from attending classes in universities' campus throughout Mexico and large part of the world—and, importantly, prevented any face-to-face interactions with teachers and peers for more than 18 months—represent worthwhile additions to their pedagogical content knowledge. These happy discoveries will enrich the teaching and learning that, hopefully, will soon return to a semblance of normality.

COVID-19 has forced us as teachers to think more deeply—maybe like never before—about the means we rely on to achieve the learning outcomes of our respective disciplines. The importance of crafting a diversified collection of practical activities might be one of the main implications that can be drawn from the teaching experiences described in this report—particularly when training students to be competent in an interdisciplinary field such as forensic science. The variety of subjects that comprise this field—each focused on developing a particular skill set—and the diverse personal circumstances and interests that—we now realize—circumscribe the learning experience entail a more versatile understanding of the instructor's role, one that needs to pay more attention to aspects of students' backgrounds that previously might not have been considered part of its remit. The pandemic opened a breach between students and instructors that threw into sharp relief the need to aid students in becoming effective, adaptable, and self-regulated learners.

Given its highly practical nature, at the outset of the pandemic it seemed that lockdown measures critically endangered the quality of the instruction received by forensic scientists. However, upon further reflection, and after instructors came up with approaches that

circumvented the closures of universities, the pandemic has become—besides an obstacle—an agent of creative disruption that has invited teachers to be more creative and reaffirmed their commitment to the wellbeing and intellectual growth of students.

Ethics Declaration

The Head of the Teaching Unit of the FSUP of the School of Medicine of UNAM provided written ethical approval for the survey conducted to explore students' views of the methods adopted by instructors to adapt to remote teaching. Surveys such as the one we applied are in line with current practices of teacher performance assessment carried out in the FSUP.

Funding

This work was supported by Facultad de Medicina, Universidad Nacional Autónoma de México (UNAM) [grant “Apoyo de Investigación”] and by Dirección General de Asuntos del Personal Académico (DGAPA), UNAM [grant numbers IA400221, PE202421, IA205020, and PE301421 awarded to Mirsha Quinto-Sánchez, Alexa Villavicencio-Queijeiro, Carlos Pedraza-Lara, and Luis Jiro Suzuri-Hernández, respectively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors would like to thank Nahiel Greaves-Fernández for proofreading the manuscript.

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