Utilization of a mock forensic biology case to advance learning and skill development in the undergraduate classroom

Nicole M.M. Novroski[1*]

[1]*Forensic Science Program, Department of Anthropology, University of Toronto Mississauga, Mississauga, Ontario, Canada L5L 1C6*

**Corresponding author: nicole.novroski@utoronto.ca*

Abstract: The use of mock casework in forensic training programs serves an invaluable role in the practical assessment of the education, competency, and logic of trainees in forensic laboratories. However, often undergraduate programs are limited in practical offerings due to large enrollment sizes in classes, laboratory and equipment availability, and the cost of reagents and consumables to carry out worthwhile experiments. Presented herein is the mock forensic biology case assignment that all forensic biology specialist students must complete at the University of Toronto Mississauga. The course is designed to blend theory and practice and to provide students with the necessary practice of competencies to develop into proficient, reliable forensic practitioners.

Keywords: forensic genetics, mock casework, mock evidence, evidence examination, DNA profile interpretation

Introduction

Numerous academic institutions offer undergraduate courses in forensic biology, where the primary goal is to provide students with a foundational understanding of genetics and molecular biology techniques used in forensic casework laboratories. Moreover, while the theory and principles of forensic biology can easily be instructed in the classroom, practical experience is unquestionably the best way for students to develop the necessary competencies to become forensic practitioners post-graduation. However, the realistic implementation of a forensic biology practical is challenged by various factors, including access to suitable laboratory space, ethical or biosafety considerations of working with biological material, and the cost of reagents, consumables, and equipment to carry out the examinations and analyses.

Consistent with Mabry and Schmitz (1), forensic students enrolled in post-secondary programs that meet the American Academy of Forensic Sciences, Forensic Science Education Programs Accreditation Commission (FEPAC) standards must develop the basic knowledge necessary for compelling testimony as an expert witness and must participate in a moot court exercise during their undergraduate tenure (2).

As a curriculum requirement for students enrolled in either the Forensic Biology Specialist or Double Major degree program(s) at University of Toronto Mississauga (UTM), FSC415 (Advanced Methods in Forensic Biology) is designed to challenge students in their ability to process and interpret biological evidence from a "real-life" mock case by assigning a unique case to each student at the beginning of the term and carrying out weekly practical exercises that require students to screen, collect and process biological evidence for a human identity determination.

The Forensic Biology Specialist Program at UTM is by application after the first (freshman) year of coursework is completed. Admission is competitive and merit-based, requiring students to meet a minimum performance in pre-requisite courses that are fundamental for the specialist and major programs. Consequently, only a few students are admitted per annum (e.g., 30 students or less), which is a necessary control to ensure that all specialist students have enrollment access to FSC415 in their respective senior year(s). Further, the FSC415 course is designed to provide undergraduate students with a meaningful, experiential learning opportunity.

A strong foundation in biology, genetics and forensic biology principles is required prior to enrollment in FSC415. Specifically, students must complete FSC315 (Forensic Biology) before enrolling to the advanced course. FSC315 is designed to provide a comprehensive and foundational learning experience that exposes students to the theory and practice of processing biological evidence in the laboratory. The curriculum follows a workflow of evidence collection, packaging and receiving through interpretation, comparison, statistical analysis, and report writing for short tandem repeat (STR) and mitochondrial DNA profiles.

The Forensic Science Program expects students to be sufficiently knowledgeable about the theory and history of the techniques and protocols used in the laboratory so that they can correctly and reliably interpret the DNA data generated from their mock evidence (3). For example, after attending the DNA quantification and amplification lectures in both FSC315 and FSC415, students should have a foundational understanding of the importance of DNA quantification results so that subsequent amplification and genotyping of a given DNA sample are successful. However, a student needs to acquire the necessary knowledge to interpret and prepare a sample (DNA extract) for downstream processing to ensure success of their experiments is maintained.

For a student to truly understand the technical aptitude required to be a forensic technician or scientist, they must spend enough time conducting independent experiments in the laboratory. The learning objectives of FSC415 are to provide students with the necessary theoretical background and the working knowledge to conduct independent casework analysis and give fundamental “expert witness” testimony in the competencies of blood, semen, and saliva identification, DNA interpretation, report writing and casefile review. Throughout the course, heavy emphasis is placed on quality assurance of all tests performed (i.e., data integrity via thorough documentation at every step). At the end of the semester, students are expected to have a better understanding of the theoretical background and principles of blood, semen, and saliva identification, DNA, and related disciplines such as population genetics, biochemistry, molecular biology, and statistics, as well as a working knowledge of the principles and practices of serological theories and PCR based DNA technologies as they relate to forensic analysis.

Methods

The FSC415 course curriculum was developed to follow a traditional workflow consistent with the intake, screening, and processing of forensic biological evidence. Lectures on the history, theories and methodologies occur before the laboratory (practical) exercises, to ensure that all students can review the material, clarify any concerns, and participate fully in the practical exercises. A heavy emphasis is placed on the student “*best representing the evidence*” in the case, with no vested interest in the outcome regarding the alleged suspect(s). The Forensic Biology Case File assignment accounts for 50% of the students’ final grade and therefore requires a sufficient level of commitment and investment to be successful in the course.

Mock Case Creation

Prior to the beginning of each term, evidence is prepared for up to 24 cases (maximum enrollment due to laboratory capacity restrictions), where all cases are unique concerning the alleged identity and number of the victim(s), suspect(s), and witness(es). Mock forensic biological evidence is prepared using a diversity of non-pathogenic biological substrates that include blood, semen, saliva, and associated false positives and negatives. Evidentiary items are packaged independently and sealed with various markings recorded in each case’s chain of custody log(s). Intentional errors in documentation, number/type/condition of evidence, and total number of items received, are packaged, omitted and/or included in the case file to further evaluate students on their attention to detail, logic, resiliency, and documentation capabilities.

While each case and item of evidence is being prepared, a master key of where/what/whose biological information was transferred to which item is recorded, and reference DNA profiles are generated for all samples in appropriate single source or mixture ratios according to the predicted mock evidence processing outcomes.

During the first laboratory, students select one random case file folder and are committed to that case file for the duration of the course. Each case file folder contains a police report (detailing the incident/scenario), case file number and relevant documents, and a list of associated evidence (to be processed in the laboratory). Students are instructed to first review the entirety of the case file for content/details/evidence and verify the accuracy of the evidence packaging and contents.

Basic laboratory rules are provided to the class to ensure success throughout the term. As the hypothetical forensic analyst, it becomes the students’ prerogative to pick the most pertinent samples for DNA analysis in the case, based on the facts or case history provided in the case file. However, due to time and financial constraints for the course, each student is limited to selecting only two samples for DNA analysis. For those samples where additional suspect or witness DNA profiles are necessary for interpretation, DNA profile(s) corresponding to the person(s) of interest are provided during the semester. Students are encouraged to consider the following questions before beginning their evidence examination: *Do you, as the analyst, expect to find the victim, suspect, or another unknown DNA profile from the evidence tested? What, if any, of the submitted evidence is probative in your case? With the evidence items submitted as your basis for forming a hypothesis, will it be possible to conduct a DNA comparison if all samples tested generate a suitable profile for interpretation?*

Chain of Custody, Evidence Examination and Sample Collection

The case file folder provides a log of all activities associated with the physical evidence folder. Students must log the date and time of any evidence and sample handling, where the Teaching Assistant for the laboratory acts as the evidence custodian. Students then are responsible for recording and documenting when/how/where their evidence was processed and documenting with sketches or photography all items examined.

Evidence and sub-sample labeling are required throughout the course, and students must adhere to the instructions provided in the assignment instructions. The police record and evidence are labelled according to an arbitrary *Police File Number*, whereas only the case file is assigned a *Laboratory File Number*. Students are therefore responsible for subsequently assigning any collected swabs, cuttings or other samples with unique sample (or sub-sample) number(s) that follow internal (laboratory) format.

Three laboratory sessions (weeks two through four) are provided so students can open, visualize, document, and process their physical evidence. During this time, students are provided with the resources necessary to perform presumptive testing for blood, semen or saliva on their items and the associated mock documentation worksheet(s) for recording their experiments, results, and interpretations of finding(s). As each case file is unique, the evidentiary items provided to each student differ, preventing any opportunity for plagiarism or information exchange.

Presumptive blood testing utilizes the Kastle-Meyer and human-specific blood testing methods (i.e., cassettes with human-specific antigens). Presumptive saliva testing utilizes the Phadebas press test, and presumptive semen testing utilizes the acid phosphatase (AP) test, prostate specific antigen (PSA; p30) test, and, if deemed necessary, microscopy. Students are reminded that presumptive testing can be specific and sensitive, but also have limitations. For example, presumptive positive results do not necessarily guarantee that a DNA profile will be obtained and that negative results for semen can still result in a DNA profile. Detailed instructions for conducting the test(s) are provided, and all tests are both demonstrated and explained in the laboratory.

At the end of the three weeks of evidence examination, students should have performed a thorough evidence examination on the relevant evidentiary items and taken samplings/cuttings of evidence/exemplars, where appropriate. Students are evaluated on their decision-making during the evidence examination laboratory, including how the chain of custody is recorded in the case file, the seals including date and analysis on the evidence packaging, the processing and sub-sampling of the physical evidence, and the tests conducted.

Sample Processing, Extraction and Quantification

Students are instructed to proceed with two samples for extraction, one sample per week during the two available DNA extraction laboratories (in weeks five and six). A traditional manual extraction laboratory is offered in week five, whereas a differential manual extraction laboratory is offered in week six. Each student will process one sample plus control during each of these laboratories. Students are reminded that when they suspect semen or the possibility for generating a resultant Y-chromosomal DNA profile from their sample, they should proceed with their challenging sample during the (second) differential extraction laboratory. While the goal of the differential extraction is to separate epithelial cells from sperm cells, the differential extraction laboratory still allows students to generate a viable DNA profile from the totality of biological material in their sample (i.e., in instances where no sperm/semen is present). Detailed instructions for conducting the extraction(s) are provided in advance using the web platform for the course, where all tests are demonstrated and explained during the laboratory practical.

The DNA Quantification laboratory immediately follows the extraction laboratories during week seven, where students quantify the amount of total, degraded, and male-specific DNA in each of their DNA extracts and controls. They are provided with the raw data for analysis, sample plate setup and analysis worksheets to prepare for DNA amplification in week eight.

DNA Analysis and Interpretation

Following the DNA quantification lab, students must determine how much DNA is required for their amplification (PCR) reaction experiments in week nine. In lecture, students are educated using $C_1V_1=C_2V_2$, where they are first required to identify their starting concentration (from the quantification output) to calculate volume/quantity of DNA needed to reach the desired concentration and volume for the amplification chemistry. For those students whose concentration falls below the ideal input amount – likely due to incorrect/poor sampling or a poor DNA extraction(s), the course instructors prepare backup samples each of the associated case(s). DNA quantification is heavily emphasized in the FSC315 curriculum, and while quantification using the associated chemistries and instrumentation is reviewed in both the lecture and laboratory components of FSC415, the responsibility falls on the student, working as the hypothetical analyst, to interpret the quantification results and calculate the necessary input for the amplification reaction. A worksheet is provided to assist students in their quantification and amplification calculations, but the teaching assistants do not verify their results to ensure correctness.

Week ten of the course involves genotyping all samples using fragment analysis on a capillary electrophoresis instrument. Students are provided with all manuals, procedures, and documentation. They are asked to review which forensic markers are included in the amplification (PCR) kits being used to be aware of what information they will generate (i.e., autosomal markers, Amelogenin, Y-chromosomal STR data).

In week eleven, students are provided with their resultant DNA profiles from their sample(s) and controls and allelic ladders necessary for interpretation. As the University currently only has one copy of the genotyping software for the laboratory, the teaching assistant and instructor generate the DNA profiles for each case. Students are given a demonstration of the software and must practice DNA profile interpretation of single source and multiple contributor samples in the classroom. Students are faced with (at most) two-person DNA mixtures in some instances, especially if the mock forensic casework was an alleged sexual assault. Given that students are still relatively inexperienced in DNA profile interpretation in this course, their mock DNA profiles are designed to be resolvable in a major:minor contributor approach, using the theory and reference materials provided in the course. For those students who miscalculated their input DNA amounts for the amplification reaction(s), their raw data is presented to them for review, and alternate profiles are provided for interpretation in their case file. As overblown or negative result profiles are uninterpretable, there is value in showing students how sensitive the technologies and chemistries have become, and how little errors can result in catastrophic consequences. However, the overall goal is to develop further their practical and analytical skills, where useable DNA profiles are necessary for statistical determinations and profile comparisons. Statistical analyses are required for all profiles that warrant interpretation. Allele frequency data tables are provided to students to calculate match statistics, whereas the likelihood ratio is encouraged in samples with multiple contributors. A thorough lecture and detailed guidelines are provided so that students can appropriately assess which statistic is most appropriate for their evidence.

Final Report Writing and Submission

In weeks eleven and twelve, students are provided open laboratory time to consult with the teaching assistant and use the space for DNA interpretation, statistical calculations and generation of conclusion(s) for their case files. Final case reports are due at the end of the week in the twelfth week of class – via electronic upload (for plagiarism verification) and manual submission.

Example reports from various agencies are provided to students so that they can visualize how forensic biological data is reported and disseminated to external agencies. Case File submissions from each student are evaluated on the totality of the case file contents as well as the final report. Students have a copy of the rubric for the case file throughout the course and can rely upon the rubric to ensure the completeness of the case file contents and report before submission.

Outcomes of the Course

Student feedback after taking FSC415 has been incredibly positive, where students leave the course with an appreciation for the challenges faced by forensic practitioners in casework laboratories. Further, student's commitment to solving their case is particularly advantageous, and watching students process their evidence, collect their samples, and ultimately be rewarded for their effort and scientific competence is sufficient evidence that the course is achieving the learning outcomes outlined in the syllabus. An annual review of the variability in student case files and reports offers an opportunity to identify course weaknesses and refine any ambiguous instruction(s).

Funding is an obvious limitation for this course, as the cost of DNA quantitation, DNA amplification and fragment analysis via capillary electrophoresis are incredibly prohibitive. However, considering the overwhelmingly positive feedback from students who have completed FSC415, the Dean's Office at UTM has committed an annual budget to support the cost of consumables and reagents as well as equipment maintenance for the course to run as it is currently designed. Ultimately, by allowing students to perform actual experiments with real reagents and equipment, their level of investment and their experiential learning are drastically increased.

The apparent benefit of the mock forensic case is increased preparedness for graduate research and employment opportunities. Not only will students be able to communicate the theory of forensic biology, but they will have the practical skills and capabilities to carry out all aspects of the traditional forensic biology workflow. Many forensic laboratories have a practical component built into their interview process. After taking FSC415, students with only an undergraduate degree may present as equally competitive to those with post-graduate degrees.

Conclusions and Future Directions

The mock forensic biology case has proved to be an invaluable exercise in FSC415. As the course has now been offered three times, refinements have been made to address bottlenecks in course preparation and execution as well as to incorporate student feedback on the strengths and limitations of the flow of the practical exercises. A comprehensive notebook of all worksheets has been created and is provided to students for easy access throughout the term. Quality assurance is built into the course delivery and learning outcomes, where students test and utilize viable reagents and equipment, run controls at every step along their casework processing journey, and interpret the control and reagent blank data (as would actual forensic practitioners in an accredited laboratory).

In the upcoming iterations of the FSC415 course, a reference set of evidence, DNA samples and profiles will be created to minimize within-term data generation and analysis (i.e., when students make errors and replacement samples/profiles are required to move forward).

References

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