Evaluation of a Relay-Style Format for Experiments in an Undergraduate Trace Evidence Laboratory Course

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Abstract: Trace evidence analysis courses should prepare students with both appropriate laboratory techniques and the collaborative skills which may be beneficial to their future careers. A traditional or non-relay laboratory format that includes comparison of unknown evidence from a crime scene to known samples from suspects adequately addresses laboratory techniques. However, this approach does not foster peer collaboration or expose students to the use of known libraries. A comparison of the non-relay format with a relay format was undertaken. The relay format is a unique approach for collaborative learning in which one group of students compiles their data into a library of knowns that is passed to another group of students for further expansion and finally to a third set of students for use in their case file analysis. Comparison of the methods was achieved using observations from instructors acting as participant-observers and through student reflection questionnaires. The results indicate that passing information from one group of students to the next and the inclusion of case file peer reviews required a shift in student thinking from an individualistic mindset to a collaborative one as students understood that their peers would utilize their results. The library development and case file peer review exposed students to more variety in the presentation of analysis results and forced reflection on the clarity each provided. The relay format also yielded a more relaxed pace through the analyses to encourage deeper analysis of student results and conclusions.

Keywords: cooperative learning; forensic science education; trace evidence; laboratory course.

Introduction

In a particular case, evidence collected from a crime scene may be processed and analyzed by multiple people. For trace evidence analyses (fibers, tapes, impressions, glass, etc.), the submitted samples of unknown origin are generally compared to known samples from the scene or a suspect for identification purposes. Multiple characteristics between the unknown and known samples must be consistent with each other for identification or association of class characteristics. The strength of the comparison is based on the number of compared characteristics and the uniqueness of those characteristics. In many cases, a sample submitted for analysis is compared to a library of samples from known sources. Available forensic libraries may include the results of past or current cases (Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) Trace Evidence Unit Reference Collections or National Integrated Ballistic Information Network (NIBIN)), manufacturer-provided reference samples (FBI Lab Fiber Library, National Automotive Paint File (NAPF), or National Forensic Tape File (NFTF)) (1), or other materials of known sources collected for comparison (International Forensic Automotive Paint Data Query (PDQ) or National Center for Forensic Science Ignitable Liquids Database) (1). With varied sources, libraries have differing constructions and an analyst must determine the most useful information provided for comparison and recognize the limitations that may be posed by relying on the work of others.

Previously, a trace evidence laboratory course utilized a case file format wherein students were provided evidence from a fictitious crime scene (unknown) as well as from corresponding suspects (knowns) for analysis. The students would have to acquire, analyze, and compare results from the knowns and unknowns summarizing their results in a written case file format. They would have one week for completion of each evidence type. Due the tight timeline, students were only able to analyze one or two knowns for each case file.

Traditional style undergraduate labs operate on predetermined standard procedures that are followed to obtain data which leads to a lack of independent thought and interpretation of results during the lab period (2,3). The limited scientific thinking that occurs during this time affects final report-out activities that are expected of students at the end of a lab since students cannot adequately make connections between the data obtained in lab and the background knowledge that is provided during lecture (4,5). A student's critical thinking skills should be developed during upper-level laboratory courses which may benefit from a differing teaching approach than those encountered in lower-level laboratory courses (6).

To provide students' experience in developing and utilizing libraries as well as gain experience working collaboratively on a case with other analysts, a relay structure for a trace evidence undergraduate laboratory course was utilized. The relay structure breaks the analysis of a type of evidence into several rotations with each rotation being completed by a different set of students. The relay begins with a complete analysis of items from known sources and students summarizing their results from the week in a library format. That library of known samples is then passed to a second set of students that expand the library to include additional known samples. The expanded library is passed to a third set of students who finally utilize the library as they compare their unknown item from a fictional crime scene to the library entries. The third set of students generates a case file that summarizes the results of the unknown analysis and comparison to known sources. The students who began the evidence library at the start of the relay complete a peer review of the final case file generated.

In addition to collaboration through the library-building experience, students also collaborate through helping each other with instrument and microscope operation. Students can own their expertise from performing an earlier rotation of a relay when helping those completing later rotations of the relay for a collaborative effort that builds confidence. Several chemistry-based laboratory formats that promote collaborative experiments include an inquiry-based approach (7,8), problem-based learning (9), peer-led team learning (10), cooperative group learning (11-15), and constructivism (16) within the chemistry laboratory course. Similar to the aims of this laboratory format, the approaches listed above were developed to address observations that students lacked preparation for lab and showed poor understanding of concepts utilized in their lab experiments (12). A common aim across all of these formats is to develop an investigative approach to student thinking that utilizes guiding questions in hope that students will create an open dialogue with their peers regarding the lab (7-8,10-11).

These approaches encourage students to become the 'expert' on troubleshooting instrument operations, designing a standard operating procedure (SOP), or conducting experimental designs where mistakes in the development of these tasks are a learning experience (8-9,11-12,16-18). Through each study, collaborative learning in lab groups/partners was encouraged to result in more independent student actions in the lab coinciding with learning from their peers. Students now become accountable to their peers, not only their instructor. The quality of their work will affect the group's outcome in the lab resulting in increased motivation to learn and problem-solve through lab instruction. This encourages enrichment of the learning experience to utilize laboratory time in an effective problem-solving manner (12,15). A relay-style approach to collaborative student learning in the laboratory was presented for use in the context of a single experiment in an instrumental analysis laboratory course (19). While this presentation was not specific to a trace evidence course, the premise of developing knowledge between students through progressive rotations building to a completed final product was the foundation for developing this study.

The transition to relay-style labs aims to improve several aspects of a trace evidence laboratory course. First, this format promotes a collaborative learning approach, encouraging students to bring their best work into their peer collaborations. Second, the experience of building their own library and utilizing libraries made by other students (rather than national or instrumentation-provided databases) develops a deeper understanding of the limitations of libraries and reinforces the need to analyze the top library results separately to confirm their comparison results. The combination of these aims yields students with a deeper understanding of the techniques and analysis, providing a stronger foundation of analytical skills required for future forensic scientists.

As a previous literature review on the state of forensic science education noted, "there is no published research on laboratory education effectiveness" for forensic chemistry courses, including those in trace evidence (20). This study had students analyzing evidence using both a non-relay and relay format. The purpose of this research was to devise and compare a relay teaching strategy to the non-relay teaching strategy for identifying unknown samples. The type of evidence was different for the relay and non-relay teaching strategies. This study's research questions addressed how students perceived or utilized libraries with a relay teaching strategy and how having both relay and non-relay teaching strategies in a course affected the students' evaluation of evidence.

Methods

Course Description

At the authors' institution, trace evidence lecture and laboratory courses are offered to junior-level forensic science majors with a concentration in forensic chemistry. Instrumentation and microscopy courses are pre-requisite requirements providing the students with an understanding for most of the instrumentation utilized in this course. The primary learning objective for the trace evidence laboratory is to provide students with experience in evidence-specific analyses common with trace evidence. Traditionally, the laboratory covers eight main evidence types: footwear impressions, fire debris, firearms/ballistics, fibers, tapes, glass, documents/inks, and automotive paint (in cases of unforeseen circumstances or university closure that necessitate a missed lab period, automotive paint is removed). Each experiment is focused on a specific type of evidence with the procedures for analysis aligned with Scientific Working Group (SWG) or Organization of Scientific Area Committees for Forensic Science (OSAC) guidelines for the evidence type. The majority of students enroll in their forensic science capstone the following semester wherein they will be tasked with collection, analysis, and testimony of pieces of evidence. Preparing students for independent laboratory work and case file preparation is a secondary learning objective. This study focuses on the laboratory portion of the course and two teaching strategies (non-relay and relay) were utilized for the pre-COVID-19 portion of the two Spring 2020 semester sections.

One of the instructors was also the lecture instructor and is referred to as lab/lec instructor in the Results and Discussion. The second instructor worked as a full-time managerial chemist analyzing paint samples and developing matching formulas for car paint and is referred to as lab only instructor in the Results and Discussion. The lab only instructor is also a previous graduate of the program and took a variation of this course. The graduate teaching assistant for both sections was an undergraduate in this course the previous Spring semester.

Non-relay Teaching Strategy

In previous semesters, students learned the analysis process for each type of evidence through directly comparing known samples to an unknown sample as part of a case study structure. Students were usually given only one or two known sources for comparison and were asked to do a direct comparison rather than utilize a library of knowns. Students did not utilize results from other groups. Thus, students were not asked to narrow down potential sources of the evidence but were primarily focused on the aspect of direct comparison. This one group/student only procedure is referred to as the non-relay teaching strategy for this study. Students are assessed utilizing a case file format summarizing a complete analysis protocol including their observations from the known samples and criteria used to identify their unknown sample. In addition, the case file report includes answers to questions relating to evidence and lab techniques similar to questions they may receive as part of a testimony covering the case.

For the Spring 2020 semester, this format was used at the start of the semester covering impressions (shoe prints) and fire debris evidence, introducing the students to the process of working with evidence samples from multiple sources and developing a case file to summarize their analysis. Furthermore, the non-relay teaching strategy was used with evidence procedures that cannot be completed within a single laboratory period, such as the impression molds' 24-hour cure or the overnight bake time for the fire debris activated charcoal strip headspace method.

Relay Teaching Strategy

For the relay teaching strategy summarized in **FIGURE 1**, three different types of evidence were considered at the same time (Spring 2020: fibers, duct tape, and firearms/ballistics; **FIGURE 2**). With the relay format, groups rotated through each evidence type over four weeks. Students in the first two rotations each had one week to build a library of known samples. The first and second rotation groups were responsible for performing a complete analysis of evidence provided from known sources and documenting their results in a digital library. Students could choose the format and arrangement of the library but were instructed to include all observations and images recorded for each piece of evidence. A digital copy of the initial library was submitted by the first group and then expanded to a complex library by the second group to include additional entries. The initial and complex libraries were graded and checked before the start of the unknown analysis.

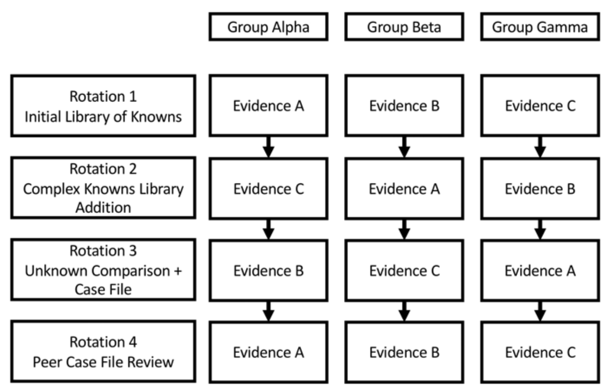

FIGURE 1 Proposed group rotation schedule.

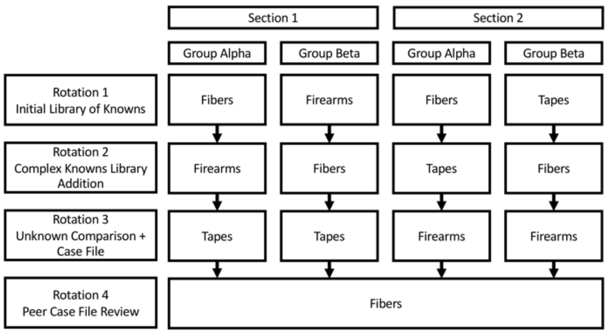

FIGURE 2 Rotation schedule for Spring 2020 with smaller section sizes and COVID-19 accommodations.

The third rotation was to have a two-week time frame for the analysis of an unknown sample and comparison analysis with the known they suspect to be the source. Due to the COVID-19 pandemic requiring the transition from face-to-face to on-line instruction, data for the unknown had to be provided to the third group. The third rotation group used the library created by the two previous groups to identify the unknown and wrote a case file utilizing the data provided. Case files were graded by the instructors and graduate teaching assistant. A single fibers case file was also developed by the lab/lec instructor and graduate teaching assistant for all students to use as the peer case file review.

Since the initial library development began with the basic analysis of the evidence, the first group for the rotations reviewed the completed case file stating the strengths and weaknesses of the analysis. Thus, the first rotation students were able to view the more complex analysis performed in the second rotation and the unknown comparison performed by the third rotation. These peer reviews were a written report evaluated as part of the students' grades for the lab.

Observation and Self-Reflection Collection

Student questionnaires were approved by the authors' Institutional Review Board before the start of this qualitative study to collect feedback from the students throughout the term. The authors were also approved as participant-observers to record their observations and reflections. For the two Spring 2020 sections, six of the nine students provided consent to participate with zero students dropping out during the study. Another researcher who is part of the team but did not teach the lab gathered the consent forms and kept them to prevent bias from the instructors and graduate teaching assistant. Students were assigned a number in order for the students to remain anonymous. Regardless of their decision to participate in the study, students were expected to complete the same workload relating to experiments. Students worked in groups for both the non-relay and relay portions of this study, consistent with previous years' course designs. Group membership was changed between the non-relay evidence types. The groups remained the same for the entirety of the relay rotations. Groups consisted of two students with one group of three students due to a section having an odd number of students.

Questionnaires were administered after each of the non-relay evidence experiments and after each rotation of the relay experiments. These questionnaires were given to the students to be completed and returned to the outside researcher (not instructors or graduate teaching assistant) and were graded for completion, not on content of the answers. Only the questionnaires submitted by students who provided consent were analyzed for this study. The questions varied for each rotation of the relay, with the initial rotation group not completing their reflections until after the conclusion of the case file peer review. A summary of the questionnaires for the non-relay experiments and for each stage of the relay experiments are shown in **TABLE 1**. The questions were provided as open response questions with no word limitations. In addition to student feedback, weekly observations were written by the instructors and a graduate teaching assistant. The lab/lec instructor, lab only instructor, and graduate teaching assistant recorded their observations in separate notebooks. These observations included impressions regarding the time constraints students were under, how they approached situations, actions they struggled with completing or comprehending, and what students did well with throughout the lab. The graduate teaching assistant also provided observations comparing their experience as a student with all non-relay lab formatting with their observations of the combination of non-relay and relay evidence lab format.

Results

Non-Relay Teaching Strategy

For the impressions (shoe prints) evidence, none of the students reported a ten on a 1-10 scale on being confident about identifying their unknown. One student (202014) reported a five, and another student (202016) reported a 7.5 with the remaining four students (202009, 202012, 202015, 202016) reporting an eight. Only one of the students (202014) mentioned in their questionnaire that they had to return to a control sample to identify more indentations to assist with their unknown analysis.

The fire debris analysis had three students (202009, 202014, 202016) rate their unknown identification a nine on the 1-10 scale. A fourth student (202015) ranked their identification as a seven to eight while a fifth student (202012) ranked their confidence as a seven. Only one student (202018) reported a four due to the gas chromatography mass spectrometry (GC-MS) spectrum

TABLE 1 *Questions Included in Each Questionnaire Used (NR = Non-relay Case File; R1 = Rotation 1 Students After Completion of Case File Review; R2 = After Rotation 2; R3 = After Rotation 3)*

Question	NR	R1	R2	R3
How many different controls did you analyze?	X	X	X	
How many characteristics for the controls did you originally classify?	X	X	X	
Please list the characteristics that you used below and explain your choice including method of analysis.	X	X	X	
After you began the analysis for your unknown, did you have to return to the controls to classify other characteristic(s) to aid in your identification of the unknown?	X			
If you answered Yes, list below the additional characteristic(s) that you determined you needed and explain why you may have not considered these with your initial analysis.	X			
Identify and explain which control characteristic was the easiest to distinguish between controls.	X	X	X	
Identify and explain which control characteristic was the most difficult to distinguish between controls.		X	X	
How many of your control characteristics did you use to identify your unknown?	X			X
How many of your control characteristics did you not use to identify your unknown?	X			X
Please list the characteristics that you used below and explain your choice including method of analysis.				X
Which characteristic was the most useful for you to identify your unknown? Explain this choice.	X			
What characteristic was the least useful for you as you identified the unknown?	X			
On a scale of 1 to 10, how confident are you that the unknown was correctly identified? (1: pure wild guess; 5: I have a 50-50 feeling; 10 - I am confident). Explain your ranking.	X			
After reviewing the completed case file, what information from your initial library development was used to identify the unknown?		X		
What information from the continuation of the library development did you find interesting? Did you not include this information in your initial library development? If not, why?		X		
Upon seeing the completed case file including the complex known library and unknown identification, how did/could that potentially influence your library development with this project or in the future?		X		
What aspect of the initial development of the library was the least useful for you as more controls were added to the library?			X	X
What aspect of the known library was the least useful for you as you identified the unknown?				X
After you began the analysis for your unknown, did you have to return to the controls to classify other characteristic(s) to aid in your identification of the unknown?				X
On a scale of 1 to 10, how confident are you that the unknown was correctly identified? (1: pure wild guess; 5: I have a 50-50 feeling; 10 - I am confident). Explain your ranking.				X
R2: Upon seeing another group's initial library development, how did/could that potentially influence your library development with this project or in the future? R3: Upon seeing this evidence's library…			X	X

"gave the class of the ignitable source and the range of a medium, but I cannot narrow it down any further to a specific source." One of the six students (202014) did discuss having to return to the known sample to compare the peaks.

The graduate teaching assistant reflected upon their experience the previous year in this course having to analyze all the different types of evidence in a non-relay format:

> *As a student in Trace evidence lab a casefile was completed each week after finishing a traditional style lab. This was often stressful on students with the course load expected in the program. It was expected of students to analyze 1-2 known exhibits and an unknown to make a comparison between evidence types. Often times, the procedure was by the book meaning it was detailed step-by-step and students carried out the lab noting observations and obtaining data. This was conducted in a manner that did not leave time for students to think about the scientific reasoning behind their data until they were out of lab and ready to write a casefile.*

The pressure mentioned by the graduate teaching assistant during their student days was due to the fact that the majority of the evidence was analyzed for unknowns and knowns in a one lab period except for impressions and fire debris which had one and a half lab periods to account for the additional sample prep time required for those evidence types.

Observation notebooks from the instructors and graduate teaching assistant all discussed the students having questions about the open-ended aspects of the mixing of the materials to collect their impression evidence. Students tended to ask questions and attempted to measure specifically with balances for their materials instead of allowing the observed consistency of the mixture to indicate correctness. Because the instrumentation and overall comparison techniques utilized in the non-relay labs were introduced in previous courses, students' instructions were written to provide fewer details. Also, some groups struggled working together as group assignments were made by where the students sat instead of student-formed groups. Students may or may not have known their partners before this class and group assignments changed between evidence types.

Both instructors and the graduate teaching assistant mentioned that the students were more comfortable with the fire debris evidence. While some students did not use the example provided to guide sample preparation, others understood the expectations and utilized the example for proper sample preparation. In addition, this evidence utilizes GC-MS instrumentation which the students had used in their previous instrumentation course. The questionnaires did not indicate any issues with the instrumentation only with the peak interpretation because their unknown was not exactly like their known samples.

Relay Teaching Strategy

For the complex library questionnaire (second rotation of the relay), one student (202009) on the duct tape evidence discussed: "Our group wants to change the presentation of our results for the presentation of our results for the future." This student also mentioned that they appreciated the way that they were able to compare their exhibits to the previous rotation's exhibits. Student 202015 reflected upon their previous work:

> *After seeing another group's development, I would work more with my group on what information we deem important enough to include in our library. We all seem to have different ideas of what is specifically important to include, which might mean that we do not all include the same characteristics about our exhibits.*

This student's comments also are reflected by the lab only instructor's observation: "*Another positive aspect of the relay approach was the students would push each other to success!"*

For the relay's case file rotation, only duct tape and firearm evidence types had questionnaires evaluated. All three students submitting firearms questionnaires (202009, 2020215, and 202016) recognized that they did not have enough information to identify their unknown, causing their confidence ranks to be eight (202009), seven (202015), and five (202016). With firearms, the bullet unknowns are characterized by striations and the threshold number may not have been reached, but these students indicated in their questionnaires that they did not revisit the known samples to double check. Student 202016 felt that the "*analysis left a lot to be desired and felt incomplete…*"

Students with the duct tape evidence were not confident in their unknown analysis with one student (202012) ranking themselves as an eight. Another student (202018) assigned a rank of nine but this student identified matching torn ends of the duct tape. A third student (202014) had a confidence of five, claiming exhibit 2 had a missing piece of information for comparison. This student did return to the known samples though they did not mention locating the missing information.

The peer review of the case file had all students reviewing a fibers case file that the lab/lec instructor assembled. The peer review timeframe occurred after the university went to an on-line format due to the COVID-19 pandemic. Fibers was chosen as a common evidence type for the case file review as every group had analyzed fibers in one of the previous rotations and the time constraints for the lab/lec instructor with the sudden on-line transition. The student-produced fiber libraries were also provided to each section. Two students (202015 and 202016) mentioned organization of the library and case file information was an aspect that they would change with Student 202015 stating:

> *I would also make sure that all figures/data are in a clear order. In the case file, certain figures were not in a very good order (like adding information about exhibits 1, and then 5, and then ftir results of 5 and then 1). I would make sure all information is in order, not separated.*

While this observation assists with clarity this student also "*would not include all aspects of the examination*." By excluding some information, the potential of missing important information to identify the unknown while eliminating other possibilities might be missed.

Discussion and Conclusion

In Spring 2020, an undergraduate trace evidence laboratory course evaluated evidence using two different teaching strategies. The first strategy was a traditional comparison of knowns to an unknown, which had been used in previous iterations of the course. The second strategy was a relay-style rotation, building libraries of known samples to be used in comparison with an unknown sample.

In both teaching formats, students were observed to experience some pressure. In the non-relay format, one week was provided for evaluation of knowns and unknowns and completion of the case file. This resulted in a deadline-driven external pressure on the students.

With the relay-style, four weeks of rotation provided time for reflection on evidence collection and analysis of unknowns. The relaxed pace also allowed more time for students to critically think about each evidence type and their evaluation of information. The pressure then shifted from external deadlines to the internal pressure of students' knowing that peers will see and use their work at every step (12,15,19). The lab-only instructor observed this shift, noting "*some students seemed nervous or worried about their work influencing their peers. It was not an individual work anymore*." In addition, the lab/lec instructor reflected on the decreased instructor pressure for grading completed case files each week. The relay format provided additional time between case file assignments for feedback to not only be given by the instructor but also to be reviewed and incorporated by the students.

The internal pressure of peer collaboration also fostered a growing interdependence in the lab, mimicking a "team" approach common in industrial laboratories. The graduate teaching assistant noticed and reflected about this difference between the two teaching strategies:

> *The only time we interacted with our peers [in a non-relay only semester] was when we discussed our observations or had questions about next steps… [In the relay-style] Many students began asking questions about instrumentation and the reasoning behind results to past lab groups who worked with that evidence type. This allowed students to be an expert on an evidence topic or instrumentation which resulted in the instructors being there to mediate and offer feedback when students needed help connecting lecture content to lab results.*

Student confidence in their lab results was not solely based on the quality of data generated by their peers, but also in their own analysis and in part on the type of unknown evidence being analyzed. For example, result confidence was highest for fire debris when students were previously exposed to a similar type of analysis in the prerequisite instrumentation course. But students were uncomfortable with the lessened detail in the instructions. The heightened confidence in result with previous exposure to analyses and the building of comfort with interpreting instructions lay a groundwork for their capstone experience and future career work, which require these skills. Confidence was lowest for evidence types that utilized brand new techniques such as comparison microscopy and scanning electron microscopy (SEM) in the firearms experiment. Other relay style evidence analysis utilized new instrumentation and lab techniques. In addition, not every relay-style evidence analysis provides a clear result. Students had to set aside inherent biases and grapple with the disappointment of not finding a "match" between their unknown and one of the knowns analyzed by previous groups. This is more aligned with a true forensic lab experience where not every case has a firm result in favor of an identification.

While students have been previously exposed to instrumentation libraries for Fourier transform infrared spectroscopy (FTIR) spectra and MS spectra in their instrumentation courses, students developed libraries for known samples to be shared with their peers in the relay format. Upon reviewing other students' libraries, students noted organization and completeness as factors in the quality of the library they were given. However, students in the second rotation lacked the confidence to reorganize the initial library when adding additional known evidence samples. The libraries often included more information than was necessary for a basic comparison between the knowns and unknown. Student 202015 did not appreciate that this is often the case with libraries when they noted they would have included less information in the library accompanying the case file review. But the additional information can be helpful in considering alternative conclusions for a case file. For instance, students are so focused on trying to prove the similarities between the analysis results, they may overlook characteristics that limit or do not support those conclusions. This leads students to an internal bias that is an ethical issue among forensic scientists.

Both a traditional non-relay format and a relay-format were included in an undergraduate trace evidence laboratory course in Spring 2020. While the non-relay format provided students experience in individual analysis and case file development, the relay format fostered interdependence between student groups and provided several additional advantages as observed by the instructors for this course. The shift from an external pressure from deadlines to an internal pressure of being required to show their work to peers, encouraged students to do their best work. Through developing libraries and performing case file reviews, students were exposed to differing approaches for presenting analysis results and reflected on the appropriateness or clarity of each approach. Finally, while they still developed case files, the relaxed pace of the relay format provided more time for students to critically evaluate their own analyses so as to avoid inherent bias. Future work includes continued collection of student questionnaires for trace evidence laboratory and follow-up questionnaire at the end of the students' capstone course.

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