FORENSIC EPISTEMOLOGY: STUDYING THE CRIME SCENE

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Abstract

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Forensic epistemology is the study of knowledge as it relates to forensic science and can be broken into four sources; intuitive, authoritative, logical and empirical. In a four-phase research approach, I explored reasoning skills (logical knowledge) used by crime scene experts and methods (empirical knowledge) for forensic case-specific experimentation. First, the reasoning skills of crime scene investigators (CSI) and bloodstain pattern analysts (BPA) were tested, correlated to demographics and reasoning categories were compared. Practitioner's with graduate level education performed better on the reasoning test, however, significant differences were not found between test scores and years of experience. Similarly, there was no difference between test scores and employment status (specifically, police or civilian employees), for the CSI group nor within the BPA group. This information suggests that level of education plays the most important role in the development and use of reasoning skills, whereas experience and employment status are not as influential. Second, I investigate potential strategies in selecting data types for case-specific experimentation in pattern-interpretation disciplines within forensic science. I also examined the epistemic status of practitioner case experimentation in forensic science. Practitioners were more confident in a mixed-method approach when conducting case-specific experimentation. In addition, there is a knowledge gap in experimental design for some forensic practitioners. Third, is a reprint of the introductory section of my published book entitled *The Scientific Method in Forensic Science: A Canadian Handbook* that abridges knowledge gained from this dissertation with further evidence-based literature review and experiential examples. This phase summarizes the scientific method in forensic science and provides guidance for forensic science students and practitioners. The final phase merges the findings from the primary studies with a literature review; offering scientific evidence supporting suggested research and pedagogic strategies that can help increase the epistemic status of forensic science.

Keywords

forensic epistemology, forensic science, hypothetico-deductive reasoning, research models, logic, case-specific research, crime scene, bloodstain pattern analysis, crime scene investigator, expert.

Preface

This thesis is written in manuscript format, and the main chapters have been published, or have been submitted for publication. Chapters 2 has been published in the Canadian Society of Forensic Science Journal (CSFSJ) and chapter 3 is under peer review by the CSFSJ. Chapter 4 is the preface from a textbook to be published by Canadian Scholars Press (CSP) in June 2020. Chapter 5 has been published in Forensic Science International: Synergy (FSI). The names of coauthors are indicated on the title page of each chapter. Applicable copy right releases have been obtained and can be found in Appendix C.

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I gratefully dedicate this dissertation to my wife, June. Without her encouragement and pragmatic advice, this PhD would not have been completed.

Dr. Paul Wilson has been a friend, colleague and academic guide for so many years I cannot remember all his contributions to my education. He has supported me thorough a BSc, MSc and a PhD, making me forever thankful.

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Finally, this research was not attainable without the forensic students and practitioners who participated in the surveys. I hope my work has benefit to the forensic science community.

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“You cannot hope to build a better world without improving the individuals. To that end, each of us must work for our own improvement, and at the same time share a general responsibility for all humanity, our particular duty being to aid those to whom we think we can be most useful.”

- Marie Curie, 1923

Chapter 1: General Introduction

Forensic Epistemology

Forensic Science is experiencing new scrutiny with wide-ranging implications, leading to a potential paradigm shift in the field. This thesis is part of the movement toward that paradigm shift. To improve knowledge and reduce error rates, this thesis posits that forensic science must move from an experiential-based to an evidence-based platform that is founded in empirical data and requires critical thinking and complex analytical skills. Nevertheless, this transition is challenging because the final product of a forensic investigation is associated with law enforcement, lawyers and the courts in a system where practitioners may not have the background skills, funding or time to conduct research (Houck, 2015). The forensic science professional can also be required to answer case-specific research questions pertinent to an investigation and the courts. Researching a case-specific question involves answering a research question from a specific event that occurred in the past (Linacre, 2013; Milliet, Delemont, Sapin, & Margot, 2015; Mitchell, Walker, & Monahan, 2011; Monahan, Walker, & Mitchell, 2009; Ulriksen & Dadalauri, 2014). This type of research can present validity challenges, such as time limits, limited sample sets, uncontrolled variables, contextual bias and other unknowns leading to justification of assumptions. All of these complications make the selection of research methods more complex and problematic (Dror, 2014; Kueffer, 2006; Kukucka, Kassin, Zapf, & Dror, 2017; Mavridis & Aitken, 2009; van den Eeden, de Poot, & van Koppen, 2016). As a result, some questions for the forensic community are emerging: i) What is the epistemic status of forensic science?; ii) Do knowledge gaps exist for forensic practitioners?; and (iii) if there are knowledge gaps how can these be narrowed or closed?

This thesis is organized into four broad phases that explore these questions. First, I have tested forensic practitioner reasoning skills and analyzed these data to learn about possible gaps in knowledge and analytic processes. Second, I have investigated case-specific research data types and practitioner research design knowledge by surveying forensic practitioners within three pattern interpretation disciplines. Third, I have co-authored a textbook on the application of the scientific method in forensic science which involved extensive secondary research and builds on phases one and two to offer a practical pathway forward in closing identified gaps. Finally, I have explored evidence in current literature focused on supporting pedagogic and research strategies that can help increase the epistemic status of forensic science.

The chapters within this dissertation are independent investigations yet tie together to form a contribution to the epistemic status of forensic science. It is important to be clear about key terms that will be applied in this thesis: Epistemology is the study of knowledge and can be broken into four sources; intuitive, authoritative, logical and empirical (Bhatta, 2013; Kivunja & Kuyini, 2017). Forensic science is defined as the “application of science to the law” and this is particularly relevant to my epistemological research ("AAFS," 2018). Especially important, to apply science, a forensic practitioner requires domain knowledge in the forensic science profession, logical inference and the ability to make evidence-based decisions which must be measured against intuitive and authoritative knowledge (Andersen & Hepburn, 2016; Gauch, 2003).

In court, the forensic practitioner is attempting to justify that a belief (scientific conclusion) is true and not just mere luck (Zalta, 2018). Above all, this requires the production of evidence and logic that explains the context of that evidence. As an example; a bloodstain pattern analyst who has no scientific education observes a pattern at a crime scene. They produce a categoric conclusion based on authority (experience making or seeing patterns) that the pattern is an impact pattern. Conversely, a second analyst who is educated in scientific concepts develops a hypothesis that the pattern could be an impact pattern but also develops an alternative hypothesis that it could be satellite spatter from a drip pattern (another mechanism). To falsify the original hypothesis, this analyst completes a trajectory analysis (which is an accepted method within the scientific community) producing evidence validating that the pattern was indeed created from an impact event. The second analyst used scientific reasoning (logic), quantitative data and empirical evidence to support an evidence-based conclusion. This knowledge played a significant role in developing a scientifically justifiable conclusion that was not based on intuition or experience (authority) alone.

Most scholars support the notion that a belief can be justified by the production of evidence, but physical evidence alone is insufficient to form a conclusion in forensic analysis. Importantly, logic, research, perception, introspection, memory, and rational intuition should be used in deciding the degree of validity of the evidence (Zalta, 2018). In my research I have evaluated the use of reasoning by practitioners in the disciplines of crime scene investigations (CSI) and bloodstain pattern analysis (BPA). I have also explored the use of research methods (data types) in friction ridge, footwear and bloodstain pattern analysis. The results support the use of logic and empirical knowledge in these forensic science disciplines and at the same time rejects decisions based merely on intuition and authority.

Reasoning at the Crime Scene and Beyond

The science that is being applied to assist the judicial system, in principle, must be researched and validated to provide reliable data (Mnookin, 2010). However, recent assessments of forensic science by the scientific and law communities have identified a need for a paradigm shift to more science in forensic science (Evett, Berger, Buckleton, Champod, & Jackson, 2017; Goudge, 2008; Guarnera, Murrie, & Boccaccini, 2017; NAS, 2009; PCAST, 2016; Pollanen, Bowes, VanLaerhoven, & Wallace, 2013). This shift began in the mid 2000's when a lack of scientific rigour was identified within certain forensic fields (Cavender & Deutsch, 2007; Saks & Koehler, 2005). In addition to these assessments, publicized errors have accelerated this call for a paradigm and have resulted in a societal lack of confidence in forensic science overall. One notable example of publicized errors was the unlawful arrest of an American, Brandon Mayfield, in May 2004 by the Federal Bureau of Investigations (FBI) for the bombing attack of a commuter train in Madrid, Spain. This arrest was based solely on a mistaken fingerprint identification. The fingerprint impression was found on a bag of detonators associated with the attack and was eventually attributed by the Spanish National Police to an

Algerian (Justice, 2006; Tangen, 2013). At the time, Brandon Mayfield spent two weeks in jail because of this error. These types of events and assessments increase concern surrounding the recognition of potential risks within the existing crime scene expert (CSE) system ("Innocence Canada," 2018; "Innocence Project," 2018).

Beyond the high-level concerns marked by forensic errors, the consequences for the justice system resulting from inadequate scientific rigour in forensic investigations are even more concerning. Equally important, the CSI professional is the first point of contact with evidence, and in most cases this evidence is the foundation of ensuing forensic science inquiries. Therefore, the decision-making processes used at the crime scene can set the stage, not just for the subsequent forensic investigation but also for the complete judiciary process. Crime scene investigators are key to the outcome of a case as they may make choices on the relevance of evidence at a scene, the appropriate collection methods of evidence, the control of bias and the analyses of reconstruction events (Houck, Crispino, & McAdam, 2017; Ludwig, Fraser, & Williams, 2012; Saldivar, 2017).

The technical knowledge of crime scene evidence collection in itself is daunting, as specified in the National Institute of Justice publication *Crime Scene Investigation: A Guide for Law Enforcement* (NIJ, 2013). In this guide, the authors provide a list of 15 areas requiring expertise, including ignitable liquids, bodily fluids, sexual assault evidence, bombs and explosives, documents, firearms, ammunition, tool marks, trace evidence, footwear and tire impressions, motor vehicle, electronic and digital evidence and fingerprints. Julian et al. (Julian, Kelty, & Robertson, 2012) researched the critical issues at the crime scene and suggested three interrelated themes that determine reliable forensic crime scene processing by CSI personnel; recognition of a crime scene, identifying expertise and control of a complex scene.

As an example of how these three themes become important, we can consider how a single piece of evidence, such as a highly probative deoxyribonucleic acid (DNA) sample, could help to convict or exonerate a person. If this DNA sample was missed and not collected at the scene because of poor CSI reasoning skills, the result could be that an individual charged for the offence is wrongly convicted of an offence that they did not commit (Type I error, a false positive finding) or the guilty individual is not located for the offence and remains a danger within society (Type II error, a false negative finding). The combination of critical assessments, forensic errors and importance of reliable forensic crime scene processing provide wide-ranging evidence of the risks to the justice system.

A second group of specialists, closely related to the CSI group, are bloodstain pattern analysts (BPAs). Due to the nature of their work BPAs not only attend crimes scenes that contain bloodstain patterns, but they provide complex interpretations and court opinions on this evidence (James, Kish, & Sutton, 2005; Peschel, Kunz, Rothschild, & Mützel, 2011). Therefore, it is well established that BPAs are required to use formal reasoning skills to successfully complete their work (Latham, 2011a, 2011b; Taylor & Osborne, 2018).

This becomes more critical when considering that: (i) the interpretation of bloodstains has a high degree of subjectivity; and, (ii) the environment is information rich, making the analyses vulnerable to cognitive bias (Charman, Kavetski, & Mueller, 2017; Dror, Morgan, Rando, & Nakhaeizadeh, 2017; Kukucka et al., 2017; Oliver, 2018; Osborne, Taylor, & Zajac, 2016; Osborne & Taylor, 2018). These two issues alone make it important for BPAs to have knowledge in science and hypothetico-deductive reasoning. Zajac et al. (Zajac, Osborne, Singley, & Taylor, 2015) have suggested that awareness, training, objective methods, peer review and testing multiple hypotheses are ways of minimizing the risks of contextual bias in bloodstain pattern analysis. To employ these tasks, a BPA must be scientifically educated and practice the scientific method.

Given the necessity for change in forensic science and the CSE, the research of this thesis provides possible solutions to some of these challenges, based on a four-phase project. Chapter 2 (which reports on phase 1) explores the use of reasoning by CSE professionals. Chapter 3 (which reports on phase 2) examines how case-specific research is conducted within the pattern interpretation disciplines. These research phases provided a window into the thinking of practitioners and helped to determine where there were areas for improvement related to CSE professionals' reasoning skills and case-specific contexts in three disciplines.

Chapter 4 of this dissertation takes advantage of the findings in phases one and two in order to design a textbook that responds to CSE needs. The textbook is entitled, *The Scientific Method in Forensic Science: A Canadian Handbook* and is in publication with Canadian Scholars Press Inc. In addition, information from extensive literature reviews on scientific philosophy, research design, critical thought, problem solving, statistics, ethics, bias and communication skills - and how these topics relate to forensic science - have been included. The book will be published in June 2020, and chapter 4 of this dissertation is a reprint of the *Preface* of the textbook.

The primary studies of this thesis suggest that there is a knowledge gap for some forensic practitioners in formal reasoning and case-specific research design. Combining these results with a literature review, the fourth phase (Chapter 5) offers evidence supporting pedagogic and research strategies that can help increase the epistemic status of forensic science.

The following chapters provide evidence supporting the novelty of each research phase, the methodologies and the significant contribution of my research to increase scientific rigour within forensic science.

References

AAFS. (2018). Retrieved from https://www.aafs.org/about-aafs/

Andersen, H., & Hepburn, B. (2016). Scientific Method. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Summer 2016 ed.).

Bhatta, B. (2013). Research methods in remote sensing. In. Dordrecht: Springer.

Cavender, G., & Deutsch, S. K. (2007). CSI and moral authority: The police and science. *Crime, Media, Culture, 3*(1), 67-81. doi:doi:10.1177/1741659007074449

Charman, S. D., Kavetski, M., & Mueller, D. H. (2017). Cognitive Bias in the Legal System: Police Officers Evaluate Ambiguous Evidence in a Belief-Consistent Manner. *Journal of Applied Research in Memory and Cognition, 6*(2), 193-202. doi:10.1016/j.jarmac.2017.02.001

Dror, I. E. (2014). Practical Solutions to Cognitive and Human Factor Challenges in Forensic Science. *Forensic Science Policy & Management: An International Journal, 4*(3-4), 105-113. doi:10.1080/19409044.2014.901437

Dror, I. E., Morgan, R. M., Rando, C., & Nakhaeizadeh, S. (2017). Letter to the Editor - The Bias Snowball and the Bias Cascade Effects: Two Distinct Biases that May Impact Forensic Decision Making. *Journal of Forensic Sciences, 62*(3), 832-833. doi:10.1111/1556-4029.13496

Evett, I. W., Berger, C., Buckleton, J., Champod, C., & Jackson, G. (2017). Finding the way forward for forensic science in the US—A commentary on the PCAST report. *Forensic Science International, 278*, 16-23.

Gauch, H. G. (2003). *Scientific Method in Practice*. New York, USA: Cambridge University Press.

Goudge, S. T. (2008). *Inquiry into Pediatric Forensic Pathology in Ontario* (Q. s. P. o. Ontario Ed.). Toronto.

Guarnera, L. A., Murrie, D. C., & Boccaccini, M. T. (2017). Why do forensic experts disagree? Sources of unreliability and bias in forensic psychology evaluations. *Translational Issues in Psychological Science, 3*(2), 143.

Houck, M. (2015). *Professional Issues in Forensic Science*. San Diego, CA: Elsevier.

Houck, M. M., Crispino, F., & McAdam, T. (2017). *The science of crime scenes*: Academic Press.

Innocence Canada. (2018). Retrieved from http://www.innocencecanada.com/

Innocence Project. (2018). Retrieved from https://www.innocenceproject.org/about/

James, S. H., Kish, P. E., & Sutton, T. P. (2005). *Principles of bloodstain pattern analysis: theory and practice*: CRC Press.

Julian, R., Kelty, S., & Robertson, J. (2012). "Get it right the first time" : critical issues at the crime scene. *Current Issues in Criminal Justice, 24*(1), 25-37.

Justice, U. S. O. o. (2006). *A Review of the FBI's Handling of the Brandon Mayfield Case: Unclassified Executive Summary*: U.S. Department of Justice.

Kivunja, C., & Kuyini, A. B. (2017). Understanding and Applying Research Paradigms in Educational Contexts. *International Journal of Higher Education, 6*(5). doi:10.5430/ijhe.v6n5p26

Kueffer, C. (2006). Integrative Ecological Research: Case-Specific Validation of Ecological Knowledge for Environmental Problem Solving. *GAIA - Ecological Perspectives for Science and Society, 15*(2), 115-120.

Kukucka, J., Kassin, S. M., Zapf, P. A., & Dror, I. E. (2017). Cognitive Bias and Blindness: A Global Survey of Forensic Science Examiners. *Journal of Applied Research in Memory and Cognition, 6*(4), 452-459. doi:https://doi.org/10.1016/j.jarmac.2017.09.001

Latham, H. M. (2011a). Reasoning, the Scientific Method, and Bloodstain Pattern Analysis – Assuring that the Questions are being Answered Correctly. *Journal of Forensic Identification, 61*(4), 333-340.

Latham, H. M. (2011b). Using and Articulating the Scientific Method in Bloodstain Pattern Analysis. *Journal of Forensic Identification, 61*(5), 487-494.

Linacre, A. (2013). Towards a research culture in the forensic sciences. *Australian Journal of Forensic Sciences, 45*(4), 381-388. doi:10.1080/00450618.2012.738246

Ludwig, A., Fraser, J., & Williams, R. (2012). Crime Scene Examiners and Volume Crime Investigations: An Empirical Study of Perception and Practice. *Forensic Science Policy & Management: An International Journal, 3*(2), 53-61. doi:10.1080/19409044.2012.728680

Mavridis, D., & Aitken, C. G. (2009). Sample size determination for categorical responses. *Journal of Forensic Sciences, 54*(1), 135-151. doi:10.1111/j.1556-4029.2008.00920.x

Milliet, Q., Delemont, O., Sapin, E., & Margot, P. (2015). A methodology to event reconstruction from trace images. *Science & Justice, 55*(2), 107-117. doi:10.1016/j.scijus.2015.02.001

Mitchell, G., Walker, L., & Monahan, J. (2011). Beyond Context: Social Facts as Case-Specific Evidence. . *Emory Law Journal, 60*(5), 1111-1154.

Mnookin, J. L. (2010). The Courts, The NAS, and the Future. *Brooklyn Law Review, 75*(4), 1-67.

Monahan, J., Walker, L., & Mitchell, G. (2009). The limits of social framework evidence. *Law, Probability and Risk, 8*, 307−321. doi:10.1093/lpr/mgp020

NAS. (2009). *Strengthening Forensic Science in the United States: A Path Forward* (T. N. A. Press Ed.). Washington: National Academy of Sciences.

NIJ. (2013). *Crime Scene Investigation: A Guide For Law Enforcement*. National Forensic Science Technology Center.

Oliver, W. R. (2018). Comment on Kukucka, Kassin, Zapf, and Dror (2017), “Cognitive Bias and Blindness: A Global Survey of Forensic Science Examiners”. *Journal of Applied Research in Memory and Cognition, 7*(1). doi:10.1016/j.jarmac.2018.01.008

Osborne, N. K., Taylor, M. C., & Zajac, R. (2016). Exploring the role of contextual information in bloodstain pattern analysis: A qualitative approach. *Forensic Science International, 260*, 1-8.

Osborne, N. K. P., & Taylor, M. C. (2018). Contextual information management: An example of independent-checking in the review of laboratory-based bloodstain pattern analysis. *Science & Justice*. doi:10.1016/j.scijus.2018.01.001

PCAST. (2016). *Report to the President Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature - Comparison Methods (Executive Summary)*. USA.

Peschel, O., Kunz, S., Rothschild, M., & Mützel, E. (2011). Blood stain pattern analysis. *Forensic science, medicine, and pathology, 7*(3), 257-270.

Pollanen, M. S., Bowes, M. J., VanLaerhoven, S. L., & Wallace, J. (2013). *Forensic Science in Canada: A Report of Multidisciplinary Discussion*. Toronto: Centre for Forensic Science and Medicine, University of Toronto.

Saks, M. J., & Koehler, J. J. (2005). The Coming Paradigm Shift in Forensic Identification Science. *Science, 309*.

Saldivar, A. (2017). Minimum Education Requirements for Crime Scene Investigators. *Themis: Research Journal of Justice Studies and Forensic Science, 5*(1), 10.

Tangen, J. M. (2013). Identification personified. *Australian Journal of Forensic Sciences, 45*(3), 315-322. doi:10.1080/00450618.2013.782339

Taylor, M. C., & Osborne, N. K. P. (2018). Letter to the Editor-A Contribution to Contextual Information Management in Bloodstain Pattern Analysis: Preliminary Idea for a Two-Step Method of Analysis. *Journal of Forensic Sciences, 63*(1), 341. doi:10.1111/1556-4029.13705

Ulriksen, M. S., & Dadalauri, N. (2014). Single case studies and theory-testing: the knots and dots of the process-tracing method. *International Journal of Social Research Methodology, 19*(2), 223-239. doi:10.1080/13645579.2014.979718

van den Eeden, C. A. J., de Poot, C. J., & van Koppen, P. J. (2016). Forensic expectations: Investigating a crime scene with prior information. *Science & Justice, 56*(6), 475-481. doi:https://doi.org/10.1016/j.scijus.2016.08.003

Zajac, R., Osborne, N. K. P., Singley, L., & Taylor, M. C. (2015). Contextual Bias: What Bloodstain Pattern Analysts Need to Know. *Journal of Bloodstain Pattern Analysts, 31*(2), 7-16.

Zalta, E. N. (2018). Epistemology. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Vol. 21). Stanford, CA: Stanford Encyclopedia of Philosophy.

Chapter 2: Forensic Epistemology: Testing the reasoning skills of crime scene experts

A version of this chapter has been published.

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Contributions: PW and CB participated in the design of the study and helped in editing the draft manuscript. MI designed the study, distributed the surveys, completed the statistical analysis, interpreted the results and drafted the manuscript. All authors read and approved the final manuscript.

Abstract

In recent years, crime scene analysis is transitioning from being a technical discipline to a scientific process. This progression is shifting the forensic practitioner examining crime scenes into a deeper level of scientific reasoning. This study evaluates the use of reasoning by practitioners in the disciplines of crime scene investigations and bloodstain pattern analysis. A well-established classroom test of scientific reasoning (CTSR) was distributed online to active crime scene investigators (CSI) and bloodstain pattern analysts (BPA) ($n = 213$) using Qualtrics software. The survey provides quantitative data on the reasoning ability of the participating practitioners along with demographic information on education, employment status (specifically, police or civilian), and work experience. Linear regression analyses indicate that there is a significant difference between CTSR scores and education level. The higher educated practitioner (graduate level) performed better on the reasoning test. No significant differences were found between the test scores and the years of experience, even when sectioned into 5-year increments of 5 to 25+ years of experience. Similarly, there was no difference between the test scores and employment status for the CSI group and within the BPA group. This information suggests that the level of education plays the most important role in the development and use of reasoning skills; whereas experience and employment status are not as influential. The test scores were also mapped to Piaget's categories; concrete operational; transitional; and formal operational reasoners, with 69.5% of CSI and 77% of BPA scoring as formal operational reasoners. We recommend that a CTSR be used for testing current and future (tertiary forensic students) practitioners for evaluating reasoning skills and identifying scientific learning gaps. This study also supports further research into forensic epistemology and pedagogy, to deepen our knowledge of science in forensic science.

Key words: forensic epistemology, crime scene investigators, bloodstain pattern analysts, reasoning, scientific method, education

Introduction

This study evaluates the use of reasoning by crime scene experts (CSE). We studied two groups of forensic practitioners: (i) crime scene investigators (CSI); and, (ii) bloodstain pattern analysts (BPA). Depending on the scene task, the level of reasoning varies for the CSI professional from basic reasoning to hypothetico-deductive reasoning (scientific method). Recent research suggests a movement within forensic science from a purely technical to a more scientific approach (Crispino, 2008; Crispino, Ribaux, Houck, & Margot, 2011; de Leeuwe, 2017; Harrison, 2006; Horswell & Edwards, 1997; Jamieson, 2004; Julian, Kelty, & Robertson, 2012; Ludwig, Fraser, & Williams, 2012; Makin, 2012; Milliet, Delémont, & Margot, 2014; Perepechina, 2017; Saldivar, 2017; Shaler, 2012). Much of this research indicates that the CSE professional should use the scientific method when examining a scene. To date, we could find no published articles on comprehensive testing of active crime scene experts that focus on assessing their level of reasoning. What is interesting to note, however, is that there has been a growing body of research, particularly since 2000, on reasoning and higher order thinking (see Baber, Smith, Cross, Hunter & McMaster, 2006; Kelty, Julian & Robertson, 2011; Resnikoff, Ribauz, Rossy, Baylon & Jendly, 2016; Houck, Crispino & McAdam, 2017 as examples) (Baber, Smith, Cross, Hunter, & McMaster, 2006; Houck, Crispino, & McAdam, 2017; Kelty, Julian, & Robertson, 2011; Resnikoff, Ribaux, Baylon, Jendly, & Rossy, 2015). This study aims to build upon this burgeoning area of study. This is important because use of the scientific method inherently involves formal operational reasoning, which is described as thinking in the abstract and being able to test multiple hypotheses (Bao, Xiao, Koenig, & Han, 2018; Coletta & Phillips, 2005; Lawson, 1985; Lawson, 2013; Teig & Scherer, 2016). In a simplified but relatively consistent organization of levels of reasoning, Piaget (Piaget, 1932), and subsequently other theorists/researchers identified three categories; concrete operational reasoning (the beginning of logical thought), transitional operational reasoning (a stage between concrete and formal), and formal operational reasoning (understanding abstract concepts and hypotheses testing) (Lawson, Alkhoury, Benford, Clark, & Falconer, 2000; Moore & Rubbo, 2012). These levels or categories of reasoning offer a useful structure for considering the types of reasoning that may be used in crime scene investigations. Extensive studies on the psychometric skills required by CSI, such as Kelty et al. (Kelty, 2011; Kelty & Gordon, 2012; Kelty et al., 2011), support our research conclusions, however the sample set in these studies was small (n=18) and all participants were peer nominated, high performing CSI. The researchers were interested in determining how to recruit high performing CSI, not assessing a large sample set of random experts. Our research examines a large random sample set addressing reasoning and higher order thinking within two groups, CSI and BPA.

Due to the nature of their work BPA do not just examine blood letting scenes; they offer complex interpretations and court opinions on this evidence (James, Kish, & Sutton, 2005; Peschel, Kunz, Rothschild, & Mützel, 2011). The analysis involved in these interpretations and testimonials require formal reasoning skills (Latham, 2011a, 2011b; Taylor & Osborne, 2018). Yet, there is no known research that examines the level of reasoning skills and education that might be required by someone examining and reporting on blood letting events.

Given the lack of research on the skills and education of analysts, this study attempts to make more explicit connections between formal reasoning, education and crime scene investigation and bloodstain pattern analysis work. We selected education level, employment status and years of experience as the demographics for this research because these features have been the subject of great debate within the disciplines of CSI and BPA. Historically, forensic police practitioners have relied on experience as being more important than science and metrological methods or education, and the CSI and BPA disciplines have been dominated by policing institutions (Baber et al., 2006; Capsambelis, 2002; CPC, 2018; DOJ, 2004; Illes, Dalley, Kish, Taylor, & Yamashita, 2010; PCAST, 2016; Saldivar, 2017). The CSI and BPA disciplines, for the most part, are controlled within the policing environment, creating a culture were police personnel are the dominant employees with civilian crime scene expert employment and task assignment being limited. Researching relationships between reasoning skills and education, employment status and years of experience can provide evidence to support hiring practises. Further, identifying optimal skill sets and education levels may help to mitigate risk in the justice system. Given all of the above, we test the following three hypotheses:

First, there is a relationship between greater education and the ability to apply formal reasoning to crime scene evidence that results in more accurate analyses.

Second, crime scene expert experience plays a less significant role on the ability to apply formal reasoning to crime scene evidence.

Third, the employment status of a crime scene expert is independent of one's reasoning ability.

Selection of Reasoning Skills Assessment Tool

In this study, we assess the reasoning skills of active CSE by administering a well-established reasoning test developed by Lawson et al. (Lawson, 2003; Lawson, 1978; Lawson, 2004; Lawson, 2005; Lawson et al., 2000; Lawson, Baker, Didonato, Verdi, & Johnson, 1993; Lawson & Daniel, 2011; Lawson et al., 1991), the Classroom Test of Scientific Reasoning (CTSR). This test replaces an old and labour intensive, but well-researched system of inquiry, that required experienced interviewers as well as specialized materials and equipment and that was not practical for 'typical' classroom use (Lawson, 1978). Efforts to test and develop reasoning skills in higher education is more recently supported by Fuller et al. (Fuller, Campbell, Dykstra, & Stevens, 2009). In this book, the authors provide theoretical framing related to how higher education students reason and they review the progress of reasoning research since the 1970s. This information is pertinent to our research because the most advanced stage of reasoning defined by Piaget (Piaget, 1932), and subsequently many others (Bao et al., 2009; Bao et al., 2018; Coletta, 2017; Coletta & Phillips, 2005; Lawson, 1985; Moore, 2012; Teig & Scherer, 2016), that is - formal operational reasoning – is in focus for this study.

The CTSR remains well-used today with reputable organizations employing the test in 2019, some of which include Physport (PhysPort), WebAssign (WebAssign), the University of Toronto (Harrison, 2015) and iSTAR Assessment, which is funded by the US National Science Foundation, the National Institute of Health and Ohio State University ("iStar Assessment," 2010). These organizations are currently using the CTSR to test reasoning at the university, college, high school and middle school levels.

As detailed above, the literature indicates that CSE should use formal reasoning in their work, however we know of no studies to date which have tested the formal reasoning skills of individuals employed to examine a crime scene. The results generated from this research provide novel findings on the relationships between the CTSR test scores and education level, employment status and years of experience for crime scene experts. This information supports the investigation of deeper epistemic questions in forensic science and exploring methods for more formally characterizing the complexity of, and predictors of, CSE reasoning.

Methods

Within this study, we incorporate the CTSR method used by Lawson et al. (Lawson, 1978; Lawson, 2004; Lawson, 2005; Lawson et al., 2000; Lawson et al., 1991) to test the reasoning process of research participants. The CTSR is a formal reasoning survey with 24 multiple-choice questions paired to assess 12 inter-related formal reasoning constructs to test a participants' ability to apply formal reasoning to solve problems

(Lawson, 2005). These test questions and the added demographic questions can be found in Appendix A.

Validity of the CTSR has been well documented in previous research studies (Bao et al., 2009; Bao et al., 2018; Coletta, 2017; Coletta & Phillips, 2005; Ding, Wei, & Liu, 2016; Lawson et al., 2000; Moore, 2012; Opitz, Heene, & Fischer, 2017; Zimmerman, 2000) and operates as one of the seminal tests at this time. Furthermore, we consulted with Dr. Lawson directly to determine the suitability of the survey for use on CSE. In fact, Dr. Lawson has researched similar practitioner-reasoning issues for medical clinical diagnostics (Lawson & Daniel, 2011). This application also supported the use of the full CTSR in our research as evidence-based analysis is a common practise to both disciplines (Carter, 2015; Cave & Molina, 2014; Greenhalgh, 2014; Hansen, 2014; Leake, 2007; Paciocco, 2009). In addition, Bao et al. (Bao et al., 2018) indicate that caution should be used when testing below upper year university levels. It was found that low test score can be correlated with low performing students and that there was a ceiling effect for the Lawson CTSR. Students beyond senior high school or early college have shown to perform well on the test. Therefore, the test has been considered an easy CTSR and the CSEs tested in our study should all be producing grades above 80% (Bao et al., 2018).

The Lawson CTRS does have its critics however we feel it is an appropriate test for testing the reasoning skills of CSE (Bao et al., 2018; Hanson, 2016; Pratt & Hacker, 1984). Bao et al. (Bao et al., 2018) provide the most current literature review and analysis of the Lawson CTRS, indicating that the test has good overall reliability but breaks down when the subskills are disaggregated for analysis. Nonetheless, the tool has been validated recently, and consistently for use in assessing overall formal reasoning (Coletta, 2017; Coletta & Phillips, 2005; Coletta, Phillips, & Steinert, 2007; Hacker, 1989; Lawson, 1978). As such, this study focuses on the overall results and formal reasoning skills.

The main objective of the study is to determine if and at what level crime scene investigators are using reasoning and to compare those data to the demographic questions. The resulting information revealed associations between the variables in the study, such as use of reasoning and education level. To acquire these data, we developed and distributed an online survey, once ethics approval had been granted by the Trent University Research Ethics Board (REB) for administration.

The complete questionnaire along with additional demographic questions was distributed electronically to CSI and BPA professionals using the Qualtrics software available from Trent University. The International Association of Identification (IAI) and the International Association of Bloodstain Analysts (IABPA) were solicited for approval to distribute a voluntary, anonymous electronic questionnaire to their members. The global membership of the IAI consists of active practitioners in the fields of forensic identification, investigation and scientific examination of physical events ("International Association for Identification," 2016). With membership registration, individuals provide information on their fields of expertise, thus a list of those members who are crime scene investigators is easily produced. The IAI forwarded the email addresses of 2927 active CSI members, providing a comprehensive population for random sampling. The global membership of the IABPA consists of "forensic experts specializing in the field of bloodstain pattern analysis" ("IABPA," 2018). The IABPA forwarded the email addresses of 1110 active BPA members, providing a comprehensive population for random sampling. Using a random sampling function within Microsoft Excel 2016, 2510 participants were contacted to participate. A robust random sample set was determined to be 76 participants (n=76) from each group, using power analysis within R (R, 2018).

Results and Discussion

The results of our research are separated into three clusters, with both CSI and BPA practitioner groups represented in each cluster. The first cluster of findings reports CTSR survey test means, medians and standard deviations, along with an assessment of types of reasoning used. In the second cluster of findings, linear regression analysis explains the relationship between variables. This analysis helped to investigate associations between the CTSR scores (dependent variable) and education level, employment status and years of experience (independent variables). Finally, we analyzed for interactions between the independent variables; education, employment status, and years of experience using three-way factorial ANOVA analysis and where needed, post hoc interaction testing within the variable.

CTSR Survey Test Scores and Reasoning Categories

The CSI (n = 116) and BPA (n = 97) practitioner test score means, medians and standard deviations provide a starting point for considering further study into the reasoning skills of these groups. The CTSR was scored using all 24 questions (12 scenarios with two-part question for each, resulting in 24 items for scoring). The examination of grades for this study offers insight into the CSE ability to reason, at what level, and suggests further research is required into the epistemic state of forensic science. The test employed within this study is reported to be an easy CTSR. Therefore, the CSE tested in our study should all be producing grades above 80% (Bao et al., 2009; Bao et al., 2018), making the mean scores too low at 66.8 for the CSI group and 72.9 for the BPA group (Table 2.1). The standard deviation for the CSE is approximate 19.5%. This is also a concern given the fact that the marks ranged from 16.7% to 100% (See Table 2.1). The floor of these marks is particularly low, with 30.5 % of the CSI and 23.2% of the BPA who were not using formal reasoning during the test.

Table 2.1 CTSR summary statistics for CSI and BPA

Group	n	Mean	Min	Max	SD	Median
CSI	116	66.8	16.7	100	19.6	70.8
BPA	97	72.9	25	100	19.4	75

The test scores also provide the level of reasoning by mapping them to Piaget's (Inhelder & Piaget, 1958; Piaget, 1932) long-standing categories: Concrete operational reasoners (early stage of logical thought) score below 25% on the whole test; transitional operational reasoners (a stage between concrete and formal) score between 25% and 58%; and formal operational reasoners (advanced stage of abstract conceptual reasoning and hypotheses testing) score above 58% (Lawson et al., 2000; Moore & Rubbo, 2012). The results of this mapping can be viewed in Figures 2.1 and

2.2. In the CSI group, 69.5% of participants were identified as formal reasoners and the BPA group was at 76.8%.

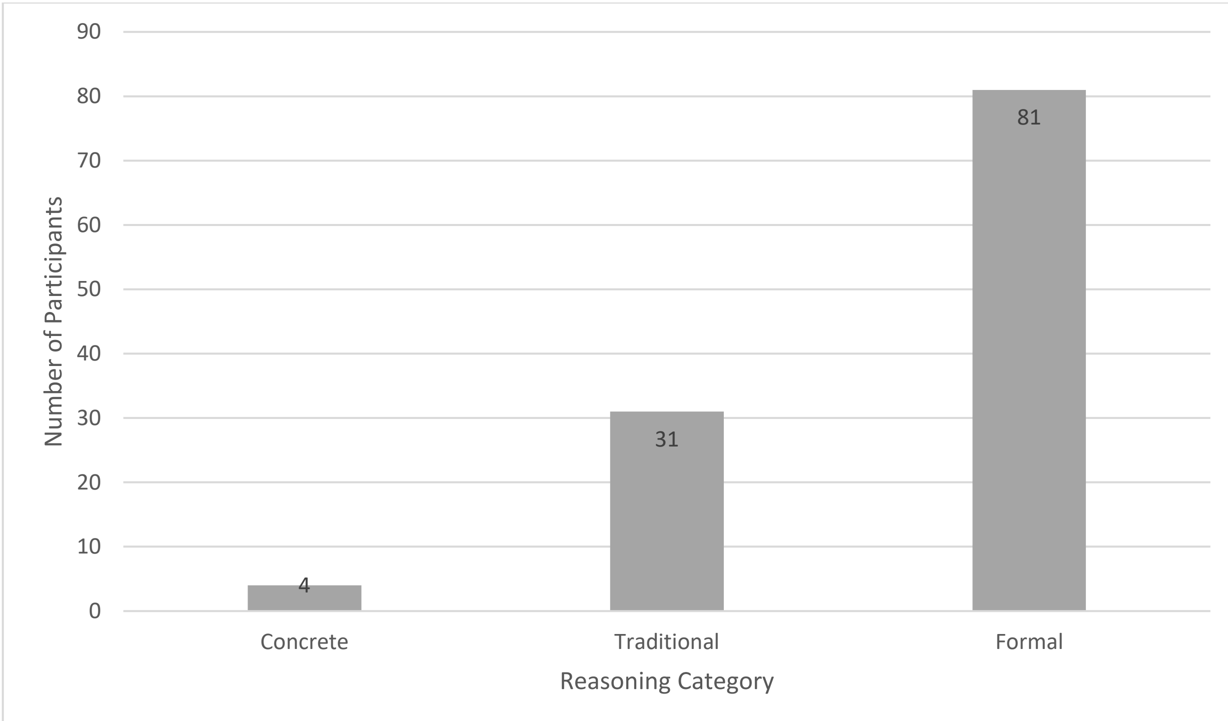

Figure 2.1 Reasoning categories of CSI participants (n=116)

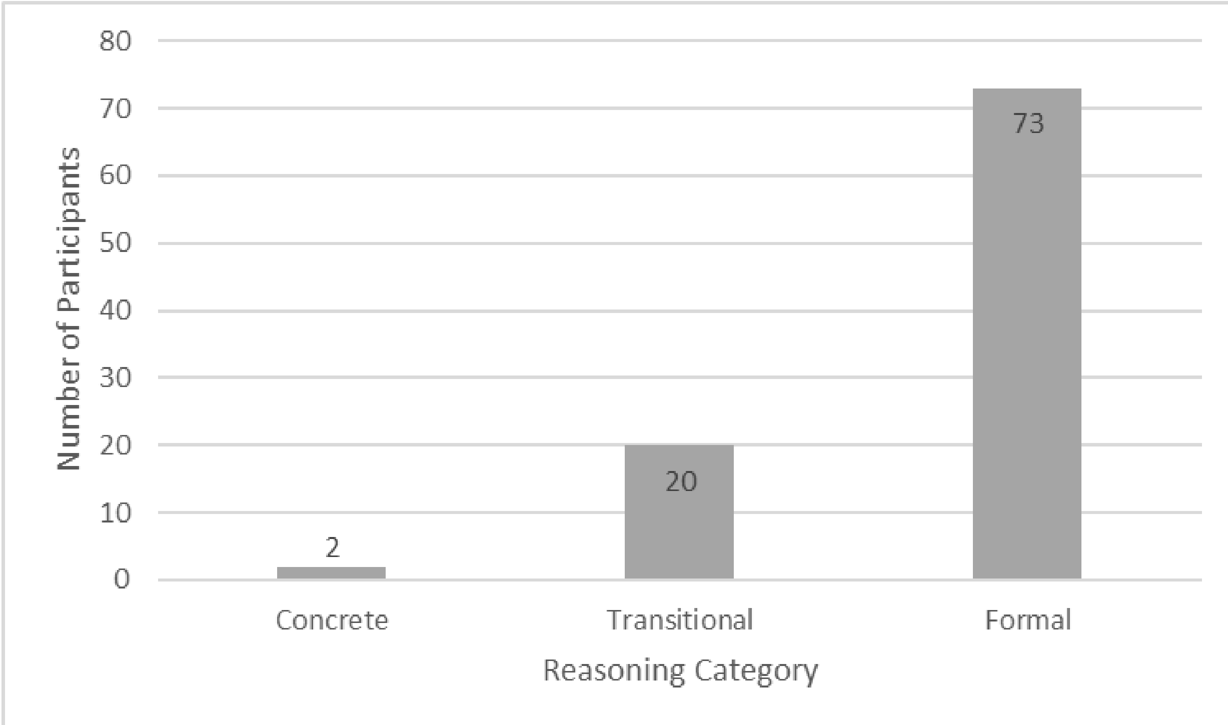

Figure 2.2 Reasoning categories of BPA participants

Table 2.2 depicts the percent of formal reasoning by education level. The result in Table 2.2 supports the attainability of the high scores by these groups, as 90.5 % of the graduate level participants are formal reasoners.

Table 2.2 Percent formal reasoners for CSI (n=116) and BPA (n=97) practitioners by education level

Group	College	Undergraduate	Graduate
CSI	48%	69%	88%
BPA	38%	76%	93%

The information on the grades and low numbers of formal reasoners suggests that there may be a lack of formal reasoning skills within the CSE groups. The following are the results of the statistical analyses used within this research to offer validation and contribute new knowledge on this issue.

Linear Regression Analysis

Linear regression analysis was used to determine if there was a relationship between variables; the CTSR test scores and the participant's education level, employment status (police or civilian) and years of experience for both groups.

Table 2.3 Linear regression analysis for CSI reasoning testing

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	68.410	5.635	12.141	<2e-16
Education (Undergrad)	6.976	4.576	1.525	0.1303
Education (Grad)	14.887	5.182	2.873	0.0049
Employment (Civilian)	-6.310	4.035	-1.564	0.1208
Years (6-10)	-8.688	4.739	-1.833	0.0696
Years (11-15)	-5.113	5.832	-0.877	0.3826
Years (16-20)	-9.644	6.660	-1.448	0.1505
Years (21-25)	-8.991	11.570	-0.777	0.4388
Years (25+)	-7.766	6.175	-1.258	0.2112

Residual standard error: 19.16 on 107 degrees of freedom

Multiple R-squared: 0.114, Adjusted R-squared: 0.04775

F-statistic: 1.721 on 8 and 107 DF, p-value: 0.1017

Table 2.4 Linear regression analysis for BPA reasoning testing

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	40.7071	2.2642	17.978	< 2e-16
Education (Undergrad)	25.7387	2.4721	10.412	< 2e-16
Education (Grad)	48.9047	2.4483	19.975	< 2e-16
Employment (Civilian)	2.9346	2.2070	1.330	0.18710
Years (6-10)	-0.9864	2.2621	-0.436	0.66388
Years (11-15)	0.4632	2.7264	0.170	0.86547
Years (16-20)	-3.1182	3.6337	-0.858	0.39317
Years (21-25)	-7.4456	3.9146	-1.902	0.06048
Years (25+)	-10.0823	3.6019	-2.799	0.00631

Residual standard error: 7.555 on 87 degrees of freedom

Multiple R-squared: 0.8613, Adjusted R-squared: 0.8485

F-statistic: 67.53 on 8 and 87 DF, p-value: < 2.2e-16

The p-values listed in Tables 2.3 and 2.4 as Pr(>|t|) have been interpreted using a significance level of p = 0.05 and illustrate that there was a statistically significant difference between the CTSR test scores for education levels. The higher educated practitioner (graduate level) performed better on the test for both groups. This linear regression indicates a relationship between the test scores and years of experience for CSI 6-10 years and BPA 25+ years groups. There was no relationship in employment status for both groups. The evidence from Table 2.2 and post hoc testing (see Tables 2.7-2.10) suggests that the level of education may be most important for the development and use of reasoning skills; whereas experience and employment status may not contribute to the use of reasoning skills. Figures 2.3 – 2.8 provide a set of boxplots that graphically represent those data.

When observing Figures 2.3 and 2.4 the boxplots support the significant difference in education level with a positive upsurge in the participants test scores as the level of education increases. As such, our hypothesis that there is a positive relationship between greater education and the ability to apply formal reasoning to crime scene evidence, resulting in more accurate analyses seem to be worthy of further research and review.

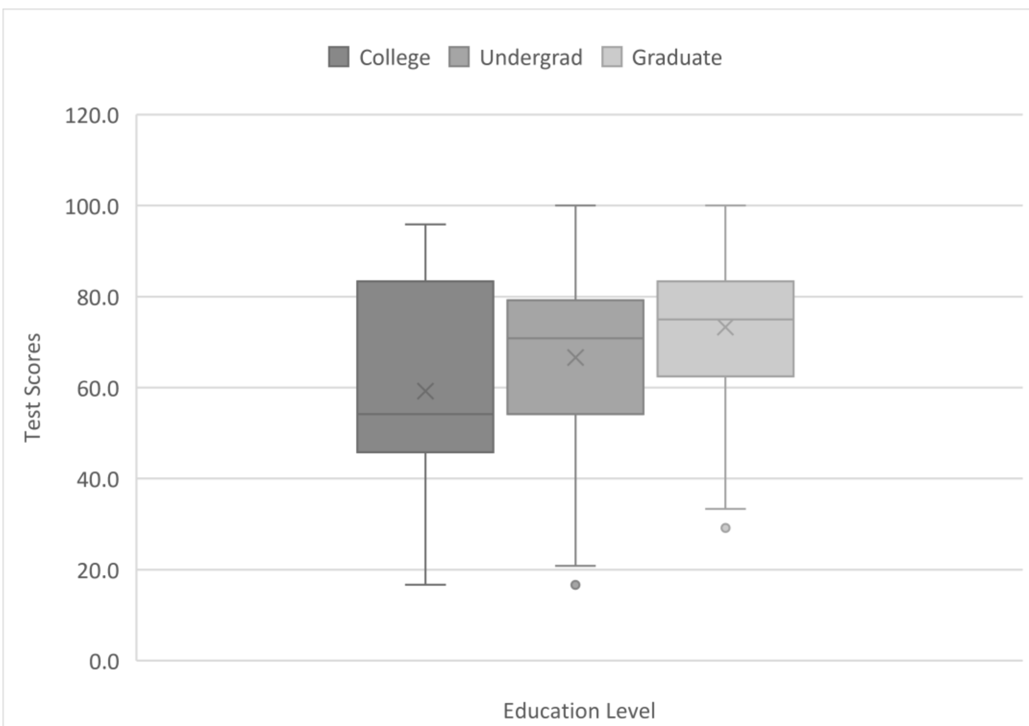

Figure 2.3 Boxplot of CSI CTRS scores and education level with sample sizes being: College - 27, Undergrad - 55, Graduate – 34

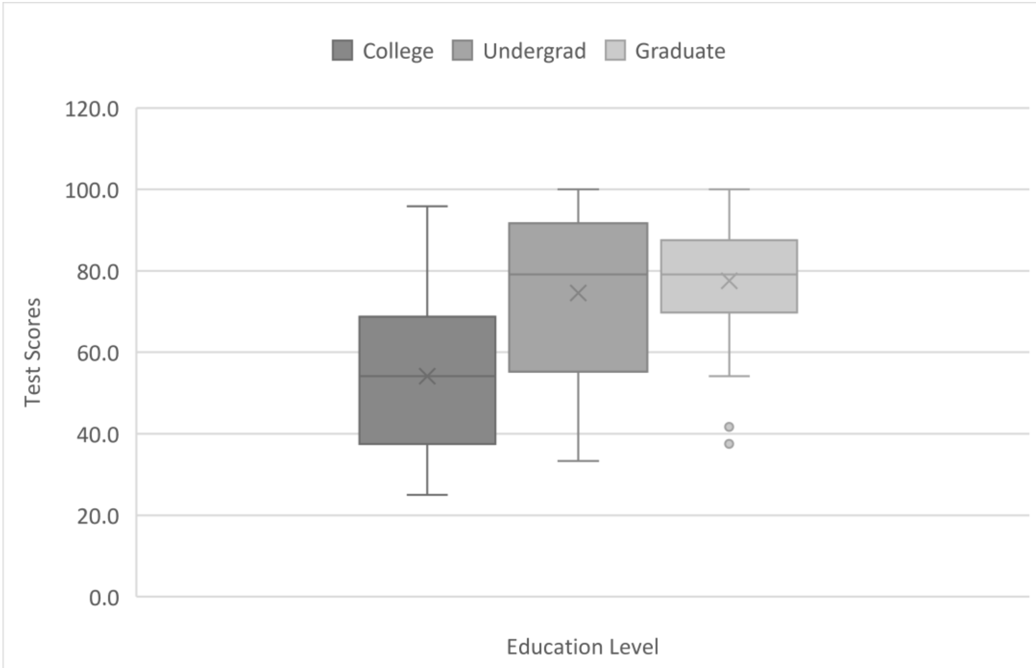

Figure 2.4 Boxplot of BPA CTRS scores and education level with sample sizes being: College - 13, Undergrad - 41, Graduate – 43

The results in Tables 2.3 and 2.4 on employment status are supported by the boxplots in Figure 2.5 and 2.6. The plots depict a consistent distribution, are comparatively tall, with the BPA police and civilian medians being very similar and the CSI police and civilian medians identical. These findings support our hypothesis that the employment status of a crime scene expert is not correlated to one's reasoning ability.

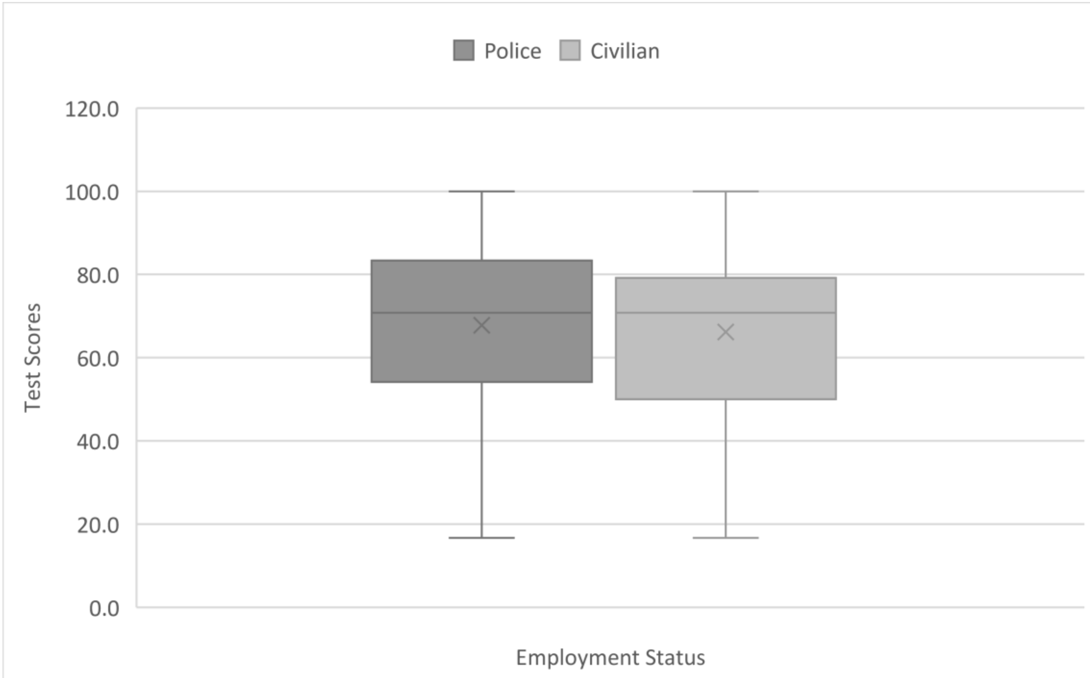

Figure 2.5 Boxplot of CSI CTRS scores and employment status with sample sizes being: Police - 49, Civilian – 67

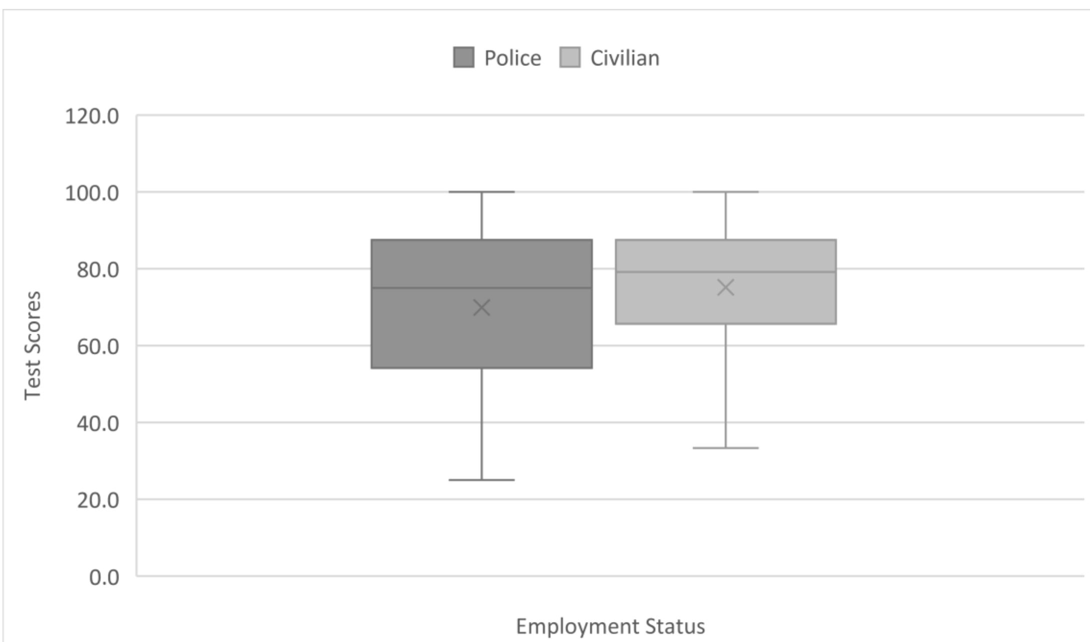

Figure 2.6 Boxplot of BPA CTRS scores and employment status with sample sizes being: Police – 42, Civilian – 55

The statistical analyses, specifically the post hoc testing (Tables 2.9 and 2.10), also reveal that there was no relationship between test scores and years of experience for both groups in this study. The box plots in Figure 2.7 and 2.8 support these results by depicting a consistent distribution with similar medians (other than the low median for CSI 6-10 years and BPA 25+ years groups where a post hoc test was performed, see Tables 2.9 and 2.10) and all plots are comparatively tall. These data suggest that the number of years that a crime scene expert has been in the field (experience level) play a relatively less significant role on the ability to apply formal reasoning to crime scene evidence than education level.

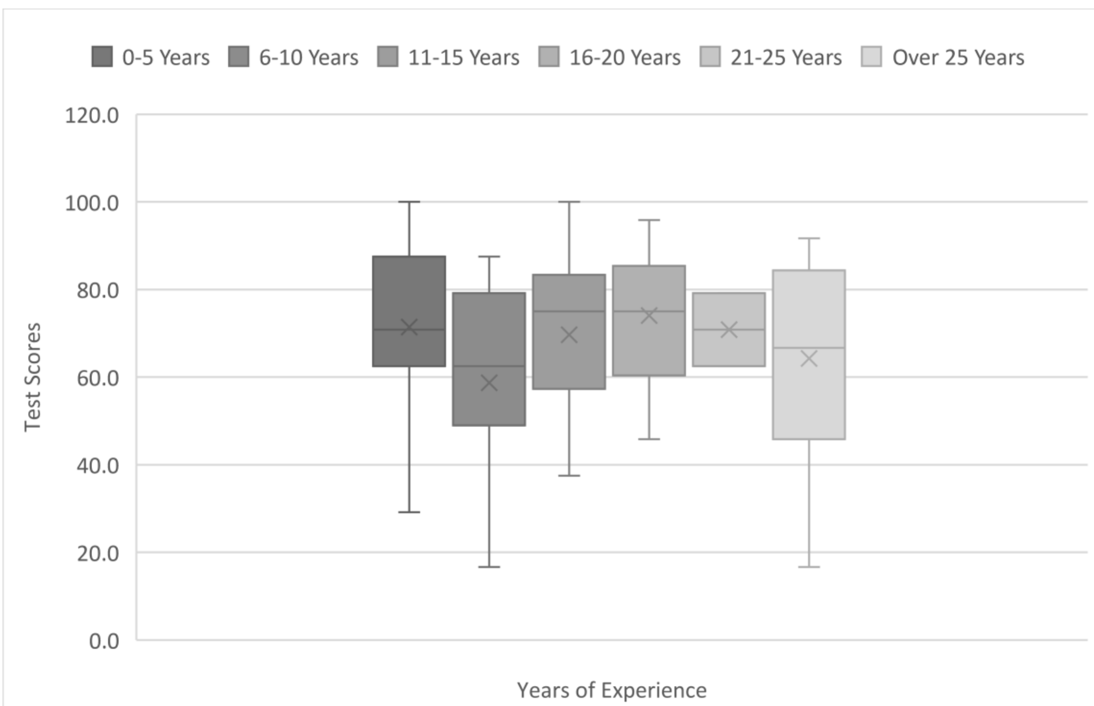

Figure 2.7 Boxplot of CSI CTRS scores and years of experience with sample sizes being: 0 to 5 - 34, 6 to 10 - 34, 11 to 15 - 18, 16 to 20 - 13, 21 to 25 - 3, over 25 – 14

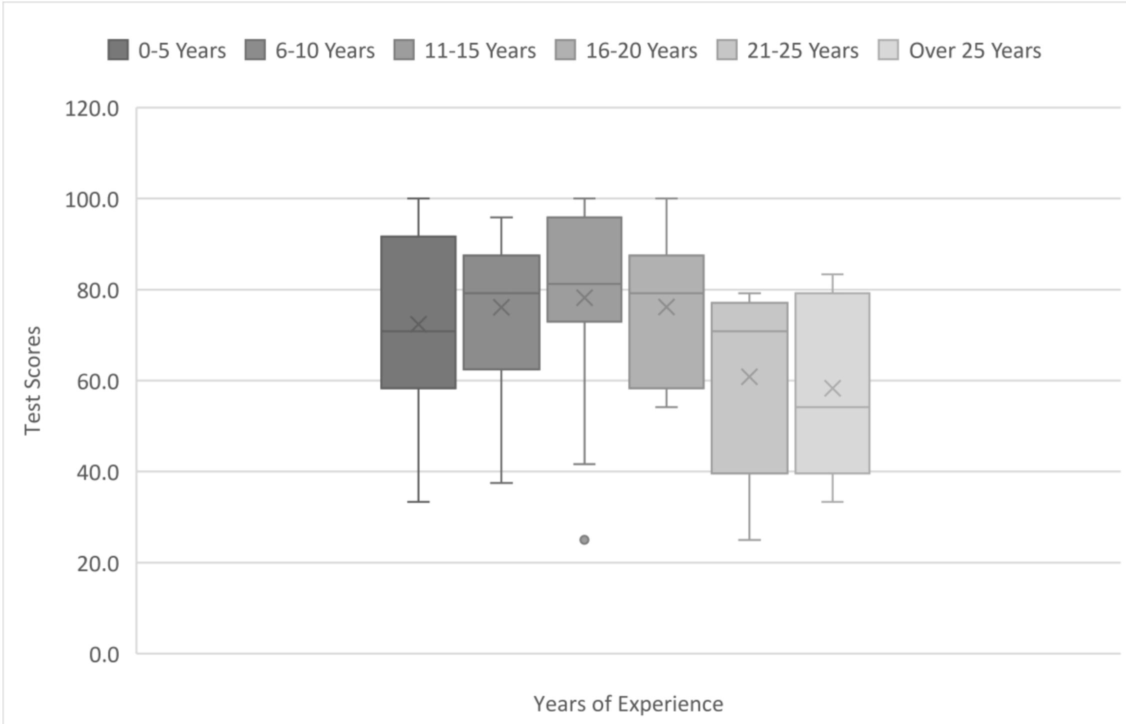

Figure 2.8 Boxplot of BPA CTRS scores and years of experience with sample sizes being: 0 to 5 - 36, 6 to 10 - 23, 11 to 15 - 18, 16 to 20 - 7, 21 to 25 - 5, over 25 - 8

ANOVA Interaction Analyses

The linear regression results have addressed the main question of this study: Are there any associations between the test scores and education level, employment status or years of experience, however it does not test interactions between the variables. A three-way factorial ANOVA analysis (Tables 2.5 and 2.8) identified a significant difference between the education levels for both the CSI and BPA groups. There is an interaction between education levels in both the CSI and BPA groups, and an indication of interaction among the CSI 6-10 years and BPA 25+ years groups. Therefore, post hoc tests were completed to understand which levels revealed an interaction.

Table 2.5 Summary of interactions between variables for CSI

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Education	2	2967	1483.5	4.504	0.0138
Employment	1	496	496.1	1.506	0.2231
Years	5	1589	317.8	0.965	0.4440
Education:Employment	2	482	241.2	0.732	0.4838
Education:Years	10	4788	478.8	1.453	0.1712
Employment:Years	4	3049	762.3	2.314	0.0638
Education:Employment:Yrs	5	2619	523.9	1.590	0.1714
Residuals	86	28328	329.4		

Table 2.6 Post hoc test interactions between education levels for CSI

Education Level	College	Undergraduate
Undergraduate	0.237	-
Graduate	0.014	0.248

Note: Tukey multiple comparisons of means 95% family-wise confidence level

Table 2.7 Post hoc test showing no interaction between years of experience for CSI

Years of Experience	0-5	6-10	11-15	16-20	21-25
6-10	0.66	-	-	-	-
11-15	0.99	1.00	-	-	-
16-20	0.72	1.00	1.00	-	-
21-25	0.97	1.00	0.46	1.00	-
25+	0.63	1.00	0.9.5	1.00	1.00

Note: Tukey multiple comparisons of means 95% family-wise confidence level

Table 2.8 Summary of Interactions between variables for BPA

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Education	2	30050	15025	292.087	<2e-16
Employment	1	6	6	0.110	0.7407
Years	5	778	156	3.024	0.0155
Education:Employment	2	121	60	1.174	0.3149
Education:Years	9	724	80	1.564	0.1423
Employment:Years	2	46	23	0.444	0.6433
Education:Employment:Yrs	1	319	319	6.211	0.0150
Residuals	73	3755	51		

The analysis of interactions (ANOVA) shown in Table 2.5 and 2.8 indicate that the education levels are impacting the results within this study but does not show which level of education is different. The post hoc Tukey's HSD (honestly significant difference) tests, which are a single-step multiple comparison procedure (see Tables 2.6 and 2.9) offers this demarcation. The CSI group shows a significant difference between the graduate and the college (technical training) level education, and there was a statistically significant difference between the BPA graduate level education and the other education levels. For both groups, the higher educated practitioner (graduate level) performed better on the test however there are outliers (high and low marks) within each group.

Table 2.9 Post hoc test interactions between education levels for BPA

Education Level	College	Undergraduate
Undergraduate	<2e-16	-
Graduate	<2e-16	<2e-16

Note: Tukey multiple comparisons of means 95% family-wise confidence level

Table 2.10 Post hoc test showing no interaction between years of experience for BPA

Years of Experience	0-5	6-10	11-15	16-20	21-25
6-10	0.98	-	-	-	-
11-15	0.89	1.00	-	-	-
16-20	1.00	1.00	1.00	-	-
21-25	0.80	0.58	0.46	0.74	-
25+	0.42	0.22	0.15	0.46	1.00

Note: Tukey multiple comparisons of means 95% family-wise confidence level

Tables 2.5 and 2.8 suggest that there could be a significant difference in the CSI 6-10 years and the 25+ year level within the BPA group. Post hoc testing in Tables 2.7 and 2.10 indicated that there is no significant relationship. These analyses reveal that there was no relationship between the test scores and years of experience for both groups, but we suggest further research is required to gain a deeper understanding of how experience can contribute to formal reasoning. The findings of this study are the first of their kind and additional studies are essential for further corroboration or contestation. Next, we will address a substantive limitation within this study.

Limitation

For the sake of manageability, this study used one measurement tool, the Lawson CTSR, to assess the CSE. We believe focusing on one assessment tool could be limiting to forensic institutions and that other options should be considered. Currently there are multiple assessment tools that could be used in determining reasoning skills (Opitz et al., 2017). Additional areas of assessment for CSE could include tests suggested by other researchers (Julian et al., 2012; Kelty, 2011; Kelty & Gordon, 2012; Kelty, Robertson, & Julian, 2017; Saldivar, 2017). Our research was focused on testing reasoning skills but contributes to the larger discussion on forensic epistemology. We recognize that more research is needed to tease out knowledge requirements in forensic science, and to consider alternate methods of assessing higher order thinking.

Conclusion

The information from this study establishes that further investigation is required into the epistemic status within forensic science. The research has shown that there may be knowledge gaps within the CSE group tested at all education levels and that the use of a CTSR is beneficial in determining the gaps for the CSE, their organizations and the judicial system. We would argue that having a strong background in the scientific method and scientific philosophy is critical in accomplishing CSE tasks. Beyond these cognitive abilities, we refer back to the seminal work done by Kelty et al. (Kelty, 2011; Kelty & Gordon, 2012; Kelty et al., 2011) where the researchers point out the importance of psychometric skills such as: knowledge, life experience, communication, professionalism, approach to life and stress management as requirements for high performing CSIs.

The information from this research is important to organizations that employ CSE, as it better supports an understanding of reasoning skills and points to how these skills may relate to education level, employment status (specifically, police or civilian practitioners) and years of experience. The CTSR or similar measure could be considered for use as an employment pre-test, but possibly also as an assessment tool for currently employed CSE professionals in determining potential needs for further education or training in the scientific method. Further, a CTSR type tool could be considered in identifying education gaps for forensic science students.

We have shown that education level is central to higher order reasoning skills within the CSI and BPA groups tested. Testing two groups offers research triangulation and support for application of a CTSR model in other forensic science disciplines. This epistemic understanding of the nature and scope of reasoning in forensic science should have an application in policy and best practise development, specifically for groups such as; the USA Organization of Scientific Area Committees for Forensic Science, federal, state and provincial governments who set forensic standards. In addition, our research provides new knowledge to the forensic community on formal reasoning and it's use by CSE. This result supports the importance of education, even though, historically, forensic police practitioners have typically referred to experience as more important than education, and have limited task assignment of civilian employees (CPC, 2018; DOJ, 2004; Goudge, 2008; Illes et al., 2010; OPC, 2016; Paciocco, 2009). Our research in this initial study has shown that there was no significant statistical difference in the CTSR test scores between police or civilian employees or in years of employment. We hope this information will encourage police organizations to rethink the importance of education, policies on civilian employment and task assignment, and the practice of accepting evidence as valid based on experience alone.

Finally, this study is a foray into expanding epistemic understanding in forensic science. Research on the nature and scope of knowledge for a forensic science practitioner has had limited attention. We envision this is the beginning of a larger forensic community discussion and intend on developing a series of research projects. Replication studies will be important in further validating the findings here and further research on the use of data types when answering case-specific research questions and other issues surrounding practitioners doing case-specific research are also needed.

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References

Baber, C., Smith, P., Cross, J., Hunter, J. E., & McMaster, R. (2006). Crime scene investigation as distributed cognition. *Pragmatics & Cognition, 14*(2), 357-385. doi:doi:10.1075/pc.14.2.14bab

Bao, L., Cai, T., Koenig, K., Fang, K., Han, J., Wang, J., . . . Luo, Y. (2009). Learning and scientific reasoning. *Science, 323*(5914), 586-587.

Bao, L., Xiao, Y., Koenig, K., & Han, J. (2018). Validity evaluation of the Lawson classroom test of scientific reasoning. *Physical Review Physics Education Research, 14*(2), 020106.

Capsambelis, C. R. (2002). So your student wants to be a crime scene technician? *Journal of Criminal Justice Education, 13*(1), 113-127.

Carter, K. (2015, February-March). Evidence-based medicine. *Townsend Letter*.

Cave, R., & Molina, D. K. (2014). Evidence-based evidence: a practical method for Bayesian analysis of forensic evidence. *Law, Probability and Risk, 14*(2), 135-145. doi:10.1093/lpr/mgu019

Coletta, V. P. (2017). Reaching More Students Through Thinking in Physics. *The Physics Teacher, 55*(2), 100-105.

Coletta, V. P., & Phillips, J. A. (2005). Interpreting FCI scores: Normalized gain, preinstruction scores, and scientific reasoning ability. *American Journal of Physics, 73*(12), 1172-1182.

Coletta, V. P., Phillips, J. A., & Steinert, J. J. (2007). Interpreting force concept inventory scores: Normalized gain and SAT scores. *Physical review special topics-physics education research, 3*(1), 010106.

CPC. (2018). Canadian Police College. Retrieved from http://www.cpc-ccp.gc.ca/programs-programmes/forensic-ident-judiciaire/fic-cij-eng.htm

Crispino, F. (2008). Nature and place of crime scene management within forensic sciences. *Science & Justice, 48*(1), 24-28. doi:10.1016/j.scijus.2007.09.009

Crispino, F., Ribaux, O., Houck, M., & Margot, P. (2011). Forensic science – A true science? *Australian Journal of Forensic Sciences, 43*(2-3), 157-176. doi:10.1080/00450618.2011.555416

de Leeuwe, R. (2017). The hiatus in crime scene documentation: Visualisation of the location of evidence. *Journal of Forensic Radiology and Imaging, 8*, 13-16.

Ding, L., Wei, X., & Liu, X. (2016). Variations in university students' scientific reasoning skills across majors, years, and types of institutions. *Research in Science Education, 46*(5), 613-632.

DOJ. (2004). *Education and Training in Forensic Science: A Guide for Forensic Science Laboratories, Educational Institutions, and Students*: National Institute of Justice.

Fuller, R. G., Campbell, T. C., Dykstra, D. I., & Stevens, S. M. (2009). *College Teaching and the Development of Reasoning*.

Goudge, S. T. (2008). *Inquiry into Pediatric Forensic Pathology in Ontario* (Q. s. P. o. Ontario Ed.). Toronto.

Greenhalgh, T. (2014). *How to read a paper: The basics of evidence-based medicine*: John Wiley & Sons.

Hacker, R. (1989). The construct validities of some group tests of intellectual development. *Educational and Psychological Measurement, 49*(1), 269-275.

Hansen, H. F. (2014). Organisation of evidence-based knowledge production: evidence hierarchies and evidence typologies. *Scandandinvian Journal of Public Health, 42*(13 Suppl), 11-17. doi:10.1177/1403494813516715

Hanson, S. T. (2016). *The assessment of scientific reasoning skills of high school science students: A standardized assessment instrument.* Illinois State University,

Harrison, D. M. (2015). *Factors correlated with students' scientific reasoning ability in an introductory university physics course*. University of Toronto, Toronto.

Harrison, K. (2006). Is Crime Scene Examination science, and does it matter anyway? *Science & Justice, 46*(2), 65-68. doi:http://dx.doi.org/10.1016/S1355-0306(06)71576-3

Horswell, J., & Edwards, M. (1997). Development of quality systems accreditation for crime scene investigators in Australia. *Science & Justice, 37*(1), 3-8. doi:10.1016/s1355-0306(97)72134-8

Houck, M. M., Crispino, F., & McAdam, T. (2017). *The science of crime scenes*: Academic Press.

IABPA. (2018). Retrieved from http://www.iabpa.org/

Illes, M. B., Dalley, I., Kish, P. E., Taylor, M. C., & Yamashita, A. B. (2010). Bloodstain Pattern Analysis Part 1. Training and Educational Materials. *Journal of the Canadian Society of Forensic Science, 43*(1), 31-37.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic Books.

International Association for Identification. (2016). Retrieved from https://www.theiai.org/index.php

iStar Assessment. (2010). Retrieved from http://www.istarassessment.org/about/

James, S. H., Kish, P. E., & Sutton, T. P. (2005). *Principles of bloodstain pattern analysis: theory and practice*: CRC Press.

Jamieson, A. (2004). A rational approach to the principles and practice of crime scene investigation: I. Principles. *Science & Justice, 44*(1), 3-7. doi:10.1016/s1355-0306(04)71678-0

Julian, R., Kelty, S., & Robertson, J. (2012). "Get it right the first time" : critical issues at the crime scene. *Current Issues in Criminal Justice, 24*(1), 25-37.

Kelty, S. F. (2011). Professionalism in Crime Scene Examination: Recruitment Strategies Using the Seven Key Attributes of Top Crime Scene Examiners. *Forensic Science Policy & Management: An International Journal, 2*(4), 198-204. doi:10.1080/19409044.2012.706689

Kelty, S. F., & Gordon, H. (2012). Professionalism in Crime Scene Examination: Recruitment Strategies, Part 2: Using a Psychometric Profile of Top Crime Scene

Examiners in Selection Decision Making. *Forensic Science Policy & Management: An International Journal, 3*(4), 189-199. doi:10.1080/19409044.2013.858799

Kelty, S. F., Julian, R., & Robertson, J. (2011). Professionalism in Crime Scene Examination: The Seven Key Attributes of Top Crime Scene Examiners. *Forensic Science Policy & Management: An International Journal, 2*(4), 175-186. doi:10.1080/19409044.2012.693572

Kelty, S. F., Robertson, J., & Julian, R. (2017). Beyond Technical Training to Professionalism in Crime Scene Examination: Enhancing Cognitive, Leadership, and Social Abilities in Career Development Programs. *Forensic Science Policy & Management: An International Journal, 8*(3-4), 65-78. doi:10.1080/19409044.2017.1370039

Latham, H. M. (2011a). Reasoning, the Scientific Method, and Bloodstain Pattern Analysis – Assuring that the Questions are being Answered Correctly. *Journal of Forensic Identification, 61*(4), 333-340.

Latham, H. M. (2011b). Using and Articulating the Scientific Method in Bloodstain Pattern Analysis. *Journal of Forensic Identification, 61*(5), 487-494.

Lawson, A. (2003). Allchin's Shoehorn, or Why Science is Hypothetico-Deductive. *Science & Education, 12*(3), 331-337. doi:10.1023/a:1024090727385

Lawson, A. E. (1978). The Develoment and Validation of a Classroom Test of Formal Reasoning. *Journal of Research in Science Teaching, 15*(1), 11-24.

Lawson, A. E. (1985). A review of research on formal reasoning and science teaching. *Journal of Research in Science Teaching, 22*(7), 569-617.

Lawson, A. E. (2004). The Nature and Development of Scientific Reasoning: A Synthetic View. *International Journal of Science and Mathematics Education, 2*(3), 307-338. doi:10.1007/s10763-004-3224-2

Lawson, A. E. (2005). What is the role of induction and deduction in reasoning and scientific inquiry? *Journal of Research in Science Teaching, 42*(6), 716-740. doi:10.1002/tea.20067

Lawson, A. E. (2013). Hypothetico-deductive Method. 1-2. doi:10.1007/978-94-007-6165-0_260-1

Lawson, A. E., Alkhoury, S., Benford, R., Clark, B. R., & Falconer, K. A. (2000). What kinds of scientific concepts exist? Concept construction and intellectual development in college biology. *Journal of Research in Science Teaching, 37*(9), 996-1018. doi:10.1002/1098-2736(200011)37:9<996::aid-tea8>3.0.co;2-j

Lawson, A. E., Baker, W. P., Didonato, L., Verdi, M. P., & Johnson, M. A. (1993). The role of hypothetico-deductive reasoning and physical analogues of molecular interactions in conceptual change. *Journal of Research in Science Teaching, 30*(9), 1073-1085. doi:10.1002/tea.3660300906

Lawson, A. E., & Daniel, E. S. (2011). Inferences of clinical diagnostic reasoning and diagnostic error. *J Biomed Inform, 44*(3), 402-412. doi:10.1016/j.jbi.2010.01.003

Lawson, A. E., McElrath, C. B., Burton, M. S., James, B. D., Doyle, R. P., Woodward, S. L., . . . Snyder, J. D. (1991). Hypothetico-deductive reasoning skill and concept acquisition: Testing a constructivist hypothesis. *Journal of Research in Science Teaching, 28*(10), 953-970. doi:10.1002/tea.3660281006

Leake, L. J. (2007). *A Guide To Producing an Evidence-based Report*. University of Toronto.

Ludwig, A., Fraser, J., & Williams, R. (2012). Crime Scene Examiners and Volume Crime Investigations: An Empirical Study of Perception and Practice. *Forensic Science Policy & Management: An International Journal, 3*(2), 53-61. doi:10.1080/19409044.2012.728680

Makin, D. A. (2012). Symbolic Evidence Collection or "If All Else Fails, Throw Some Dust Around". *Forensic Science Policy & Management: An International Journal, 3*(3), 126-138. doi:10.1080/19409044.2013.780834

Milliet, Q., Delémont, O., & Margot, P. (2014). A forensic science perspective on the role of images in crime investigation and reconstruction. *Science & Justice, 54*(6), 470-480. doi:10.1016/j.scijus.2014.07.001

Moore, J. C. (2012). Transitional to formal operational: Using authentic research experiences to get non-science students to think more like scientists. *European Journal of Physics Education, 3*(4), 1-12.

Moore, J. C., & Rubbo, L. J. (2012). Scientific reasoning abilities of nonscience majors in physics-based courses. *Physical Review Special Topics - Physics Education Research, 8*(1). doi:10.1103/PhysRevSTPER.8.010106

OPC. (2016). Forensic Identification Officer Program: Course Training Standard. In (pp. 138). Ontario Police College, Ministry of Community Safety and Correctonal Services: Queen's Printer for Ontario.

Opitz, A., Heene, M., & Fischer, F. (2017). Measuring scientific reasoning–a review of test instruments. *Educational Research and Evaluation, 23*(3-4), 78-101.

Paciocco, D. (2009). Taking a" Goudge" out of Bluster and Blarney: An" Evidence-Based Approach" to Expert Testimony. *Canadian Criminal Law Review, 13*(2), 135.

PCAST. (2016). *Report to the President Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature - Comparison Methods (Executive Summary)*. USA.

Perepechina, I. (2017). Crime stain as a forensic object: Some essential aspects of examination. *Forensic Science International: Genetics Supplement Series, 6*, 531-533.

Peschel, O., Kunz, S., Rothschild, M., & Mützel, E. (2011). Blood stain pattern analysis. *Forensic science, medicine, and pathology, 7*(3), 257-270.

PhysPort. Retrieved from https://www.physport.org/assessments/assessment.cfm?A=CTSR&S=4

Piaget, J. (1932). *The moral judgment of children*.

Pratt, C., & Hacker, R. G. (1984). Is Lawson's Classroom Test of Formal Reasoning Valid? *Educational and Psychological Measurement, 44*(2), 441-448. doi:10.1177/0013164484442025

R. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Retrieved from https://www.r-project.org/

Resnikoff, T., Ribaux, O., Baylon, A., Jendly, M., & Rossy, Q. (2015). The polymorphism of crime scene investigation: An exploratory analysis of the influence of crime and forensic intelligence on decisions made by crime scene examiners. *Forensic Science International, 257*, 425-434. doi:10.1016/j.forsciint.2015.10.022

Saldivar, A. (2017). Minimum Education Requirements for Crime Scene Investigators. *Themis: Research Journal of Justice Studies and Forensic Science, 5*(1), 10.

Shaler, R. C. (2012). *Crime Scene Forensics: A Scientific Method Approach*. Boca Raton, Florida: CRC Press.

Taylor, M. C., & Osborne, N. K. P. (2018). Letter to the Editor-A Contribution to Contextual Information Management in Bloodstain Pattern Analysis: Preliminary Idea for a Two-Step Method of Analysis. *Journal of Forensic Sciences, 63*(1), 341. doi:10.1111/1556-4029.13705

Teig, N., & Scherer, R. (2016). Bringing Formal and Informal Reasoning Together-A New Era of Assessment? *Front Psychol, 7*, 1097. doi:10.3389/fpsyg.2016.01097

WebAssign. Retrieved from http://www.webassign.net/features/textbooks/ctsr1/details.html?l=subject

Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental review, 20*(1), 99-149.

Chapter 3: Forensic Epistemology: Exploring Case-Specific Research in Forensic Science

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Abstract

Conducting research from a forensic case question can present complications that lead to justifying problematic assumptions, such as time length since event, research time limits, limited sample sets, uncontrolled variables and other unknowns. Our inquiry into forensic epistemology explores the use of data types for case-specific research within three, separate pattern-interpretation disciplines. This research raised questions surrounding the required level of practitioner research skills and research methodology used. We developed three cases from different pattern-interpretation disciplines: a friction ridge analysis; a bloodstain pattern analysis; and a footwear impression analysis. For each case, a series of experiments were derived using three different data types: a quantitative approach (using numeric data), a qualitative approach (using image data) and a mixed-method approach (using both numeric and image data). Electronic files were compiled for each case and research method and forwarded by Qualtrics Software to forensic practitioners (n = 278) within the prescribed discipline. Demographic questions on practitioner education level and years of experience were included in the survey, along with open ended comment areas. The dependent variable was the participant's percent confidence in providing an opinion from the data type used. Linear regression analyses indicated that practitioners were more confident using a mixed-method data approach. No differences were found between the percent confidence levels and discipline type. Similarly, there was no significant difference between the confidence levels and years of experience or the participant's education level. The qualitative data analysis validated the quantitative results in that the practitioners were more confident with a mixed-method research approach.

Key words: forensic epistemology, forensic science, research methods, data type, case-specific research, forensic analysis

Introduction

Case-specific research is the approach of answering a question that is pertinent to an investigation and the courts (Kueffer, 2006; Milliet, Delemont, Sapin, & Margot, 2015; Mitchell, Walker, & Monahan, 2011a, 2011b; Ulriksen & Dadalauri, 2014). The fundamental difference between academic research and forensic case-specific research is that the latter examines past events with no knowledge of what happened at the time of the event. Conducting research from a forensic case question can present complications that lead to justifying problematic assumptions, such as time length since event, research time limits, limited sample sets, uncontrolled variables and other unknowns (Kueffer, 2006; Mitchell et al., 2011b).

The multi-disciplinary nature of forensic science assures that its academic research methods encompass a wide range of those disciplines, spanning from qualitative studies in anthropology to quantitative research in DNA typing (Aboud, Gassmann, & McCord, 2015; Damas et al., 2015). A recent explosion of forensic research includes articles identifying areas that should be explored within the various forensic disciplines and explaining how to conduct the research (Attinger, Moore, Donaldson, Jafari, & Stone, 2013; Bono, 2011; Gertner, 2011; Margot, 2011; Mnookin et al., 2011; NAS, 2009; "OSAC Research & Development Needs ", 2017; PCAST, 2016; Pollanen, Bowes, VanLaerhoven, & Wallace, 2013; Saks, 2010). Saks (Saks, 2010) has gone so far as to suggest three research strategies forensic researchers could use to identify suitable techniques from the comparison disciplines: black-box studies, a DNA model and the basic research model. Most of the comparison disciplines require subjective judgement on the uniqueness of an object, such as a fingerprint, and may not be based entirely on quantifiable evidence (Saks, 2010). Black-box studies, for example, are designed to control input and output without knowledge of the internal working, a strategy that can provide information on the accuracy of a subjective examination task performed by an expert (Saks, 2010). Alternatively, the DNA research model uses the most secure method to date, DNA typing, and could be used as a model to make the other comparison disciplines more robust (Saks, 2010). The comparison disciplines also have many beliefs around evidence and how it is processed that need to be tested as hypotheses in a basic research model (Saks, 2010). This method validation will help increase the scientific rigour within forensic science, as the resulting literature will aid the practitioner when conducting examinations and providing expert analyses (Bono, 2011; Gertner, 2011; Margot, 2011; Mnookin et al., 2011; "OSAC Research & Development Needs ", 2017; Saks, 2010).

Another well-documented area of forensic research is the case study. To illustrate the extensive case study submissions, an abstract search of the term “case study” within the *Forensic Science International* journal yielded 1649 articles published between 2016 and 2018 ("Scolarsportal," 2018). Many of these manuscripts were submitted as case reports and serve to distribute case information to practitioners. However, it is important to note that the case study is not considered research by some (Houck, 2015).

The forensic disciplines seem well-informed on how to complete academic research, with wide-ranging papers describing repeatable methods, suggestions on research models and a vast distribution of novel case information (Kelty & Julian, 2011; Langenburg, 2011; Mnookin et al., 2011). However, few studies provide insight on conducting research from case-specific questions and overcoming the inherent challenges with this type of research. As a result, large disparities exist within the literature on the methods used for conducting case-specific research. The following examples depict the extremes of rigour within the literature. A study of suspected fatal falls by Cross (Cross, 2006), that passed the peer review of a scientific forensic journal, depicted planned projects that apparently used appropriate scientific principles and controlled experimentation to predict possible outcomes of past case-specific events. However, within an appeals trial one of experiments in the article was highly criticized by the courts as being “a series of not particularly sophisticated experiments” ("R. v. Wood," 2012). In contrast, a bloodstain pattern analysis study conducted by MacLean et al. (MacLean, Powley, & Dahlstrom, 2001) attempted to identify a bloodstain pattern (high velocity impact spatter) found at a crime scene that was proposed to have been created by a gun shot into a victim. This research had a limited sample set (three trials without repeats) with little consideration to scientific design and used only observational (qualitative) information to provide a conclusion.

These case-specific research examples raise questions surrounding the required level of practitioner research skills and research methodology used. Bryce et al. (Bryce, Rankin, & Hunt, 2019) conducted research on the assessment of competency schemes for the forensic sciences. This research identified key skills that are required by forensic service providers from tertiary graduates who are potential employees. The results of the study provide direction to undergraduate and postgraduate programs and was developed from collaborative research with forensic science employers, practitioners and academic stakeholders. Twenty-one key skills were identified in this research including; transferable skills in experimental design. The study also suggests that forensic science educators need to close the theory-practice gap by balancing academic and practical program content. These findings are significant to our research on forensic epistemology because the forensic science community has listed experimental reasoning and the ability to apply these concepts in the field as key forensic practitioner skill sets.

Beyond the forensic science literature, there have been recent court cases that provide some direction to the forensic practitioner on the importance of robust scientific research methodologies when conducting case-specific research. In R. v. Millard ("R. v. Millard ", 2018) , a shooting reconstruction expert witness's opinion was ruled as inadmissible based on confirmation, professional creditability and contextual bias. Beyond the issue of bias, (although an important subject in research) the Judge pointed out her concerns that the re-creation of the scene completed by the witness was not a proper scientific experiment, citing the lack of replication, quantitative data and hypotheses development. The witness also failed to falsify hypotheses, control variables and rejected evidence that did not support his opinion. There was also a concern if the methodology was attributed to inadequate training or failure to apply the training ("R. v. Millard ", 2018). The R. v. Frances ("R. v. France," 2017) ruling highlights the necessity for case-specific literature review in forensic science. The expert witness provided a categoric opinion that blunt force trauma to a deceased was from an assault. A literature review by the defence produced extensive evidence that, within the case circumstances, the trauma could have been caused by an accidental fall. This supports the need for forensic practitioners to be competent in basic scientific and research principles.

In the Supreme Court of Arizona an appeal was launched, State v. Romero ("State v. Romero," 2016), to consider if the trial court abused its discretion by not allowing a defence expert witness to testify. The witness was being offer as an expert in experimental design and was challenging methods used by forensic firearm examiners. The supreme court decision specified: that the expert was qualified as an expert in experimental design and the assessment of methods used by firearms examiner; that the witness testimony would help the jury in understanding the differences between comparison analysis and the scientific method; and that the witness testimony would help the jury with assessing the weight of the scientific evidence. The Supreme Court found that the lower court decision for preclusion of the expert witness was an error of law ("State v. Romero," 2016).

In our research, we have applied a mixed-method experimental design (using both quantitative and qualitative data) that compares different data use in three forensic disciplines. Given all the above, we test the following hypothesis: there is a relationship between the confidence level of the forensic practitioner’s opinion and the use of mixed-method data in case-specific research methods. Other objectives are to investigate: if there is a difference between the forensic disciplines when considering confidence level; and does education or experience level play a role on the ability to apply case-specific research. The following describes the methods used.

Methods

This study applies a multi-disciplinary approach using triangulation, the use of multiple methods or data sources, to investigate case-specific research (Carter, Bryant-Lukosius, DiCenso, Blythe, & Neville, 2014; Foss & Ellefsen, 2002). We developed three cases from different pattern-interpretation disciplines: a friction ridge analysis (FR), a bloodstain pattern analysis (BPA) and a footwear impression analysis (FW). For each case, we create a series of experiments using three different research methods: a quantitative approach (QN) (using numeric data), a qualitative approach (QL) (using image data) and a mixed-method approach (MM) (using both numeric and image data). Demographic questions on practitioner education level and years of experience were included in the survey, along with open ended comment questions. These fabricated research cases and data allow for knowledge of the right answer within an invented investigation, thereby eliminating the typical challenges of case-specific research. Electronic files were compiled for each case and research method and forwarded to a forensic practitioner who is an expert within the prescribed discipline. Ethics approval was granted by the Trent University Research Ethics Board (REB) for the administration of the surveys. The forensic analyses are separated into the subsequent headings.

Friction Ridge and Footwear Studies: Forensic Analysis

Friction ridge skin analysis is the comparison of finger or palm prints that are located at a crime scene with known print samples from a person. Footwear impression analysis is the comparison of footwear impression found at a crime scene with a suspect shoe (PCAST, 2016). To collect data for the friction ridge and footwear studies, the IAI was solicited for approval to distribute a voluntary, anonymous electronic questionnaire to their members. The association supplied a list of active friction ridge and impression evidence experts. These experts completed the analytical stage of comparing unknown impressions found at a scene with suspected known impressions associated with an individual by using those data supplied. The participants were selected from a list of 2214 fingerprint experts and 1684 impression experts using a random-assignment sampling function within Microsoft Excel 2016.

Three surveys were developed from the same case example each discipline including: quantitative; qualitative; and mixed-method data. For both disciplines we supplied a very basic data analysis approach that would be common knowledge for academic researchers. The quantitative example was an ANOVA test with boxplots indicating significant p-values that provided evidence of the patterns being the same as that from the crime scene. The qualitative example contained one image of the suspect pattern that was found within a scene. Images of test impressions created in a laboratory environment were supplied for visual comparison. The mixed-method contained the same information from both quantitative and qualitative examples. A sample survey can be viewed in Appendix A.

Bloodstain Pattern Study: Forensic Analysis

Bloodstain pattern analysis is the examination of static bloodstains and bloodstain patterns to provide information of the mechanism that may have created them and an interpretation of the sequence of events ("IABPA," 2018). The International Association of Bloodstain Pattern Analysis (IABPA) is the principal organization for bloodstain pattern analysts and was solicited for approval to distribute a voluntary anonymous electronic questionnaire to their members. The global membership of this organization (37 countries) consists of individuals who are experts in the field of bloodstain pattern analysis ("IABPA," 2018). All members, a list of 1114 bloodstain pattern analysts, were requested to participate and randomly assigned to a survey.

Three surveys were developed from the same case example, a partial impact pattern, for the bloodstain analysts including: quantitative; qualitative; and mixed-method data. We supplied standard area of origin (AOO) quantitative data that is used in impact pattern validation within bloodstain pattern analysis and a standard set by the IABPA and the Organization of Scientific Area Committees (OSAC) (IABPA, 2018; OSAC, 2018). The qualitative example contained one image of a suspect impact pattern that was found within a scene and only the upper portion of the pattern was supplied. Similar Images of test impressions created in a laboratory environment were supplied for visual comparison. The mixed- method contained the same information from both quantitative and qualitative examples.

In summary, a total of 5012 experts were contacted with a final sample set of 278 participants (n=278). The participant sample set for each discipline was selected from a list of experts using a random sampling function, and the resulting participants randomly assigned to the respective research method (Bordens & Abbott, 2011). The different research methods for each case were forwarded independently to the other cases and the practitioners. Using the power analysis function within R a robust random sample set was determined to be 252 individuals (N=252) with group assignments of 27 individuals for each method within each discipline (R, 2018). The surveys were distributed electronically using Qualtrics software and the practitioners asked to rank and comment on their level of confidence in providing information to a court based on the research information provided.

Each survey within this study contained three open-ended questions. The questions were the same and presented in similar style within all nine surveys, a preview can be found in Appendix A, questions 3,7 and 9. The sample sets were different for the qualitative analysis due to dropped questions by the participants; the research method set is n = 278 and the disciplines set is n = 263. Those qualitative data collected were analyzed using thematic analysis and coded within NVivo 12 Plus (Braun & Clarke, 2006; Kalyal, 2019; NVivo, 2018). The participant comments were manually coded, and recurring themes began to emerge. Criteria was developed for these themes and the coding was reanalyzed for each response from the participants allowing for a clear pattern to appear. We have analyzed themes that can be judged by objective criteria and these themes and criteria are reported as:

1) Literature review: whether the participant indicates they would conduct a literature search for the research study.
2) Research Task Irrelevant Information: if the participant requested case information such as; scene context, medical reports, lab reports or reconstruction reports that may bias the research.
3) Research Task Relevant Information: if the participant requested more scientific data such as; quantitative, qualitative or any type of further analyses.
4) Quantitative Measure BPA: if the participant requested an area of convergence (AOC) or area of origin computation.
5) Quantitative Measure FR and FW: if the participant requests computation of or discussed p-values.

The results of our research are separated into two clusters, with both methods and disciplines represented in each cluster. The first cluster of findings reports those quantitative data collected where linear regression analysis explains the relationship among variables. We tested for interactions between the independent variables that include: method, discipline, education, and years of experience using three-way factorial ANOVA analysis and when needed, *post hoc* interaction testing within the variable. In the second cluster of findings, qualitative data were coded and analyzed using thematic analysis within NVivo 12 Plus (Braun & Clarke, 2006; Kalyal, 2019; NVivo, 2018). The following section presents detailed results of each theme.

Results and Discussion

Strategies for case-specific research exist within different areas of study, however, these approaches generally apply to only existing problems such as an ongoing ecological issue that requires solutions in that specific field situation (Kueffer, 2006). That is, forward-moving academic research is being applied to real-life, ongoing problems. The fundamental difference between case-specific research in more traditional fields and forensic science is that forensic research deals with no, or limited, knowledge of past events. This distinction makes the selection of research methods more complex and problematic, and at this time there is no direction on how to implement this framework.

Quantitative Analysis

Linear regression analysis was used to determine if there was a relationship among variables; the percent confidence scores and the research method, forensic discipline, participant's education level, and years of experience.

Table 3.11 Linear regression analysis for case-specific research method data type

Coefficients:	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	50.89814	16.50587	3.084	0.00228
Discipline (FR)	7.94943	6.36292	1.249	0.21272
Discipline (FW)	-8.57739	6.95733	-1.233	0.21880
Method (QL)	-17.48458	6.39504	-2.734	0.00671
Method (QN)	-16.32410	6.62652	-2.463	0.01444
Education (C)	-0.09827	16.43203	-0.006	0.99523
Education (UG)	3.09640	15.52790	0.199	0.84211
Education (M)	4.12532	15.81275	0.261	0.79440
Education (PhD)	2.02591	17.87389	0.113	0.90985
Years (5-10)	-0.91979	7.45832	-0.123	0.90195
Years (11-15)	-10.36330	8.26418	-1.254	0.21103
Years (16-20)	-6.53173	8.99364	-0.726	0.46837
Years (21-25)	-5.87297	13.17361	-0.446	0.65612
Years (25+)	-14.84813	9.11577	-1.629	0.10462

Residual standard error: 41.57 on 247 degrees of freedom
Multiple R-squared: 0.06183, Adjusted R-squared: 0.01246
F-statistic: 1.252 on 13 and 247 DF, p-value: 0.2431

The p-values reported in table 3.1 as Pr(>|t|) have been interpreted using a significance level of $p < 0.05$ and there was a statistically significant difference between the percent confidence levels for the research MM data type and the QN and QL. The practitioners were more confident in articulating a result and conclusion when analyzing the MM research models. Interestingly, there was no relationship between the confidence level and the forensic disciplines, education level nor years of experience of the participants. This information suggests that the use of a mixed-method approach could be more suitable for forensic science case-specific research across a spectrum of training. Figures 3.1 – 3.4 provide a set of boxplots that graphically represent those data.

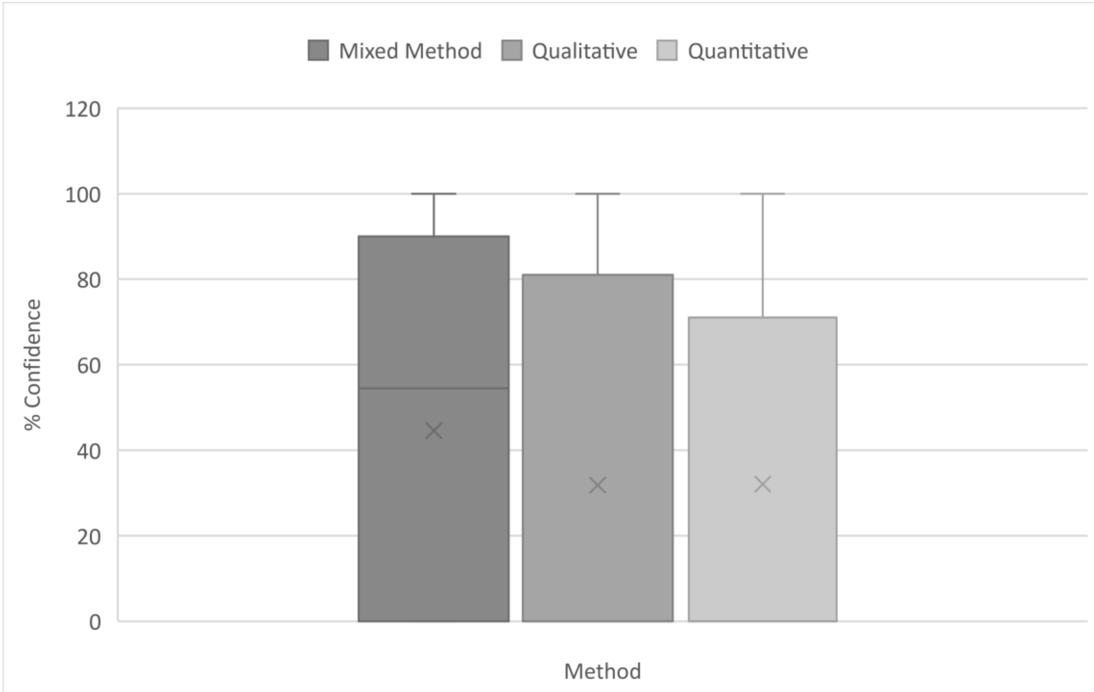

Figure 3.9 Boxplot of practitioner % confidence in research method data types with sample sizes being: Mixed Method - 86, Qualitative - 85, Quantitative – 107

When observing Figure 3.1 the boxplot supports the significant difference in the mixed-method data with a positive upsurge in the participants confidence level. As such, our hypothesis that there is a relationship between the confidence level of the forensic practitioner opinion and those mixed-method data types is supported.

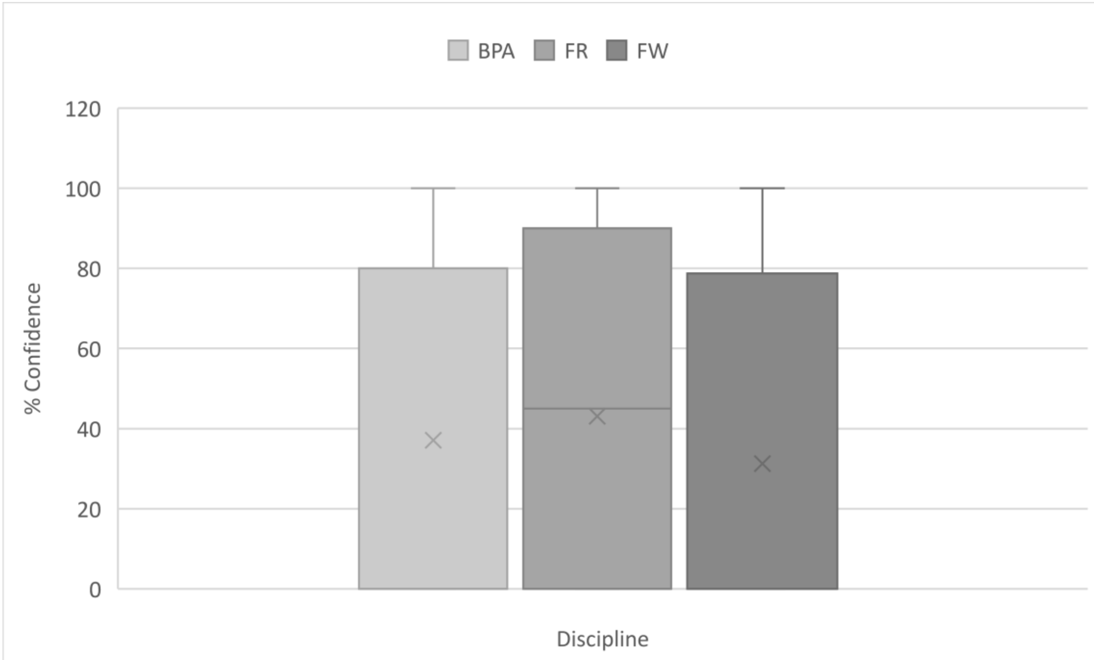

Figure 3.10 Boxplot of practitioner % confidence in research method data types by discipline with sample sizes being: BPA - 85, FR - 106, FW – 72

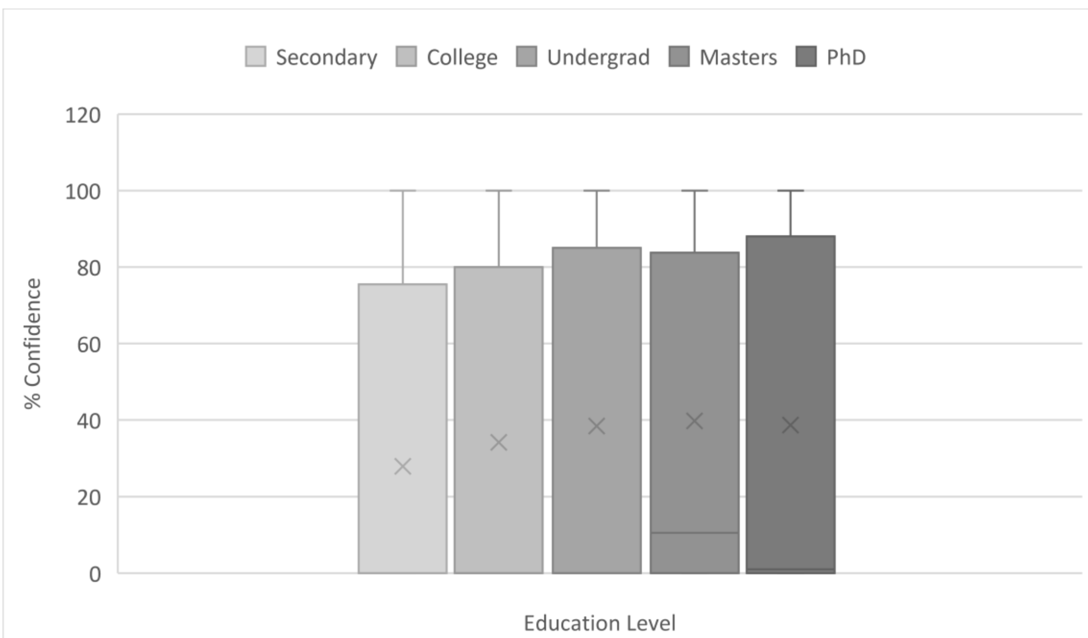

Figure 3.11 Boxplot of practitioner % confidence in research method data types by education level with sample sizes being: Secondary School - 9, College - 40, Undergraduate - 113, Masters - 80, PhD – 21

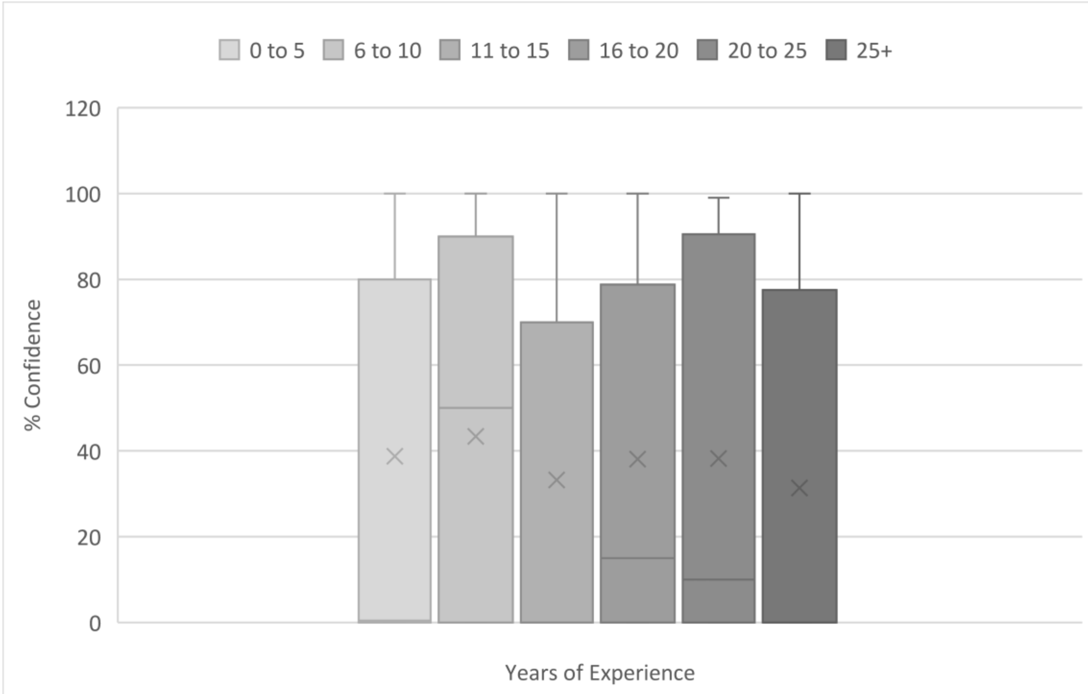

Figure 3.12 Boxplot of practitioner % confidence in research method data types by years of experience with sample sizes being: 0 to 5 - 80, 6 to 10 - 61, 11 to 15 - 43, 16 to 20 - 32, 21 to 25 - 13, over 25 – 32

The results in Table 3.2 on discipline, education level and years of experience are supported by the boxplots in Figure 3.2, 3.3 and 3.4. The plots depict a consistent distribution, are comparatively similar in magnitude, with the medians being very similar for each variable. These findings support that the forensic discipline is independent of the case-specific research method used and that forensic practitioner experience and education level play a less significant role on the ability to apply case-specific research.

The above results have addressed the main question of this study: Are there any associations between the percent confidence for the expert to offer an opinion and research method data types, the disciplines, education level or years of experience, however, it does not test interactions between the variables. A three-way factorial ANOVA analysis (Table 3.2) identified a significant difference between the research method data types. A post hoc test was completed to test for an interaction, and there was an interaction between the other independent variables within this study, see Table 3.3.

Table 3.12 Summary of interactions between variables for case-specific research data type

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Discipline	2	6083	3042	1.690	0.1883
Method	2	14566	7283	4.047	0.0196
Education	4	656	164	0.091	0.9851
Years	5	6824	1365	0.758	0.5813
Discipline:Method	4	2115	529	0.294	0.8816
Discipline:Education	8	15988	1998	1.110	0.3600
Method:Education	8	15021	1878	1.043	0.4068
Discipline:Years	10	11285	1129	0.627	0.7887
Method:Years	10	24830	2483	1.380	0.1958
Education:Years	15	37622	2508	1.394	0.1586
Discipline:Method:Education	11	17079	1553	0.863	0.5783
Discipline:Method:Years	15	25757	1717	0.954	0.5069
Discipline:Education:Years	13	10065	774	0.430	0.9564
Method:Education:Years	12	7890	657	0.365	0.9734
Discipline:Method:Education:Years	4	12585	3146	1.748	0.1429
Residuals	137	246550	1800		

Table 3.13 Post hoc test interactions between methods

Research Method	diff	lwr	upr	p adj
QL-MM	-14.808	-29.448	-0.168	0.046
QN-MM	-15.688	-31.009	-0.367	0.043
QN-QL	-0.879	-15.320	13.561	0.989

Note: Tukey multiple comparisons of means 95% family-wise confidence level

The analysis of interactions (ANOVA) shown in Table 3.2 indicate that the research method data types are impacting the results within this study. The post hoc test which is a pairwise comparison using t tests (see Table 3.3) offers a demarcation between the mixed-method and the quantitative and qualitative methods. There is a statistically significant difference between the mixed method and the other approaches.

Qualitative Analysis

The qualitative data were coded and analyzed using thematic analysis within NVivo 12 Plus. The results are presented by theme.

Literature Review

Few participants (n=20) indicated that they would conduct a literature review for the research projects presented. The friction ridge group was the highest with only 11 out of 106 (10.4%) participants signifying they would conduct a literature review. In the FR group two participants provided specific literature suggestions:

"Alice Maceo's numerous studies and articles delineating pressure distortion as well as studies conducted specifically to show the results of pressure distortion. Contributions in the Fingerprint Source Book……… There have also been a number of associated articles with study results during 2016 published in the JIF from the IAI that are worth note."

"Check out this paper......https://www.hindawi.com/journals/bmri/2012/626148/"

Figures 3.5 and 3.6 illustrate the number of participants by discipline and research method who indicated they would conduct a literature review.

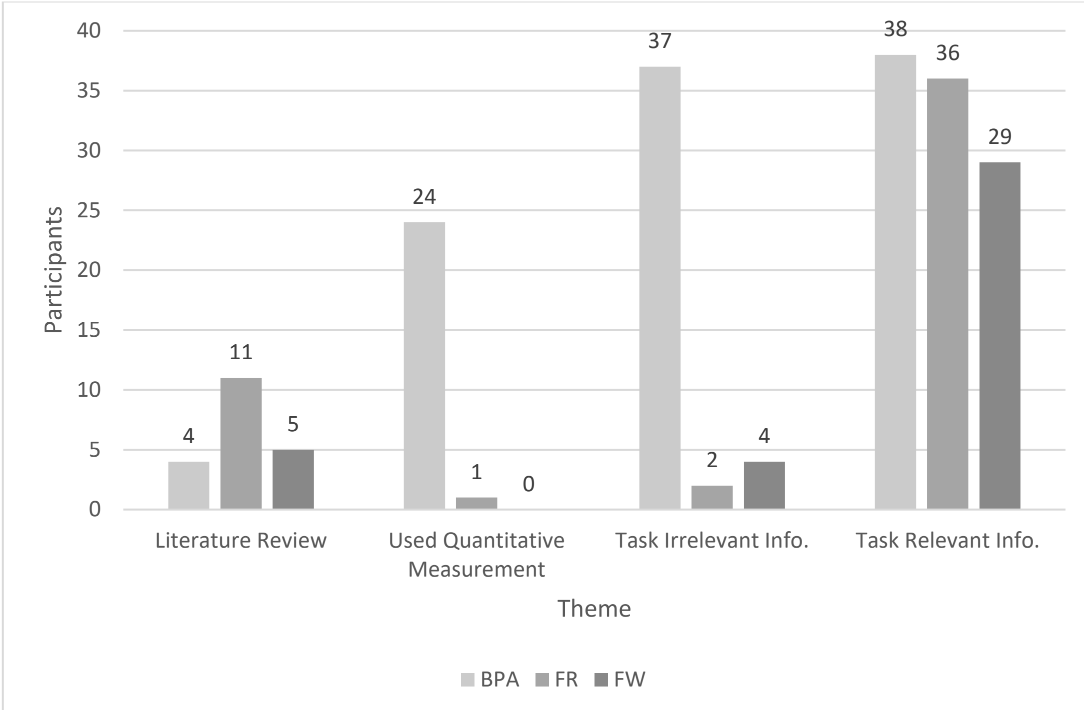

Figure 3.13 Participant comments by theme and discipline type (n=263)

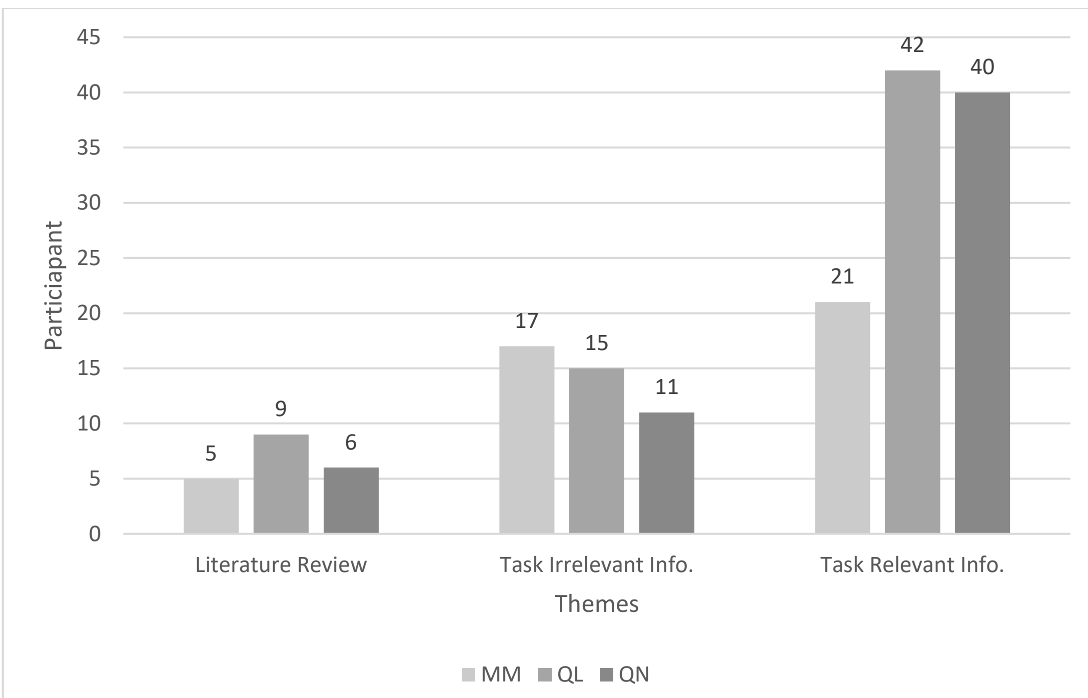

Figure 3.14 Participant comments by theme and research method data type (n=278)

Research Task Irrelevant Information

Several survey participants (n=43) requested information that was considered research task irrelevant information such as; scene context, medical reports, lab reports or reconstruction reports that may bias the research. The bloodstain analyst group was particularly high with thirty-seven out of forty-three requests being from that group (See Table 3.5). Many BPAs requested information such as stated by this participant;

"….if the wet blood source is a person, medical information on the bleeding injuries received; biology on the stains sampled to determine if the staining is blood and if so, a possible contributor; and, what was the apparent object used to create the impact event."

Other participants asked for;

"Information on the entire scene. Source of blood. Any known bloodletting wounds. Basically the rest of the BPA examination."

"I would like more qualitative analysis, using more information from the crime scene."

"I would need a lot more investigative knowledge."

The research method group task irrelevant information requests are consistent throughout those variables.

Research Task Relevant Information

There were significant requests from the practitioners for more research task relevant information such as quantitative or qualitative data or further analyses. Onehundred and three practitioners (n=103) made this type of request, with 39.2% overall requesting more of those data. The majority of these requests for information (n=82) came from the quantitative and qualitative case-specific research model participants, that is 80% of the requests. (See Figure 3.6).

A variety of positive comments looking for more research task relevant information were observed;

"I would also try to recreate the alternative hypothesis to your statement...the stain pattern"

"The qualitative research shown could also be supported with AOC and AOO calculations which would support known impact pattern characteristics,…."

"Tangent method to see if an area of origin can be determined"

"More research needed in order to state specifics (1 vs 10 lbs)."

"I would need to see significant research testing all possible variables that could affect pressure analysis prior to providing an opinion in court as to the pressure placed on an item."

"I would suggest analyzing other types of shoe tread patterns to contrast them with the evidence print."

Only one bloodstain analyst who participated in the quantitative study indicated the importance of conducting a literature review and using of math and physics (Task Relevant Information) in doing the research.

Quantitative Measure BPA

Several survey participants (n=24) requested an AOC or AOO computation. This is 20% of the overall BPA participants who completed the surveys, with six requests coming from the mixed-method group, five from the qualitative group and 13 from the quantitative group. Comments ranged in the technique that would be used to complete the task;

"hemospat analysis"

"Combination of Matlab and qualitative analysis"

"stringing method"

"Area of origin determination"

Quantitative Measure FR and FW

One participant from the FR and FW survey data wrote about the statistical analysis, P-values, indicating;

"The p-value is quite indicative that it would be highly unlikely to observe this evidence under the condition pressure = 1 lb. I'd prefer a likelihood ratio to state the weight of the evidence, but it seems from best guess that it is extremely strong support for the proposition that Pressure = 11lb and 10 lbs. Note a limitation is that the scene evidenced some overlap in the lower quartile of the boxplot, so it is possible, just unlikely to observe this evidence under the 1 lb condition."

A research experiment on a case would be specific to the case question and should be considered by the court as novel expert evidence (Gold, 2003). Therefore, the case-specific research applied by the expert requires scrutiny along with the research credentials of that expert. An expert witness must have “acquired special or peculiar knowledge through study or experience in respect of the matter on which he or she undertakes to testify”("R. *v.* Mohan," 1994). The qualification of a witness in an area of forensic expertise does not guarantee that that expert has knowledge in conducting scientific research and our results supports this. In fact, most forensic practitioners do not conduct research on a regular basis (Graner & Kronkvist, 2015; Griffiths, 2014; Kalyal, 2019; Linacre, 2013; Steinheider, Wuestewald, Boyatzis, & Kroutter, 2012). Bryard and Vink (Byard & Vink, 2014) have suggested that even the most likely practitioners to be connected with academia, forensic pathologists, work in isolation from academic activities like experimental design. The lack of rigorous methodology and the application of the reported cases of unreliable evidence from case-specific research is problematic and a risk to forensic science as the final products of case-specific research are, for the most part, presented to the court of law. The consequence of poor case-specific research can lead to unlawful arrests, conviction of the wrong person or release of the guilty.

Recommendations

Research models and data types are well known and have long histories within most academic fields and our research provides an embarkation for further research into this subject in forensic science. This gain in the epistemic status in forensic science provides meaning to this field because there is no framework on how to do research on a case-specific question. Due to the nature of the work the forensic sciences seem suited to mixed-method approaches. Our research supports the idea that mixed-method data can provide a depth and breadth of the understanding of the research question that may not be available when using just a quantitative or qualitative method. This information is complicated by the next finding within our study because one challenge when using a mixed-method research approach is that the researcher must analyze and collect different datasets. The researcher must also understand the complexity of the process and have knowledge of multiple data collection and analytical methodologies (Lanier & Briggs, 2014; Onghena, Maes, & Heyvaert, 2018). We present the following to understand if a research knowledge gap exists for forensic practitioners.

The quantitative results support that there is no relationship between the percent confidence of the participants and their years of experience or education level. The fact that, statistically, education level did not seem to play a role in providing confidence is worth further exploration. The participants research knowledge that is displayed in the qualitative results provides some guidance on this information.

Conducting a scientific literature review is a critical component of any research initiative. It is particularly important to forensic science knowing that a robust literature review could strengthen or diminish the weight of an expert's testimony in court. In our research, few of the practitioners surveyed said that they would conduct a literature review supporting the idea that a knowledge gap exists in this area. A literature review can also help risk manage a forensic practitioner’s bias within an investigation ("R. v. France," 2017; Zapf & Dror, 2017).

Research task irrelevant information can introduce bias into a case-specific research study. Therefore, the control of information (for example; what information is withheld and time of release) is extremely important in producing robust scientific research. The fictitious research cases presented in this study supported a simple research design that required no further case information, however a high number of BPAs requested research task irrelevant information such as medical or injury evidence. Due to the nature of their work, straight comparisons, only one individual from the FR and FW groups requested additional information of this type. Perhaps processes like evaluative reporting and hypothetico-deductive reasoning require more attention from forensic practitioners (Catoggio et al., 2019; Champod, Biedermann, Vuille, Willis, & De Kinder, 2016; Cook, Evett, Jackson, Jones, & Lambert, 1998a, 1998b; Lawson & Daniel, 2011).

AOC or AOO estimations should be used for the validation of an impact pattern within bloodstain pattern analysis. This validation technique has been extensively researched (Connolly, Illes, & Fraser, 2012; de Bruin, Stoel, & Limborgh, 2011; Illes & Boue, 2013; Orr, Illes, Beland, & Stotesbury, 2019) and all bloodstain analysts who completed the qualitative survey should have requested information on the AOC or AOO. This number is of concern with only five out of 29 (17%) asking for this information.

One participant from the FR and FW surveys commented on the statistical analysis, P-values. It was clear from this comment that this person was thinking in the abstract (using formal reasoning) when approaching the problem. They understood the results of the study and provided the correct answer, as the ground truth for this experiment is that the pressure = 1 lb. This individual indicated that their level of education is a Ph.D. The troubling part of this result is only one person out of 178 used the p-values as evidence or conveyed the knowledge base that the statistical analysis was understood.

The combination of: the lack of literature review; the request for task irrelevant information; no statistical relationship between confidence and education; the underused AOC and AOO by BPAs; and that only one participant from the FR and FW comments on the p-values, suggests that an epistemic gap exists for many practitioners in case-specific research and research methodologies. In fact, we did find several practitioner comments suggesting that they have a research knowledge gap;

"The only research method I know of to answer this question would be a visual analysis of latent distortion due to excessive pressure."

"I'm not a researcher, just a qualitative observation of the impressions is enough for me."

"My conclusions are not based on research, they are based on the possible conclusions and which possible conclusion has the most supporting data."

Conclusion

In conclusion, the mixed-method data type, combining quantitative and qualitative information, is most robust in supporting the confidence level of the forensic practitioner when providing an opinion on the case-specific research presented in this study. This could be due to the nature of forensic science work, where practitioners are routinely presented evidence in quantitative and qualitative forms within many disciplines (Charman, Kavetski, & Mueller, 2017; Neumann, Kaye, Jackson, Reyna, & Ranadive, 2016). Recent studies have also shown that mixed-method research is becoming more widely used in science investigations, providing more rigorous and deeper meaning to those data when compared to quantitative and qualitative methods (McKim, 2017; Onghena et al., 2018). Research triangulation by means of three forensic science disciplines (BPA, FR and FW) can support the use of mixed-method data in all the forensic sciences. Those qualitative data from the research task relevant information offers validation for the quantitative analysis of data types. The practitioners who responded to the quantitative and qualitive surveys requested more research task relevant information (80% of total) than those who responded to the mixed-method surveys. This is symptomatic of the practitioners not being confident with only having either quantitative or qualitative data types.

Finally, this study is the second into expanding epistemic understanding in forensic science. The evidence from our study supports the use of a mixed-method data collection and analysis approach for case-specific research within forensic science, however, further research is required to tease out appropriate guidelines and methodologies that would be accepted by the global scientific community. More importantly, the results support a need for forensic science practitioner education in experimental design and the use of the scientific method in case-specific research, specifically for the more complex mixed-method approaches.

References

Aboud, M. J., Gassmann, M., & McCord, B. (2015). Ultrafast STR Separations on Short-Channel Microfluidic Systems for Forensic Screening and Genotyping. *Journal of Forensic Sciences, 60*(5), 1164-1170. doi:10.1111/1556-4029.12723

Attinger, D., Moore, C., Donaldson, A., Jafari, A., & Stone, H. A. (2013). Fluid dynamics topics in bloodstain pattern analysis: Comparative review and research opportunities. *Forensic Science International, 231*(1–3), 375-396. doi:http://dx.doi.org/10.1016/j.forsciint.2013.04.018

Bono, J. P. (2011). Commentary on the Need for a Research Culture in the Forensic Sciences. *UCLA Law Review, 58*, 781-787.

Bordens, K. S., & Abbott, B. B. (2011). *Research Design and Methods A Process Approach*. New York: McGraw-Hill.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology, 3*(2), 77-101.

Bryce, C. F. A., Rankin, B. W. J., & Hunt, A. (2019). A report on the development and implementation of an assessment of competence scheme for the forensic sciences. *Forensic Science International: Synergy, 1*, 56-60. doi:10.1016/j.fsisyn.2019.03.005

Byard, R., & Vink, R. (2014). The law and the laboratory. *Forensic Sci Med Pathol, 10*(4), 481-482. doi:10.1007/s12024-013-9409-7

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & Neville, A. J. (2014). *The use of triangulation in qualitative research.* Paper presented at the Oncology nursing forum.

Catoggio, D., Bunford, J., Taylor, D., Wevers, G., Ballantyne, K., & Morgan, R. (2019). An introductory guide to evaluative reporting in forensic science. *Australian Journal of Forensic Sciences*, 1-5.

Champod, C., Biedermann, A., Vuille, J., Willis, S., & De Kinder, J. (2016). ENFSI Guideline for evaluative reporting in forensic science: A primer for legal practitioners. *Criminal Law and Justice Weekly, 180*(10), 189-193.

Charman, S. D., Kavetski, M., & Mueller, D. H. (2017). Cognitive Bias in the Legal System: Police Officers Evaluate Ambiguous Evidence in a Belief-Consistent Manner. *Journal of Applied Research in Memory and Cognition, 6*(2), 193-202. doi:10.1016/j.jarmac.2017.02.001

Connolly, C., Illes, M., & Fraser, J. (2012). Affect of impact angle variations on area of origin determination in bloodstain pattern analysis. *Forensic Science International, 223*(1-3), 233-240. doi:10.1016/j.forsciint.2012.09.009

Cook, R., Evett, I. W., Jackson, G., Jones, P., & Lambert, J. (1998a). A hierarchy of propositions: deciding which level to address in casework. *Science & Justice, 38*(4), 231-239.

Cook, R., Evett, I. W., Jackson, G., Jones, P., & Lambert, J. (1998b). A model for case assessment and interpretation. *Science and Justice, 38*(3), 151-156.

Cross, R. (2006). Fatal falls from a height: two case studies. *Journal of Forensic Sciences, 51*(1), 93-99. doi:10.1111/j.1556-4029.2005.00026.x

Damas, S., Wilkinson, C., Kahana, T., Veselovskaya, E., Abramov, A., Jankauskas, R., . . . Ibáñez, O. (2015). Study on the performance of different craniofacial superimposition approaches (II): Best practices proposal. *Forensic Science International, 257*, 504-508. doi:10.1016/j.forsciint.2015.07.045

de Bruin, K. G., Stoel, R. D., & Limborgh, J. C. (2011). Improving the point of origin determination in bloodstain pattern analysis. *Journal of Forensic Sciences, 56*(6), 1476-1482. doi:10.1111/j.1556-4029.2011.01841.x

Foss, C., & Ellefsen, B. (2002). The value of combining qualitative and quantitative approaches in nursing research by means of method triangulation. *Journal of Advanced Nursing, 40*(2), 242-248. doi:10.1046/j.1365-2648.2002.02366.x

Gertner, N. (2011). Commentary on the Need for a Research Culture in the Forensic Sciences. *UCLA Law Review, 58*, 789-793.

Gold, A. D. (2003). *Expert Evidence in Criminal Law: The Scientific Approach*. Toronto: Irwin Law Inc.

Graner, R., & Kronkvist, O. (2015). *The Past, the Present and the Future of Police Research: Proceedings from the fifth Nordic Police Research seminar*: Linnæus University studies in policing.

Griffiths, C. T. (2014). *Economics on Policing: Baseline for Policing Research in Canada*. Public Safety Canada.

Houck, M. (2015). *Professional Issues in Forensic Science*. San Diego, CA: Elsevier.

IABPA. (2018). Retrieved from http://www.iabpa.org/

IABPA. (2018). International Association of Bloodstain Pattern Analysts Bloodstain Pattern Analysis Basic Course: Course Requirements. Retrieved from http://www.iabpa.org/iabpa-training-course-standard

Illes, M., & Boue, M. (2013). Robust estimation for area of origin in bloodstain pattern analysis via directional analysis. *Forensic Science International, 226*(1-3), 223-229. doi:10.1016/j.forsciint.2013.01.030

Kalyal, H. (2019). "Well, there's a more scientific way to do it!": factors influencing receptivity to evidence-based practices in police organizations. *Police Practice and Research*, 1-15. doi:10.1080/15614263.2019.1608548

Kelty, S. F., & Julian, R. (2011). Success in Forensic Science Research and Other Collaborative Projects: Meeting Your Partners' Expectations. *Forensic Science Policy & Management: An International Journal, 2*(3), 141-147. doi:10.1080/19409044.2012.674086

Kueffer, C. (2006). Integrative Ecological Research: Case-Specific Validation of Ecological Knowledge for Environmental Problem Solving. *GAIA - Ecological Perspectives for Science and Society, 15*(2), 115-120.

Langenburg, G. (2011). Scientific Research Supporting the Foundations of Friction Ridge Examinations. In The Fingerpirnt Sourcebook, (pp. 1-27): National Institute of Justice. Retrieved from http://www.nij.gov/pubs-sum/225320.htm.

Lanier, M., & Briggs, L. T. (2014). *Research methods in criminal justice and criminology: A mixed methods approach*: Oxford University Press.

Lawson, A. E., & Daniel, E. S. (2011). Inferences of clinical diagnostic reasoning and diagnostic error. *J Biomed Inform, 44*(3), 402-412. doi:10.1016/j.jbi.2010.01.003

Linacre, A. (2013). Towards a research culture in the forensic sciences. *Australian Journal of Forensic Sciences, 45*(4), 381-388. doi:10.1080/00450618.2012.738246

MacLean, B., Powley, K., & Dahlstrom, D. (2001). A Case Study Illustrating another Logical Explanation for High Velocity Impact Spatter. *Journal of the Canadian Society of Forensic Science, 34*(4), 191-195.

Margot, P. (2011). Commentary on the Need for a Research Culture in the Forensic Sciences. *UCLA Law Review, 58*, 795-801.

McKim, C. A. (2017). The Value of Mixed Methods Research. *Journal of Mixed Methods Research, 11*(2), 202-222. doi:10.1177/1558689815607096

Milliet, Q., Delemont, O., Sapin, E., & Margot, P. (2015). A methodology to event reconstruction from trace images. *Science & Justice, 55*(2), 107-117. doi:10.1016/j.scijus.2015.02.001

Mitchell, G., Walker, L., & Monahan, J. (2011a). Beyond Context: Social Facts as Case-Specific Evidence. *Emory Law Journal, 60*, 1111-1164.

Mitchell, G., Walker, L., & Monahan, J. (2011b). Beyond Context: Social Facts as Case-Specific Evidence. . *Emory Law Journal, 60*(5), 1111-1154.

Mnookin, J. L., Cole, S. A., Dror, I. E., Fisher, B. A. J., Houck, M. M., Inman, K., . . . Stoney, D. A. (2011). The Need for a Research Culture in the Forensic Sciences. *UCLA Law Review, 58*(3), 725 - 779.

NAS. (2009). *Strengthening Forensic Science in the United States: A Path Forward* (T. N. A. Press Ed.). Washington: National Academy of Sciences.

Neumann, C., Kaye, D., Jackson, G., Reyna, V., & Ranadive, A. (2016). Presenting Quantitative and Qualitative Information on Forensic Science Evidence in the Courtroom. *Chance, 29*(1), 37-43. doi:10.1080/09332480.2016.1156365

NVivo. (2018). Retrieved from http://www.qsrinternational.com/nvivo/nvivo-products

Onghena, P., Maes, B., & Heyvaert, M. (2018). Mixed Methods Single Case Research: State of the Art and Future Directions. *Journal of Mixed Methods Research*. doi:10.1177/1558689818789530

Orr, A., Illes, M., Beland, J., & Stotesbury, T. (2019). Validation of Sherlock, a linear trajectory analysis program for use in bloodstain pattern analysis. *Canadian Society of Forensic Science Journal*, 1-17. doi:10.1080/00085030.2019.1577793

OSAC. (2018). OSAC. Retrieved from https://www.nist.gov/topics/forensic-science/crime-scene-investigation-subcommittee

OSAC Research & Development Needs (2017). Retrieved from https://www.nist.gov/topics/forensic-science/osac-research-development-needs

PCAST. (2016). *Report to the President Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature - Comparison Methods (Executive Summary)*. USA.

Pollanen, M. S., Bowes, M. J., VanLaerhoven, S. L., & Wallace, J. (2013). *Forensic Science in Canada: A Report of Multidisciplinary Discussion*. Toronto: Centre for Forensic Science and Medicine, University of Toronto.

R. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Retrieved from https://www.r-project.org/

R. v. France, (2017).

R. v. Millard (2018).

R. *v.* Mohan 1 (Supreme Court of Canada, File no. 23063 1994).

R. v. Wood, (2012).

Saks, M. J. (2010). Forensic identification: From a faith-based "Science" to a scientific science. *Forensic Science International, 201*(1-3), 14-17. doi:10.1016/j.forsciint.2010.03.014

Scolarsportal. (2018). Retrieved from http://journals1.scholarsportal.info.cat1.lib.trentu.ca:8080/browse/03790738

State v. Romero, No. No. CR-15-0039-PR, 365 358 (Ariz: Supreme Court 2016).

Steinheider, B., Wuestewald, T., Boyatzis, R. E., & Kroutter, P. (2012). In search of a methodology of collaboration: understanding researcher–practitioner philosophical differences in policing. *Police Practice and Research, 13*(4), 357-374. doi:10.1080/15614263.2012.671620

Ulriksen, M. S., & Dadalauri, N. (2014). Single case studies and theory-testing: the knots and dots of the process-tracing method. *International Journal of Social Research Methodology, 19*(2), 223-239. doi:10.1080/13645579.2014.979718

Zapf, P. A., & Dror, I. E. (2017). Understanding and Mitigating Bias in Forensic Evaluation: Lessons from Forensic Science. *International Journal of Forensic Mental Health, 16*(3), 227-238. doi:10.1080/14999013.2017.1317302

Chapter 4: The Scientific Method in Forensic Science: A Canadian Handbook

A version of this chapter will be published in June 2020.

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This is a reprint of preface from the textbook: *The Scientific Method in Forensic Science:*

A Canadian Handbook.

Preface

This book has been written for the Canadian forensic science student and professional practitioner. It provides an experience-based learning opportunity for understanding the scientific method and evidence-based analysis as they relate to forensic science in Canada. In 2015, I was assigned by my Forensic Science Department Chair to teach a course on the scientific method for second year forensic science students. I immediately reviewed the previous year's course syllabus and a copy of the textbook that had been in use. To my disappointment, the textbook was on research design for a criminology course and contained very little forensic content. My search began for a text that would support forensic science students and practitioners in Canada. Specifically, I was hoping to find a textbook that would provide the theory combined with forensic case studies and other experience-based examples. The search was unsuccessful, and in fact there were very few forensic science books available with Canadian content. This presented the opportunity to completely redevelop this course. The course was redesigned with teachings on the scientific method in forensic science; how to read a journal article; and how to write a forensic science report, with assigned readings from peer reviewed forensic and scientific journals. I taught the course for several years and was still not satisfied with content because the diversity of readings for each topic was overwhelming for one course.

That was the motivation for writing this book. The chapters to follow contain a summarization of the literature for each topic researched. They relate to forensic science in Canada and abroad. The scope of the book does not only discuss science and its connection to forensic science but, more importantly, how real-life forensic case experiences relate to the science. This book is also part of my PhD, researching forensic epistemology. Here is a summary for each chapter. Each chapter will contain a short introduction, a glossary, discussion questions, further readings and additional instructional pop outs.

Chapter 1 Introduction: The Paradigm Shift in Forensic Science?

This chapter introduces the reports that have significantly changed forensic science in Canada and internationally. These reports are reviewed from a high-level perspective while presenting information on why there has been a paradigm shift within forensic science. This will provide reasoning of the need for those interested in forensic science, to understand scientific method and evidence-based analysis. Throughout the chapters, we provide examples of how forensic science has roots in science (e.g., DNA, biology, anthropology) and policing (e.g., fingerprints, footwear comparison), and the variation in scientific underpinnings in the numerous disciplines.

Chapter 2 Concepts of Science and the Scientific Method

Chapter 2 explores how science and scientific reasoning fits within forensic science and the evolution of various forensic science disciplines. Knowledge, information, scientific explanations, and common sense will be defined and discussed. The reader will gain an appreciation for the role of scientific reasoning and how approaches such as falsification and hypothesis testing are essential to forensic applications. This will provide a foundation to the use of evidence-based practice: a central theme throughout the book.

The above chapters lead into a discussion on further skill sets and knowledge such as critical thought, problem solving, and ethics: components vital to forensic professionals.

Chapter 3 Critical Thought in Forensic Science

Critical thought is the underpinning of most university curricula. We will explore the research that defines and supports critical thinking including the idea of rationality, honesty, open-mindedness, discipline, judgment and how these fit within forensic investigations.

Problem solving is a concept that is highly connected to critical thinking. Because of this, we explore concepts on respecting and incorporating multiple perspectives, how to monitor our beliefs and knowledge, how to plan ahead, evidence-based justification and argumentation, and how to reconcile conflicts.

Chapter 4 How to Critically Review a Published Journal Article

Chapter 4 examines how to critically review a journal article. The initial appraisal will look at authorship, date of publication, addition or revision, publisher and the title of the journal. The purpose of the components of a scientific journal article, including the abstract, introduction, methods, results/discussion, and conclusion, will be discussed. We critically review each component so that readers can develop the required skill sets for doing comprehensive article reviews.

Chapter 5 What the Literature Says: From Student to Expert

A literature review is just like a criminal investigation. As a forensic scientist or investigator, you will be required to collect evidence prior to a charge being laid and any attempt at prosecution in court. The same applies to a research question or to an expert witness who has the responsibility of providing the courts with objective, impartial, and independent evidence that has been researched. In this chapter, we explore the appropriate use of high- and low-level publication sources, some basic search strategies, accessing the evidence base, types of literature reviews, and its role within research and for the forensic practitioner.

Chapter 6 The Use, Misuse, and Absence of Statistics in Forensic Science Casework

This chapter has been written to explore some case examples that used statistics or probability theory in court. We have supplied an "exercise pop out" on the statistical methods that are being discussed for those who may not be familiar with these concepts. The use of mathematics in several case studies will be explored; the application of DNA in wildlife in Canada and human DNA court cases; the 1999 murder trial and conviction of Sally Clark in the United Kingdom. The reader will learn the good and the bad of the application of statistics or probability from a practitioner view with critical scientific discussion surrounding each case.

Chapter 7 Research Design for the Forensic Science Student and Practitioner

Chapter 7 reviews the basic concepts of research design and provide forensic research examples for a correlational study and experimental design. Ideas will include quantitative, qualitative, and mixed method approaches; the stages of research design; and basic scientific concepts, such as applied versus pure research. There will be an emphasis on core research practices like planning the experiment, literature review, formulating research hypotheses and research questions.

Chapter 8 The Importance of Ethics and Bias in Forensic Science

Forensic science has an array of professional guidelines from multiple sources such as the Canadian Society for Forensic Science. The list of organizations is very large. In Chapter 8, the learning outcomes will be a basic understanding of ethics in Canadian forensic science and research, define ethics and discuss case study examples. The reader will learn about the University Research Ethics Board System within a Canadian university and the Canadian Tri-Council Policy on Ethical Conduct for Research Involving Humans.

This chapter will also cover examples of bias in forensics science and suggest possible solutions. It will stress the role of scientific method and evidence-based analysis in helping to reduce or control bias.

Chapter 9 The Key to Effective Communication in Forensic Science

This will be the synthesis of the information provided in all chapters, which has created a path of scientific research to support evidence-based reporting and presentation. The reader will see the development of report writing and court presentation style that has been reinforced from the beginning of the book. This style parallels with scientific method, academic journal articles, theses and dissertations. This chapter will also emphasize writing and oral structure, advocating for the truth, owning your expertise, and the importance of peer review. There is a notable difference between presentations in academia and in legal settings. Therefore, we emphasize a balance between scientific integrity and readability/understandability when an expert is presenting within a legal context.

This book blends scientific concepts and forensic science case examples in each chapter; making it a fundamental read for any forensic science student or professional. Chapter 1 speaks to the importance of this as forensic scientists and practitioners are required to use more science in forensic science. It discusses the need for such things as research, validation, repeatability, oversight, peer review, accountability, transparency, report structure, statistics, and bias. The rest of the book provides a foundation for the use of methods to help with these issues from a Canadian and global perspective.

Mike Illes

Chapter 5: Forensic Epistemology: A Need for Research and Pedagogy

A version of this chapter has been published.

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Contributions: PW and CB participated in editing the draft manuscript. MI completed the literature review, interpreted the results and drafted the manuscript. All authors read and approved the final manuscript.

Abstract

This is the third in a series of articles reporting on forensic epistemology. Our first two research articles presented scientific results that are based in experimental design; including quantitative and qualitative responses from forensic science practitioners to scenarios and evidence. Based on a synthesis of this research there is evidence of a knowledge gap in formal reasoning for some forensic practitioners, and a limited understanding of case-specific research. Combining these results with a review of the current literature in the field of forensic reasoning, we now offer evidence of teaching and research strategies that can help increase the epistemic status (Confidence in, and justification of knowledge) of forensic science claims. This paper focuses on an integrated narrative review using hermeneutic methods of analysis to identify: (i) the epistemic state of forensic science; (ii) strategies to increase of knowledge; (iii) the need for collaboration between practitioners and academics; and, (iv) areas for future research.

Keywords: forensic epistemology, pedagogy, experimental research design, problem-based learning, deep learning

Introduction

This study synthesizes the results from two primary studies, *"Forensic Epistemology: Testing the reasoning skills of crime scene experts"* (Illes, Wilson, & Bruce, 2019) *and "Forensic Epistemology: Exploring Case-Specific Research in Forensic Science"* (Illes & Wilson, Submitted) and amplifies evidence from these studies with a focused literature review that identifies strategies to increase the epistemic status of forensic science. Forensic practitioners work long irregular hours analyzing horrific crimes that the general public would elect to avoid. In the process, they are expected to provide superior scientific results as experts in a working atmosphere where time, funding and caseloads leave little time for scientific inquiry and collaboration with academic institutions (Champod, 2014; Graner & Kronkvist, 2015; Griffiths, 2014; Linacre, 2013). Our research suggests that forensic practitioners need greater opportunities for (i) case-based learning, (ii) research collaborations, and (iii) the development of forensic science epistemology.

The present forensic science environment of super-specialisation, where practitioners are "siloed" into one discipline diminishes the generalist approach (Pietro, Kammrath, & De Forest, 2019; Robertson & Roux, 2018; Roux, Talbot-Wright, Robertson, Crispino, & Ribaux, 2015; Stoney & Stoney, 2015). Research has shown that cumulative knowledge and experience in different domains provide a better depth and breadth of knowledge (Epstein, 2019). In the business world, for example, the ability of a team to solve ill-structured problems is largely dependent on the diversity of skills, knowledge and experience of the individuals on the team (Avdiji, Elikan, Missonier, & Pigneur, 2018; Edmondson & Harvey, 2018) yet in the field of forensic science, practitioners over the past decade have moved increasingly toward specialization (Brown, Logan, & McKiernan, 2019; Robertson & Roux, 2018). This may have caused the unintended outcome of a division between practice and theory (Kelty, Robertson, & Julian, 2017; Robertson & Roux, 2018). As a result, some questions for the forensic education community are emerging: i) Should forensic education be about gaining generalized skill sets and what are these skill sets? and ii) Does super-specialization diminish critical thought and problem-solving abilities in complex contexts, for students and practitioners? It is incumbent on forensic science educators to understand the required skills; supplying the appropriate level of theory-practice curriculum to prepare students for forensics careers as practitioners (Pietro et al., 2019; Roux, Ribaux, & Crispino, 2018).

The literature specific to forensic epistemology (justification of inferred knowledge) consists mostly of article reviews mixed with commentaries on the state of forensic science. In one early example, Chazo (Chazo, 1979) published an article on forensic epistemology outlining how it can impact court deliberation and conclusions in law. Later, in a more specific example of critique, Lynch's (Lynch, 2013) article on the evolution of DNA within the court system highlights the fact that the exceptional legal status of the "gold standard" held by DNA may not be as near to the truth as previously thought. Subsequently, in 2014 Swan (Swan, 2014) offered a framework for reconsidering forensic science approaches, where she incorporated Karl Popper's three-world ontology as one structure for analyzing forensic evidence: first world is connected to the crime scene evidence, second world consists of forensic science methodology and third world is the reconstruction of the crime as it relates to the law and ethical requirements. For more discipline specific examples, Cole and Swofford (Cole, 2009; Swofford, 2015) investigated the forensic epistemology of fingerprint comparisons, suggesting that we are undergoing a shift in conceptual understanding of how the fingerprint analysis community make friction ridge individualizations. In an article written by Crispino et al. (Crispino, Ribaux, Houck, & Margot, 2011) the scientific state of forensic science was debated with the principles from Locard (exchange principle, every contact leaves a trace) and Kirk (concept of individualization) being presented as evidence of logical epistemologies in forensic science. Later, Roux et al. (Roux et al., 2018) published a paper *"Forensic science 2020 – the end of the crossroads?"* that briefly discusses forensic epistemology, reiterating the importance of Kirk and Locard principles. Taken together, these articles and others provide a significant contribution indicating the importance of epistemology in forensic science, however they do not offer methods or strategies for increasing the knowledge of forensic students or practitioners. Further, none of these articles contain experimental research with supporting quantitative evidence to direct forensic epistemology research or pedagogy.

The objective of this article is to offer a set of effective strategies for increasing student and practitioner knowledge, based on a literature review and current research conducted by the authors in an experimental design process. The evidence includes quantitative and qualitative data types that were collected directly from forensic science practitioners. Based on our research, we inquire into current conceptions of the epistemic status in forensic science; offer possible strategies for the increase of knowledge; and recommend strategies for collaboration between practitioners, academics and policy makers.

Methods

This research explores the epistemic status of forensic science. More specifically, it uses the results from two previous studies on the reasoning skills (logical knowledge) used by crime scene experts and methods (empirical knowledge) for forensic case-specific experimentation.

The first study conducted evaluates the use of reasoning by practitioners in the disciplines of crime scene investigations and bloodstain pattern analysis. A well-established classroom test of scientific reasoning was distributed online to active crime scene investigators and bloodstain pattern analysts (n = 213) using Qualtrics software. The survey provides quantitative data on the reasoning ability of the participating practitioners along with demographic information on education, employment status (specifically, police or civilian), and work experience (Illes, Wilson, et al., 2019).

In the second study we developed three cases from different pattern-interpretation disciplines: a friction ridge analysis; a bloodstain pattern analysis; and a footwear impression analysis. For each case, a series of experiments was derived using three different data types: a quantitative approach (using numeric data), a qualitative approach (using image data) and a mixed-method approach (using both numeric and image data). We supplied data analyses that would be common knowledge for academic researchers. Electronic files were compiled for each case and research method and forwarded by Qualtrics Software to forensic practitioners (n = 278) within the prescribed discipline. Demographic questions on practitioner education level and years of experience were included in the survey, along with open ended comment areas (Illes & Wilson, Submitted).

The results from these studies is combined in this paper, with an integrated narrative review that applies hermeneutic methods (subjective systematic interpretation of the literature) of current literature (2015-19) on pedagogy and research methods to offer a synthesis of strategies that will help increase practitioner knowledge. The results are organized here in three key themes: (i) the epistemic state of forensic science; (ii) pedagogic strategies; and (iii) a call for research.

Three Key Themes

I. The Epistemic State of Forensic Science

In our first paper *"Forensic Epistemology: Testing the reasoning skills of crime scene experts"* (Illes, Wilson, et al., 2019) the research indicates that there may be knowledge gaps within the crime scene expert groups tested based on education level, employment status (specifically, police or civilian practitioner status) and years of experience. These data show that higher educated practitioners (with graduate level academic experience) performed better on the reasoning test. Interestingly, no differences were found between the test scores and the years of experience, even when comparing the lowest and highest levels of experience. Similarly, there was no significant difference between the test scores and employment status (specifically, police or civilian practitioner status) in the group. In the second paper *"Forensic Epistemology: Exploring Case-Specific Research in Forensic Science"* (Illes & Wilson, Submitted) the percent confidence level to form an opinion by forensic experts was investigated for three data types and three pattern interpretation disciplines. The results suggest that practitioners were more confident using a mixed-methods data approach. No differences were found between the confidence levels and discipline type. Similarly, there was no significant difference between the confidence levels and years of experience nor the participant's education level. The qualitative data analysis validates the quantitative results and suggests that there is a knowledge gap for forensic practitioners in case-specific research contexts.

The results of these studies suggest that there may be knowledge gaps for some forensic practitioners. They support the testing of knowledge and skills and then the delivery of appropriate pedagogies that help to close gaps, with the goal of increasing the epistemic range and accuracy of forensic students and practitioners. In order to close these gaps, we believe it is important to interrogate whether or not forensic science education is a complex environment, how graduate studies can extend knowledge and then suggest pedagogical practices that can increase reasoning and problem-solving skills for forensic scientists.

Solving Ill-structured Problems

Research supports two different types of problems; well-structured problems that would exist in “kind” or simple environments and ill-structured problems that exist within “wicked” or complex environments (Choi & Lee, 2008; Epstein, 2019). Hogarth (Hogarth, 2001) defines “kind” learning environments as circumstances where a person relies on patterns and that these patterns will remain constant, and critical thought is not necessarily required. Epstein (Epstein, 2019) uses the game of chess as an example of a kind environment. A master chess player has memorized patterns that occur on the chess board and they deploy moves according to previously learned patterns to win a game. In contrast, forensic science most usually involves a wicked environment, specifically for crime scene experts, because every crime scene is different, presenting a plethora of ill-structured or complex and multi-faceted problems. According to Shin et al. (Shin, Jonassen, & McGee, 2003) good ill-structured component skills consist of, “domain knowledge, justification skills, science attitudes, and regulation of cognition”. In forensic science and forensic science education it may be dangerous to treat an ill-structure problem type environment as a well-structured environment, because students and practitioners require different knowledge and skill sets (Jonassen, 2017). In addition, there has been an upsurge in research on the regulation of cognitive bias in forensic science, adding another layer of problem-solving complexity for forensic students and practitioners (Edmond et al., 2017; Zapf & Dror, 2017). Our research supports this need for treating forensic scenes as ill-structured. Unfortunately many forensic classroom lessons are designed as well-structured problem solving (Akinci-Ceylan et al., 2018) at this time.

Pattern recognition relies on experience and a guarantee that there is a repetitive structure (Epstein, 2019). Historically, there are forensic science disciplines that are taught and reliant on this type of well-structured environment. Many of the comparison disciplines such as friction ridge, footwear, and bloodstain pattern analysis depend heavily on pattern recognition (Dror & Cole, 2010; Langer & Illes, 2015; NIJ, 2011). Amos Tversky and Daniel Kahneman's (Tversky & Kahneman, 1974) research on highly trained experts found that experience does not help and can make things worse because it made the experts more confident. Forensic science work can be: complex; lacking set rules; missing the ground truth information in a contextually rich environment; and containing conflicting information (Zajac, Osborne, Singley, & Taylor, 2015). Unfortunately, in this type of wicked environment experience reinforces the wrong lessons and decisions (Akinci-Ceylan et al., 2018; Choi & Lee, 2008; Epstein, 2019). Research into mitigating bias in forensic science supports the need for education in problem-solving skills. Understanding processes including; linear sequential masking, filler-control procedures, hypotheses testing, the scientific method, peer review and context information management can help navigate a contextually rich forensic environment (Dror et al., 2015; Mattijssen, Kerkhoff, Berger, Dror, & Stoel, 2016; Quigley-McBride & Wells, 2018; Stevenage & Bennett, 2017; Zapf & Dror, 2017). Forensic science curriculum needs to focus on teaching ill-structured problem-solving skills and the following strategies offer direction in accomplishing this task (Ribaux, Roux, & Crispino, 2016).

Graduate Studies

The participants who had completed graduate work preformed better on the classroom test of scientific reasoning within our first study on forensic epistemology (Illes, Wilson, et al., 2019). There may be a variety of reasons for the higher marks. However as stated above, a forensic expert should be trained in ill-structure problem solving which would be more ubiquitous in graduate work (Bowen, 1990; O'Neill et al., 2019) (see Teaching Research Design to follow later). We suggest that these participants would have also experienced deeper learning (see Pedagogic Strategies also to follow later) due to the extra time in school, a more complex curriculum and possibly the exploration of new knowledge in a Ph.D. environment (Ortega & Kent, 2018). Interestingly, there was no statistical difference between the levels of education in the confidence level in developing an opinion on case-specific research problems. The following sections provide some strategies that may help with increasing the epistemic state of forensic science.

II. Pedagogic Strategies

Our research on forensic epistemology has indicated that there is a gap for practitioners in scientific reasoning skills and understanding research design, suggesting a need for deep learning (Illes & Wilson, Submitted; Illes, Wilson, et al., 2019). Thus, deep learning is defined as learning with understanding, which is the opposite to surface or rote learning where a student primarily wants to reproduce what has been learned (Beattie IV, Collins, & McInnes, 1997; Dolmans, Loyens, Marcq, & Gijbels, 2016). Although literature on deep learning in forensic science education is limited, our research and the educational literature supports the need for a deep learning environment in forensic science pedagogy (Weber, Becker, & Hillmert, 2019). Researchers such as Dolmans et al., Andersen et al. and Larmer (Andresen, Boud, & Cohen, 2000; Dolmans et al., 2016; Larmer, 2014) recommend specific teaching strategies for enhancing deep learning that can be applied to forensic science education; problem-based learning, case or experience-based learning, project-based learning, project-based forensic practitioner blended learning curriculum, teaching research design, and a scientific method and research design course. Each of these strategies is worth consideration in combination with real cases, archived evidence and controversial cases with ambiguous evidence. Figure 5.1 provides a summary of the interface between project-based, problem-based and experience-based learning followed by detailed reviews of each.

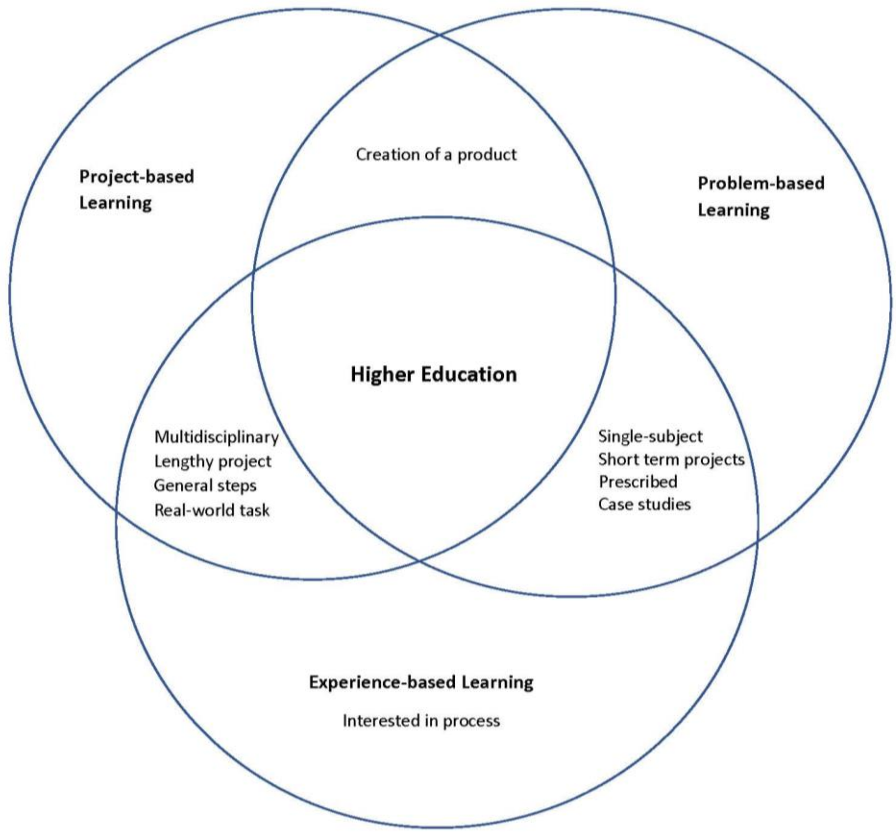


Figure 5.15: Interface between project-, problem- and experience-based learning in higher education (Andresen et al., 2000; Larmer, 2014; Ralph, 2016)

Problem-based Learning

There has been a shift in tertiary education from a teacher- to a student-centered model of teaching (Newton, Bettger, Buchholz, Kulak, & Racey, 2015). Considering the nature of forensic science work, this shift should have a positive impact in pedagogy at the university and college level (Bryce, Rankin, & Hunt, 2019; Levin, Nilsen, Bendtsen, & Bülow, 2018). In fact, one way of initiating this shift is by using a problem-based learning (PBL) model which is defined as “a pedagogical approach that enables students to learn while engaging actively with meaningful problems" (Yew & Goh, 2016). PBL has been around for about fifty years with historical records demonstrating that MacMaster University was the first learning institution to implement PBL within their medical school (Servant-Miklos, 2019). Since that time its use has spread into tertiary and K-12 learning environments on a global level (Servant-Miklos, 2019).

The literature on PBL is extensive and validation research has provided evidence of its efficacy (Dolmans et al., 2016; O'Neill et al., 2019; Servant-Miklos, 2019; Yew & Goh, 2016). Although there is adequate research supporting PBL's significant contribution to the pedagogy of practitioner-based fields such as medicine, we provide current and explicit examples that support its use in forensic science education.

Samarji (Samarji, 2012) completed an assessment on forensic science education finding that prior to 2012 there was very little published on this topic. The assessment was completed on 190 forensic science courses, on a global level, for forensic science knowledge, practice and identity. Consequently, the results suggest that there is a lack of authentic forensic science courses that included practitioner real world problem-based content. Nevertheless, researchers from the North Carolina Agriculture and Technical State University used an interdisciplinary teaching approach to create a more real-world experience in their forensic courses. This involved cross pollinating the same simulated crime scene among four different courses; Investigative Process II (CRJS 420), Survey in Forensics (CRJS 546), Basic Quantitative Writing and Computer Skills in Sociology (SOCI 101), and Quantitative Analysis I Laboratory (CHEM 232) (Fakayode, Mayes, Kanipes, Johnson, & Cuthbertson, 2016). This provided a deeper understanding of how forensic science works, promoting problem-solving, critical thought and team work for the students.

In a 2017 study, researchers tested PBL against traditional lecture-based learning for forensic medical students. Their finding indicated a significant statistical learning outcome for the PBL group (Balendran & John, 2017). Similarly, Kennedy (Kennedy, 2017) describes how a team of forensic educators reconfigured “The Pale Horse” model by Belt et al. (Belt, Evans, McCreedy, Overton, & Summerfield, 2002), which is used for assessing student problem-solving skills in chemistry, for forensic science. This model uses a fictitious suspicious death investigation where students work in groups and are gradually supplied information about the case. The Kennedy team developed a crime scene scenario problem-solving exercise that encompassed a full course over one semester. Student improvement was significant when compared to a cohort who received traditional lecture base practices. In a different type of study, Pringle et al. (Pringle, Bracegirdle, & Potter, 2017) discuss results from the introduction of forensic e-gaming into university curriculum to enhance problem-solving abilities while at the same time engaging the more technology driven “Generation Y” student cohort. The results indicated the contemporary learning environment was recommended over the traditional lecture type learning. Altogether, these examples offer diverse research supporting the use of PBL in forensic science education.

Case or Experience-Based Learning

Experiential learning has a long history dating to its development by Kolb (Kolb, 1984) in the 1970's and can be defined as learning by experience. Kolb used theories presented by John Dewey, Kurt Lewin and Jean Piaget to formulate this learning strategy that has been accepted on a global level (Kolb, 1984). Combining Dewey's experience-based model (which incorporates observation, knowledge and judgement) with the Lewinian experimental learning model (which is based on concrete experience, observation, abstract concept formation and action to test those concepts) provides a framework for Kolb's theory. The addition of Piaget's model of learning and cognitive development helps synthesize the three learning models by including the development of adult thought, specifically scientific knowledge (Kolb, 1984; Kolb, Boyatzis, & Mainemelis, 2001). These models consider the individual learning style and support group learning which should be a consideration for the educator.

More recently, and vital to this discussion, is the plethora of research supporting experience-based learning (EBL) in higher education. For a general example, Kolb et al. (Kolb & Kolb, 2005) researched the enhancement of learning in higher education suggesting the experience that students have such as feeling respected, a safe learning space and being able to act and reflect is imperative to their learning. Further, researchers have examined the use of EBL in a number of academic settings. In an article written by Balram (Balram, 2019), the author places EBL as one of the two learning styles (the second being lectures) used in geographic information systems within the tertiary environment. Equally important, nursing educators have extensively researched and used experiential learning within their curriculum presenting training scenarios in a variety of settings, the development of clinical skills, simulations, game-based play, stay-in instructor environment with full student involvement in clinic placements and drug dose calculations (Grace, Stockhausen, Patton, & Innes, 2019; Henderson, Clements, Webb, & Kofinas, 2019; Macindo, Danganan, Soriano, Kho, & Bongar, 2019; Mackie & Bruce, 2016). Another example is the use of EBL in business education where students have been afforded the opportunity to experience the business world on a global level, which is relevant to 21st Century learning (Edokpolor & Adeniyi, 2019; Petrie, Murrell, Schultz, & Jones, 2019; Tate, Subedi, & Maheshwari, 2019). Experiential learning has also been presented as one way of sustaining the development of higher education on a global level (Backman, Pitt, Marsden, Mehmood, & Mathijs, 2019).

This model has been reinforced in forensic science by Rogers (Rogers, 2017) who suggests one way of closing the theory-practice learning gap by following Kolb's methods was combining the use of traditional lectures with crime scene house practical exercises. In a similar example, a group of forensic engineer researchers used a mock aircraft accident scene as a replacement for traditional lectures within a master's-level course (Rans, Saunders-Smits, & Schuurman, 2015). The final examination was a scene investigation where the students were required to organize groups, document and collect evidence. The student feedback and a positive correlation between learning objectives and grades indicated a successful case-based learning example (Rans et al., 2015). Further studies that concentrated on a bloodstain pattern analysis course and a crime scene investigation course completed by Illes et al. (Illes, Bruce, Stotesbury, & Hanley-Dafoe, 2016; Illes, Stotesbury, Bruce, & Hanley-Dafoe, 2019) also supported the contention that real-world experience-based learning provided student improvement and engagement.

Even where a forensic training institution does not have a crime scene house, case-based learning can be used. Cresswell and Loughlin (Cresswell & Loughlin, 2017) present a clever in-class approach that supported the use of a case-based scenario in chemistry and biology courses for forensic science students. Especially important, the researchers found such strong student interest and engagement in case-based learning that they developed a interdisciplinary methodology framework for course implementation (Cresswell & Loughlin, 2017). Likewise, a 2018 study conducted by David Byrne (Byrne, 2018) investigated the use of simulated ill- structured crime scenes in the classroom to enhance student knowledge retention. The results suggested that the use of mock crime scenes in a tertiary environment enhanced both student learning and curriculum retention.

In summary, the research suggests that case-base learning requires domain specific knowledge examples in a forensic science degree program, that can be intertwined with theory, will help close any theory-practice knowledge gap (Akinci-Ceylan et al., 2018; Bryce et al., 2019). This may be problematic for some forensic teaching programs that do not have domain expert teaching staff or a real-world crime scene teaching/research facility (Asikainen & Gijbels, 2017; Illes, Bruce, Stotesbury, & Hanley-Dafoe, 2018).

Project-based Learning

Project-based learning (PjBL) as defined by Larmer et al. (Larmer & Ross, 2009), is used to engage students and guide them through a project where they provide a product or presentation. It is used to encourage 21st Century skill sets such as working in teams on real-world problems and coming up with solutions (Hutchison, 2015). PjBL has been extensively supported for used in K-12 education. For instance, in 2015 the Ministry of Education in Ontario, Canada identified PjBL as the future of education providing a deeper learning environment (Hutchison, 2015). PjBL has also been described as a way to "prepare students to master their new role as a global citizen with greater responsibilities" (Jamali, Md Zain, Samsudin, & Ale Ebrahim, 2017). Subsequently, the use of PjBL has emerged in higher education with research supporting its use in science, technology, engineering and mathematic (STEM) subjects (Ralph, 2016). In fact, the use of PjBL in secondary education has increased the number of students who pursue a post-secondary STEM education (Han, 2017).

Research supports the use of project-based learning as a way of increasing skills, such as communication, collaboration, hypotheses development, identifying learning pathways, problem-solving, and critical thought. This can be accomplished by focusing on an interdisciplinary project (involving the crime scene, police, forensic laboratory, scientists and justice system) over a longer period of time (Jamali et al., 2017; Raposo, Saúde, & Zarcos, 2018). The projects are ill-structured where students work in small groups, taking the focus from traditional teacher learning to a student-centered learning process (Raposo et al., 2018). These types of long-term projects can be accomplished in tertiary education.

Although there has been limited connection between PjBL and forensic science in the literature, we believe this type of pedagogy promises the potential for a deeper learning environment, which is suited to the goals of forensic science education. PjBL is appropriate for forensic science graduate students and practitioners because the process relies upon prior knowledge and experience as a foundation of the constructionism principles (students are actively involved) governing this pedagogy (Kokotsaki, Menzies, & Wiggins, 2016; Ralph, 2016).

Project-Based Learning for Forensic Practitioners

Our research suggests that there is a knowledge gap for forensic practitioners. Therefore, we would be remiss not to provide a strategy for practitioner adult education. Based on the research within this article we have developed a strategy entitled "Project-Based Learning for Forensic Practitioners (PrBLFP)" by combining some of the above-mentioned pedagogical concepts with a blended learning educational process.

This pedagogic concept would provide practitioners access to a deep learning adult environment where their own experience will be critical to the process and student success. The blended learning setting is beneficial to the busy adult life of a practitioner by providing some onsite traditional teaching with an emphasis on an online component. The online component provides opportunity for the development of a complex project, conducted long term and specific to a forensic domain. It offers an opportunity that would include communication, collaboration, problem-solving and critical thought using multiple 21st Century skills and technologies. The project would also incorporate the development of complex research design and formal logic skills, complex ill-structured problems spanning multiple forensic disciplines, project management and connecting practitioners with researchers on a long-term basis. Table 5.1 provides an example of the model.

Table 5.14: Example of Project-Based Learning for Forensic Practitioners (PrBLFP) Model (Raposo et al., 2018)

Model Structure	Forensic Science Example
Ill-structured Problem	A complex ill-structured problem consisting of four crime scenes within one overarching crime. CS 1: Anthropological grave site (fresh and winter) CS 2: Residence murder scene CS 3: Body transport vehicle CS 4: Second body in barn at CS 2 (skeletonized body)
Small teams working in a larger corporate environment – with tutor	The class consist of three groups of four (CS 1,2 and 3) CS 4 is found after CS 2 is under investigation and groups split into four groups of three students.
Full student learning environment	Students will conduct a full forensic investigation from crime scene to court. Group projects would include: scene processing and management (on site); evidence processing and forward to appropriate lab (online); literature reviews completed by individuals on specific area of analysis (online); each group would be tasked with a case-specific research project for their scene and requiring a full research proposal including literature review (online); and a final group presentation to the class (on site).
Assessments align with PrBL process	Assessments align with the objectives of the PrBL process

Note: the example is for a class size of 12 students

The following sections provide approaches that could be used in unison with the above noted pedagogic strategies to enhance learning.

Teaching Research Design

Research indicates that one pedagogic approach to increase formal reasoning skills is directly connected with experimental research design education (Choi & Lee, 2008; Hartmann, Upmeier zu Belzen, Krüger, & Pant, 2015). Especially important, is a history of research studies showing that participating in scientific investigations increases student capacity to conduct inquiries (Bybee, 2002; Staub et al., 2016; Waree, Ontkwanmuang, & Chanfoy, 2016). Exploring complex research design at the tertiary level will help with the development of formal reasoning and the application of a hypothetico-deductive method. To that end, students can (i) engage in the development of research questions and hypotheses, (ii) conduct literature reviews, (iii) investigate research design models, (iv) apply statistical models, and, (v) develop scientifically defendable conclusions, will help with the development of formal reasoning and the application of hypothetico-deductive method (Lawson, 2005, 2013; Waree et al., 2016).

Research by Bryce et al. (Bryce et al., 2019) placed experimental design on a list that was established by forensic employers, practitioners and academics as one of the transferable skills required by forensic science students. Further, it is imperative for forensic practitioners to understand research paradigms and the fundamental difference between academic research and forensic case-specific research (Illes & Wilson, Submitted; Illes, Wilson, et al., 2019). The latter examines past events with no knowledge of what happened at the time of the event. Conducting research from a forensic case question can present complications that lead to justifying problematic assumptions, such as time elapsed since event, research time limits, limited sample sets, uncontrolled variables and other unknowns (Mitchell, Walker, & Monahan, 2011). This distinction makes the selection of research methods more complex and problematic, and at this time there is no direction on how to implement this framework (Illes & Wilson, Submitted).

Our research on case-specific methods suggests that forensic practitioners are more confident using a mixed-methods data approach (Illes & Wilson, Submitted). This was the first study to investigate case-specific research in forensic science and can provide a baseline for further research into method development. Beyond the results of our study, a mixed-method data approach is a pragmatic style in disciplines such as friction ridge analysis, bloodstain pattern analysis or forensic anthropology where numeric and observational data are interpreted. The next research challenge will be to test a full mixed-methods experimental design approach.

If a mixed-methods approach seems relevant to forensic science, as our research has indicated, then it may be prudent to include these teachings in forensic science curriculum. In mixed-methods research design the researcher must analyse and collect different data sets while understanding the complexity of the process and having knowledge of multiple data collection and analytical methodologies (Lanier & Briggs, 2014; Onghena, Maes, & Heyvaert, 2018). Indeed, mixed-methods research pedagogy can provide critical thought relevant to both quantitative and qualitative methods.

Quantitative methods offer a deductive approach by using objective numeric data to falsify hypotheses. In contrast, qualitative methods involves an exploration that can lead to understanding a problem (Almalki, 2016). The combination of both methods can strengthen conclusions by providing research triangulation and capability to explore greater problem complexity (Malina, Nørreklit, & Selto, 2011). This can contribute to enhancing the use of problem-based learning, case or experience-based learning, project-based learning and project-based forensic practitioner blended learning curricula.

Scientific Method and Research Design Course

Considering the importance of teaching research design, as outlined above, we suggest that a scientific method and research design course be part of the first- or second-year curriculum in a forensic science degree. Although a single course on the scientific method cannot totally develop formal reasoning skills, it can initiate the acquisition of skills that should be mastered by the end of a four-year degree. The course should provide scientific theory and experience-based learning opportunities for understanding the scientific method and evidence-based analysis as they relate to forensic science. Therefore, we support the use of domain-specific knowledge examples that can be intertwined with theory to help close any theory-practice knowledge gap.

To help with the development of such a course we have authored a textbook entitled *“The Scientific Method in Forensic Science: A Canadian Handbook”* (Illes & Wilson, In Press) which emerged as part of this continuous study of forensic epistemology. This book has been written for the Canadian forensic science student and the professional practitioner. However, the issues theories and scientific processes discussed are common to the global forensic science community. This textbook emphasizes evidence-based practice using problem-, experiential- and case-based learning strategies.

A final strategy for the forensic practitioner and student regarding research skills is that they must consult research experts when considering case-specific experimental design.

III. A Call for Research

Scholarship of Teaching and Learning (SoTL) is research studying the impact of teaching on student learning (Trent, 2019). Our research has integrated SoTL examples with forensic science to provide a better understanding of how stakeholders can improve the epistemic status of forensic science. The forensic scientific community has been active in establishing scientific standards for a variety of disciplines (Wilson-Wilde, 2018). However, scientific research and standards must be accessible, understood and implemented by proficiently educated practitioners. In order to improve the quality of forensic science, there is a need for continued research into increasing the epistemic state.

Research can help with the development of policy which in turn impacts certification, accreditation, and education requirements (NAS, 2009; OSAC, 2018). One of the main steps in policy development is completing a full literature review within relevant scientific journals. However, the connection between this research and policy development can be a difficult task (Swanson, McGinty, Fazel, & Mays, 2015). Policy making is innately political with researchers and practitioners having different perspectives that can impede the impact of scientific research on the policy makers (Harris, 2015). A recent example is the heated debate between scientist and politicians on the agreement of the existence of climate change (Attari, Krantz, & Weber, 2019). Bridging this research and policy gap is equally important in forensic science.

Our research is an exploration of forensic epistemology providing evidence that knowledge gaps exist in practitioner reasoning and case-specific research skills, the use of reasoning tests to assess practitioner reasoning levels, the use of data types in case-specific research, and strategies to improve forensic epistemology. Therefore, we encourage interdisciplinary research between practitioners, educators and researchers that can help with understanding epistemology and how it can enhance pedagogy, research and policy development in forensic science.

Conclusion

This research focused on forensic epistemology, and it is the product of forensic science being a relatively new science that has experienced a paradigm shift over the past few years. Thomas Kuhn (Kuhn, 1962) described a scientific paradigm shift as a sign that the science is maturing, and that one important component of such a shift is that research is conducted to support the new paradigm. We applaud how the forensic science community has taken up this challenge with a plethora of newly published research articles, improving the science within forensic science. It is our observation that - more than ever - forensic practitioners require the collaborative support of researchers to bridge gaps and balance forensic practice with an appropriate level of scientific knowledge. This paper suggests several theoretical and practical contributions to increase knowledge in forensic science.

Theoretical Contributions

Currently, there is limited experimental design research linking forensic epistemology with tertiary level education and practitioner training. Issues raised from our two primary data studies suggest that there is a knowledge gap in formal reasoning for some forensic practitioners, and there may be a limited understanding of case-specific research contexts. Combined with the idea that super-specialization contributes to a lack of a broad-range of forensic science knowledge and siloed thinking amongst forensic scientists, this situation emphasizes the need for more SoTL (Robertson & Roux, 2018).

It is incumbent on forensic science educators to understand the required skills and supplying the appropriate level of theory-practice curriculum to prepare students for forensic science careers as practitioners (Pietro et al., 2019; Roux et al., 2018). The implementation of ill-structure problem-solving education that contains “domain knowledge, justification skills, science attitudes, and regulation of cognition” (Shin et al., 2003) is one approach to improving these cognitive skills. Combining this approach with a more advanced graduate level curriculum, (which includes extensive research design), may provide a superior learning environment for students and contribute to increasing the epistemic state in forensic science.

Practical Contributions

Combing the following pedagogical strategies offers a practical set of building blocks for increasing the epistemic state of forensic science: project-learning grounded in experiential learning and problem-solving, a scientific method and research design course for undergraduate forensic students, and a project-based forensic practitioner blended learning curriculum. However, our research to date suggests that the discussed pedagogical strategies and theoretical contributions would be most impactful if implemented in unison. The key to accomplishing the highest quality of knowledge in forensic science by these suggested strategies will be the collaboration between forensic practitioners and academics.

References

Akinci-Ceylan, S., Cetin, K. S., Fleming, R., Ahn, B., Surovek, A., Cetin, B., & Taylor, P. (2018). *Bridging the Gap Between Academia and Industry in Approaches for Solving Ill-Structured Problems: Problem Formulation and Protocol Development.* Paper presented at the ASEE Annual Conference proceedings.

Almalki, S. (2016). Integrating Quantitative and Qualitative Data in Mixed Methods Research—Challenges and Benefits. *Journal of Education and Learning, 5*(3). doi:10.5539/jel.v5n3p288

Andresen, L., Boud, D., & Cohen, R. (2000). Experience-based learning. *Understanding Adult Education and Training, 2*, 225-239.

Asikainen, H., & Gijbels, D. (2017). Do Students Develop Towards More Deep Approaches to Learning During Studies? A Systematic Review on the Development of Students' Deep and Surface Approaches to Learning in Higher Education. *Educational Psychology Review, 29*(2), 205-234. doi:10.1007/s10648-017-9406-6

Attari, S. Z., Krantz, D. H., & Weber, E. U. (2019). Climate change communicators' carbon footprints affect their audience's policy support. *Climatic Change, 154*(3), 529-545. doi:10.1007/s10584-019-02463-0

Avdiji, H., Elikan, D., Missonier, S., & Pigneur, Y. (2018). *Designing tools for collectively solving Ill-structured problems.* Paper presented at the Proceedings of the 51st Hawaii International Conference on System Sciences.

Backman, M., Pitt, H., Marsden, T., Mehmood, A., & Mathijs, E. (2019). Experiential approaches to sustainability education: Towards learning landscapes. *International Journal of Sustainability in Higher Education, 20*(1), 139-156.

Balendran, K., & John, L. (2017). Comparison of Learnng Outcomes in Problem Based Learning and Lecture Based Learning in Teaching Forensic Medicine. *Journal of Evolution of Medical and Dental Sciences-JEMDS, 6*(2), 89-92.

Balram, S. (2019). Teaching and Learning Pedagogies in Higher Education Geographic Information Science. In *GIScience Teaching and Learning Perspectives* (pp. 1-8): Springer.

Beattie IV, V., Collins, B., & McInnes, B. (1997). Deep and surface learning: a simple or simplistic dichotomy? *Accounting Education, 6*(1), 1-12.

Belt, S., Evans, E., McCreedy, T., Overton, T., & Summerfield, S. (2002). A problem based learning approach to analytical and applied chemistry. *University Chemistry Education, 6*(2), 65-72.

Bowen, C. W. (1990). Representational systems used by graduate students while problem solving in organic synthesis. *Journal of Research in Science Teaching, 27*(4), 351-370.

Brown, C. O., Logan, B. K., & McKiernan, H. E. (2019). A survey of senior practitioners regarding most desirable qualifications for hiring and advancement within forensic science. *Forensic Science International: Synergy, 1*, 221-226. doi:10.1016/j.fsisyn.2019.09.004

Bryce, C. F. A., Rankin, B. W. J., & Hunt, A. (2019). A report on the development and implementation of an assessment of competence scheme for the forensic sciences. *Forensic Science International: Synergy, 1*, 56-60. doi:10.1016/j.fsisyn.2019.03.005

Bybee, R. W. (2002). Inquiring into inquiry learning and teaching in science. In M. J & v. Z. E.H. (Eds.), *Teaching science as inquiry*: Washington, DC: American Association for the Advancement of Science.

Byrne, D. S. (2018). Enhancing Information Retention of Forensic Science Students: Incorporating a Simulated Crime Scene Practicum in the College Classroom. *Journal of Social Science Research, 13*, 2935-2945.

Champod, C. (2014). Research focused mainly on bias will paralyse forensic science. *Science and Justice, 54*(2), 107-109.

Chazo, R. (1979). Determinacy and Deliberation: An Inquiry Concerning Forensic Epistemology. *Florida State University Law Review, 7*, 237.

Choi, I., & Lee, K. (2008). Designing and implementing a case-based learning environment for enhancing ill-structured problem solving: classroom management problems for prospective teachers. *Educational Technology Research and Development, 57*(1), 99-129. doi:10.1007/s11423-008-9089-2

Cole, S. A. (2009). Forensics without uniqueness, conclusions without individualization: the new epistemology of forensic identification. *Law, Probability and Risk, 8*(3), 233-255. doi:10.1093/lpr/mgp016

Cresswell, S. L., & Loughlin, W. A. (2017). A Case-Based Scenario with Interdisciplinary Guided-Inquiry in Chemistry and Biology: Experiences of First Year Forensic Science Students. *Journal of Chemical Education, 94*(8), 1074-1082. doi:10.1021/acs.jchemed.6b00827

Crispino, F., Ribaux, O., Houck, M., & Margot, P. (2011). Forensic science – A true science? *Australian Journal of Forensic Sciences, 43*(2-3), 157-176. doi:10.1080/00450618.2011.555416

Dolmans, D., Loyens, S. M. M., Marcq, H., & Gijbels, D. (2016). Deep and surface learning in problem-based learning: a review of the literature. *Advances in Health Sciences Education, 21*(5), 1087-1112. doi:10.1007/s10459-015-9645-6

Dror, I. E., & Cole, S. A. (2010). The vision in "blind" justice: expert perception, judgment, and visual cognition in forensic pattern recognition. *Psychonomic Bulletin and Review, 17*(2), 161-167. doi:10.3758/PBR.17.2.161

Dror, I. E., Thompson, W. C., Meissner, C. A., Kornfield, I., Krane, D., Saks, M., & Risinger, M. (2015). Letter to the Editor- Context Management Toolbox: A Linear Sequential Unmasking (LSU) Approach for Minimizing Cognitive Bias in Forensic Decision Making. *Journal of Forensic Sciences, 60*(4), 1111-1112. doi:10.1111/1556-4029.12805

Edmond, G., Towler, A., Growns, B., Ribeiro, G., Found, B., White, D., . . . Martire, K. (2017). Thinking forensics: Cognitive science for forensic practitioners. *Science and Justice, 57*(2), 144-154. doi:10.1016/j.scijus.2016.11.005

Edmondson, A. C., & Harvey, J.-F. (2018). Cross-boundary teaming for innovation: Integrating research on teams and knowledge in organizations. *Human Resource Management Review, 28*(4), 347-360. doi:10.1016/j.hrmr.2017.03.002

Edokpolor, J. E., & Adeniyi, I. N. (2019). Experiential and vicarious learning approaches in developing higher-order thinking skills among business education undergraduates in federal universities. *International Journal of Educational Research, 6*(1), 1-9.

Epstein, D. (2019). *Range: How Generalists Triumph in a Specialized World*: Pan Macmillan.

Fakayode, S. O., Mayes, J. P., Kanipes, M. I., Johnson, D., & Cuthbertson, E. L. (2016). Promoting Student Learning in Criminal Justice, STEM, and Forensic Science: Aggie Sleuth Initiative (AggieSI)-Guided Inquiry Learning Experience. *Journal of Criminal Justice Education, 28*(2), 192-206. doi:10.1080/10511253.2016.1199720

Grace, S., Stockhausen, L., Patton, N., & Innes, E. (2019). Experiential learning in nursing and allied health education: Do we need a national framework to guide ethical practice? *Nurse education in practice, 34*, 56-62.

Graner, R., & Kronkvist, O. (2015). *The Past, the Present and the Future of Police Research: Proceedings from the fifth Nordic Police Research seminar*: Linnæus University studies in policing.

Griffiths, C. T. (2014). *Economics on Policing: Baseline for Policing Research in Canada*. Public Safety Canada.

Han, S. (2017). Korean Students' Attitudes toward STEM Project-Based Learning and Major Selection. *Educational Sciences: Theory and Practice, 17*(2), 529-548.

Harris, R. (2015). The Impact of Research on Development Policy and Practice: This Much We Know. In A. Chib, J. May, & R. Barrantes (Eds.), *Impact of Information Society Research in the Global South* (pp. 21-43). Singapore: Springer Singapore.

Hartmann, S., Upmeier zu Belzen, A., Krüger, D., & Pant, H. A. (2015). Scientific Reasoning in Higher Education. *Zeitschrift für Psychologie, 223*(1), 47-53. doi:10.1027/2151-2604/a000199

Henderson, B., Clements, A., Webb, M., & Kofinas, A. (2019). Exploration: Wardopoly—Game-Based Experiential Learning in Nurse Leadership Education. In *The Power of Play in Higher Education* (pp. 273-282): Springer.

Hogarth, R. M. (2001). *Educating intuition*: University of Chicago Press.

Hutchison, D. (2015). *What Works? Research Into Practice: Project-Based Learning: Drawing on Best Practices in Project Management*. Ontario.

Illes, M., Bruce, C., Stotesbury, T., & Hanley-Dafoe, R. (2016). Novel Technological Approaches for Pedagogy in Forensic Science: A Case Study in Bloodstain Pattern Analysis. *Forensic Science Policy & Management: An International Journal, 7*(3-4), 87-97.

Illes, M., Bruce, C. D., Stotesbury, T., & Hanley-Dafoe, R. (2018). A study on university student engagement within a forensic science course. *Journal of Multidisciplinary Research at Trent, 1*(1), 55-70.

Illes, M., Stotesbury, T., Bruce, C. D., & Hanley-Dafoe, R. (2019). A Study on University Student Engagement within a Forensic Science Course. *Journal of Multidisciplinary Research at Trent, 1*(1), 50-70.

Illes, M., & Wilson, P. (In Press). *The Scientific Method in Forensic Science: A Canadian Handbook*. Toronto: Canadain Scholars Press Inc.

Illes, M., & Wilson, P. (Submitted). Forensic epistemology: Exploring case-specific research in forensic science. *Canadian Society of Forensic Science Journal*.

Illes, M., Wilson, P., & Bruce, C. (2019). Forensic epistemology: testing the reasoning skills of crime scene experts. *Canadian Society of Forensic Science Journal, 52*(4), 151-173. doi:10.1080/00085030.2019.1664260

Jamali, S. M., Md Zain, A. N., Samsudin, M. A., & Ale Ebrahim, N. (2017). Self-Efficacy, Scientific Reasoning, and Learning Achievement in the STEM Project-Based Learning Literature. *The Journal of Nusantara Studies (JONUS), 2*, 29-43.

Jonassen, D. H. (2017). What makes scientific problems difficult? In *Learning to solve complex scientific problems* (pp. 3-24): Routledge.

Kelty, S. F., Robertson, J., & Julian, R. (2017). Beyond Technical Training to Professionalism in Crime Scene Examination: Enhancing Cognitive, Leadership, and Social Abilities in Career Development Programs. *Forensic Science Policy & Management: An International Journal, 8*(3-4), 65-78. doi:10.1080/19409044.2017.1370039

Kennedy, J. (2017). A Strategy for Teaching Forensic Investigation with Limited Resources. *Forensic Science Education and Training: A Tool-kit for Lecturers and Practitioner Trainers*, 87.

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267-277. doi:10.1177/1365480216659733

Kolb, A. Y., & Kolb, D. A. (2005). Learning styles and learning spaces: Enhancing experiential learning in higher education. *Academy of Management Learning and Education, 4*(2), 193-212.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*: FT press.

Kolb, D. A., Boyatzis, R. E., & Mainemelis, C. (2001). Experiential learning theory: Previous research and new directions. *Perspectives on Thinking, Learning, and Cognitive Styles, 1*(8), 227-247.

Kuhn, T. S. (1962). The Structure of Scientific Revolutions. In O. Neurath (Ed.), *International Encyclopedia of Unified Science* (Vol. 1-2). Chicago: The University of Chicago Press.

Langer, S., & Illes, M. (2015). Confounding factors of fly artefacts in bloodstain pattern analysis. *Canadian Society of Forensic Science Journal, 48*(4), 215-224.

Lanier, M., & Briggs, L. T. (2014). *Research methods in criminal justice and criminology: A mixed methods approach*: Oxford University Press.

Larmer, J. (2014). Project-based learning vs. problem-based learning vs. X-BL. *Buck Institute for Education (BIE)*.

Larmer, J., & Ross, D. (2009). Project based learning starter kit. *Buck Institute for Education*.

Lawson, A. E. (2005). What is the role of induction and deduction in reasoning and scientific inquiry? *Journal of Research in Science Teaching, 42*(6), 716-740. doi:10.1002/tea.20067

Lawson, A. E. (2013). Hypothetico-deductive Method. 1-2. doi:10.1007/978-94-007-6165-0_260-1

Levin, S. K., Nilsen, P., Bendtsen, P., & Bülow, P. (2018). Staff Perceptions of Facilitators and Barriers to the Use of a Short- Term Risk Assessment Instrument in Forensic Psychiatry. *Journal of Forensic Psychology Research and Practice, 18*(3), 199-228. doi:10.1080/24732850.2018.1466260

Linacre, A. (2013). Towards a research culture in the forensic sciences. *Australian Journal of Forensic Sciences, 45*(4), 381-388. doi:10.1080/00450618.2012.738246

Lynch, M. (2013). Science, truth, and forensic cultures: the exceptional legal status of DNA evidence. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences, 44*(1), 60-70. doi:10.1016/j.shpsc.2012.09.008

Macindo, J. R. B., Danganan, M. P. B., Soriano, C. A. F., Kho, N. S. R., & Bongar, M. V. V. (2019). A conjoint analysis of the acute and critical care experiential learning preferences of Baccalaureate student nurses. *Nurse education in practice, 36*, 125-131.

Mackie, J. E., & Bruce, C. D. (2016). Increasing nursing students' understanding and accuracy with medical dose calculations: A collaborative approach. *Nurse Education Today, 40*, 146-153. doi:10.1016/j.nedt.2016.02.018

Malina, M. A., Nørreklit, H. S., & Selto, F. H. (2011). Lessons learned: advantages and disadvantages of mixed method research. *Qualitative Research in Accounting & Management, 8*(1), 59-71.

Mattijssen, E. J., Kerkhoff, W., Berger, C. E., Dror, I. E., & Stoel, R. D. (2016). Implementing context information management in forensic casework: Minimizing contextual bias in firearms examination. *Science and Justice, 56*(2), 113-122. doi:10.1016/j.scijus.2015.11.004

Mitchell, G., Walker, L., & Monahan, J. (2011). Beyond Context: Social Facts as Case-Specific Evidence. *Emory Law Journal, 60*, 1111-1164.

NAS. (2009). *Strengthening Forensic Science in the United States: A Path Forward* (T. N. A. Press Ed.). Washington: National Academy of Sciences.

Newton, G., Bettger, W., Buchholz, A., Kulak, V., & Racey, M. (2015). Evidence-informed strategies for undergraduate nutrition education: a review. *Appl Physiol Nutr Metab, 40*(7), 652-661. doi:10.1139/apnm-2014-0368

NIJ. (2011). *The Fingerprint Sourcebook*. In A. McRoberts (Ed.), (pp. 415). Retrieved from http://www.nij.gov/pubs-sum/225320.htm

O'Neill, M., Adams, M. P., Bandelt, M. J., Chester, S. A., Cai, W., & Nadimpalli, S. P. (2019). Cohort Learning: Supporting Transdisciplinary Communication and

Problem-Solving Skills in Graduate STEM Researchers. *International Journal of Teaching and Learning in Higher Education, 31*(1), 166-175.

Onghena, P., Maes, B., & Heyvaert, M. (2018). Mixed Methods Single Case Research: State of the Art and Future Directions. *Journal of Mixed Methods Research*. doi:10.1177/1558689818789530

Ortega, S. T., & Kent, J. D. (2018). What is a PhD? Reverse-Engineering Our Degree Programs in the Age of Evidence-Based Change. *Change: The Magazine of Higher Learning, 50*(1), 30-36.

OSAC. (2018). OSAC. Retrieved from https://www.nist.gov/topics/forensic-science/crime-scene-investigation-subcommittee

Petrie, J., Murrell, A., Schultz, B., & Jones, R. (2019). *Developing Global Competency and Ethical Leadership in Business Students Through Global Service Learning.* Paper presented at the Developments in Business Simulation and Experiential Learning: Proceedings of the Annual ABSEL conference.

Pietro, D. S., Kammrath, B. W., & De Forest, P. R. (2019). Is forensic science in danger of extinction? *Science and Justice, 59*(2), 199-202. doi:10.1016/j.scijus.2018.11.003

Pringle, J. K., Bracegirdle, L., & Potter, J. A. (2017). Educational forensic e-gaming as effective learning environments for Higher Education students. *Forensic Science Education and Training: A Tool-kit for Lecturers and Practitioner Trainers*, 119.

Quigley-McBride, A., & Wells, G. L. (2018). Fillers can help control for contextual bias in forensic comparison tasks. *Law and Human Behavior, 42*(4), 295-305. doi:10.1037/lhb0000295

Ralph, R. A. (2016). Post secondary project-based learning in science, technology, engineering and mathematics. *Journal of Technology and Science Education, 6*(1). doi:10.3926/jotse.155

Rans, C., Saunders-Smits, G., & Schuurman, M. (2015). *Forensic Engineering: Learning by Accident Teaching Investigation Skills to Graduate Students using Real-Life Accident Simulations*. Paper presented at the 53rd AIAA Aerospace Sciences Meeting.

Raposo, M. A., Saúde, S., & Zarcos, A. P. (2018). *Project Based Learning: Bringing Citizen Empowerment to the Educational Agenda–Interpreting Three Learning Experiences Developed in Higher Education.* Paper presented at the Conference Proceedings. The Future of Education.

Ribaux, O., Roux, C., & Crispino, F. (2016). Expressing the value of forensic science in policing. *Australian Journal of Forensic Sciences, 49*(5), 489-501. doi:10.1080/00450618.2016.1229816

Robertson, J., & Roux, C. (2018). The forensic scientist of the future – are universities prepared? *Australian Journal of Forensic Sciences, 50*(4), 305-306. doi:10.1080/00450618.2018.1468298

Rogers, D. (2017). Considerations in Using a Crime Scene House Facility for Teaching and Learning. *Forensic Science Education and Training: A Tool-kit for Lecturers and Practitioner Trainers*, 39.

Roux, C., Ribaux, O., & Crispino, F. (2018). Forensic science 2020 – the end of the crossroads? *Australian Journal of Forensic Sciences*, 1-12. doi:10.1080/00450618.2018.1485738

Roux, C., Talbot-Wright, B., Robertson, J., Crispino, F., & Ribaux, O. (2015). The end of the (forensic science) world as we know it? The example of trace evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences, 370*(1674). doi:10.1098/rstb.2014.0260

Samarji, A. (2012). Forensic Science Education: Inquiry into Current Tertiary Forensic Science Courses. *Forensic Science Policy & Management: An International Journal, 3*(1), 24-36. doi:10.1080/19409044.2012.719580

Servant-Miklos, V. F. C. (2019). Fifty Years on: A Retrospective on the World's First Problem-based Learning Programme at McMaster University Medical School. *Health Professions Education, 5*(1), 3-12. doi:10.1016/j.hpe.2018.04.002

Shin, N., Jonassen, D. H., & McGee, S. (2003). Predictors of well-structured and ill-structured problem solving in an astronomy simulation. *Journal of Research in Science Teaching, 40*(1), 6-33. doi:10.1002/tea.10058

Staub, N. L., Blumer, L. S., Beck, C. W., Delesalle, V. A., Griffin, G. D., Merritt, R. B., . . . White, S. L. (2016). Course-based science research promotes learning in diverse students at diverse institutions. *Council on Undergraduate Research Quarterly, 38*(2).

Stevenage, S. V., & Bennett, A. (2017). A biased opinion: Demonstration of cognitive bias on a fingerprint matching task through knowledge of DNA test results. *Forensic Science International, 276*, 93-106. doi:10.1016/j.forsciint.2017.04.009

Stoney, D. A., & Stoney, P. L. (2015). Critical review of forensic trace evidence analysis and the need for a new approach. *Forensic Science International, 251*, 159-170. doi:10.1016/j.forsciint.2015.03.022

Swan, L. S. (2014). Karl Popper, Forensic Science, and Nested Codes. *Biosemiotics, 7*(2), 309-319.

Swanson, J. W., McGinty, E. E., Fazel, S., & Mays, V. M. (2015). Mental illness and reduction of gun violence and suicide: bringing epidemiologic research to policy. *Ann Epidemiol, 25*(5), 366-376. doi:10.1016/j.annepidem.2014.03.004

Swofford, H. (2015). The emerging paradigm shift in the epistemology of fingerprint conclusions. *Journal of Forensic Identification, 65*(3), 201.

Tate, U. S., Subedi, D., & Maheshwari, S. (2019). *Global Educational Tours and Business Simulations: Challenges and Benefits of Experiential Learning in Executive MBA Programs*. Paper presented at the Atlantic Marketing Association Conference, New Orleans, Louisiana.

Trent. (2019). Centre for Teaching & Learning. Retrieved from https://www.trentu.ca/teaching/research-pedagogy/scholarship-teaching-and-learning

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*(4157), 1124-1131.

Waree, C., Ontkwanmuang, K., & Chanfoy, P. (2016). A Classroom Research Skills Development of Suan Sunandha Rajabhat University' Students by Research Based Learning. *International Journal of Information and Education Technology, 6*(11), 899-903. doi:10.7763/ijiet.2016.v6.813

Weber, H., Becker, D., & Hillmert, S. (2019). Information-seeking behaviour and academic success in higher education: Which search strategies matter for grade differences among university students and how does this relevance differ by field of study? *Higher Education (00181560), 77*(4), 657-678. doi:10.1007/s10734-018-0296-4

Wilson-Wilde, L. (2018). The international development of forensic science standards - A review. *Forensic Science International, 288*, 1-9. doi:10.1016/j.forsciint.2018.04.009

Yew, E. H. J., & Goh, K. (2016). Problem-Based Learning: An Overview of its Process and Impact on Learning. *Health Professions Education, 2*(2), 75-79. doi:10.1016/j.hpe.2016.01.004

Zajac, R., Osborne, N. K. P., Singley, L., & Taylor, M. C. (2015). Contextual Bias: What Bloodstain Pattern Analysts Need to Know. *Journal of Bloodstain Pattern Analysts, 31*(2), 7-16.

Zapf, P. A., & Dror, I. E. (2017). Understanding and Mitigating Bias in Forensic Evaluation: Lessons from Forensic Science. *International Journal of Forensic Mental Health, 16*(3), 227-238. doi:10.1080/14999013.2017.1317302

Chapter 6: Synthesis and Conclusions

This study expands the epistemic state in forensic science by using experimental research design results that can support strategies in directing forensic pedagogy and case-specific research (Chazo, 1979; Cole, 2009; Crispino, Ribaux, Houck, & Margot, 2011; Lynch, 2013; Roux, Ribaux, & Crispino, 2018; Swofford, 2015). The primary studies (Chapters 2 and 3) are the first of their kind to provide evidence that there is a knowledge gap for some forensic practitioners in formal reasoning and case-specific research design. Combining these key results with a literature review offers evidence in Chapter 5 supporting pedagogic and research strategies that will help guide academic institutions and forensic service providers. Therefore Chapter 5, provides comprehensive recommendations - based on scientific evidence - that can help advance forensic epistemology by exploring: aspects of the epistemic status in forensic science; strategies for the increase of knowledge; the need for collaboration between practitioners and academia; and a call for future research.

In support of increasing the epistemic state in forensic science, I have written a book for the forensic science student and the professional practitioner, which is a timely and practical handbook providing an experience-based learning tool for understanding scientific method and evidence-based analysis and how they relate to forensic science and its casework - from the crime scene to the courtroom - within the Canadian context. We explore the paradigm shift in forensic science, highlight basic skills like scientific reasoning and literature review, as well as untangle the complexities of ethics and bias, research design, critical thought, and best practices for communication in various settings. Case examples and court testimonies are reviewed to underscore the importance of these concepts. The *"Scientific Method in Forensic Science: A Canadian Handbook"* makes for a fundamental read for students in introductory forensics, criminology, police studies, and anthropology.

Finally, this study is a foray into expanding epistemic understanding in forensic science. There has been a growing body of research, particularly since 2000, on reasoning and higher order thinking (see Baber, Smith, Cross, Hunter & McMaster, 2006; Kelty, Julian & Robertson, 2011; Resnikoff, Ribauz, Rossy, Baylon & Jendly, 2016; Houck, Crispino & McAdam, 2017 as examples) (Baber, Smith, Cross, Hunter, & McMaster, 2006; Houck, Crispino, & McAdam, 2017; Kelty, Julian, & Robertson, 2011; Resnikoff, Ribaux, Baylon, Jendly, & Rossy, 2015). This study aims to build upon this burgeoning area of study, recognizing that more research is needed to tease out knowledge requirements in forensic science, and to consider alternate methods of assessing higher order thinking. I envision this is the beginning of a larger forensic community discussion. Replication studies will be important in further validating the findings here; and much more research is required on logical, empirical, intuitive and authoritative knowledge and how it can be applied to pedagogy, research and policy development in forensic science.

References

Baber, C., Smith, P., Cross, J., Hunter, J. E., & McMaster, R. (2006). Crime scene investigation as distributed cognition. *Pragmatics & Cognition, 14*(2), 357-385. doi:doi:10.1075/pc.14.2.14bab

Chazo, R. (1979). Determinacy and Deliberation: An Inquiry Concerning Forensic Epistemology. *Florida State University Law Review, 7*, 237.

Cole, S. A. (2009). Forensics without uniqueness, conclusions without individualization: the new epistemology of forensic identification. *Law, Probability and Risk, 8*(3), 233-255. doi:10.1093/lpr/mgp016

Crispino, F., Ribaux, O., Houck, M., & Margot, P. (2011). Forensic science – A true science? *Australian Journal of Forensic Sciences, 43*(2-3), 157-176. doi:10.1080/00450618.2011.555416

Houck, M. M., Crispino, F., & McAdam, T. (2017). *The science of crime scenes*: Academic Press.

Kelty, S. F., Julian, R., & Robertson, J. (2011). Professionalism in Crime Scene Examination: The Seven Key Attributes of Top Crime Scene Examiners. *Forensic Science Policy & Management: An International Journal, 2*(4), 175-186. doi:10.1080/19409044.2012.693572

Lynch, M. (2013). Science, truth, and forensic cultures: the exceptional legal status of DNA evidence. *Studies in History and Philosophy of Science Part C: Studies in*

History and Philosophy of Biological and Biomedical Sciences, 44(1), 60-70. doi:10.1016/j.shpsc.2012.09.008

Resnikoff, T., Ribaux, O., Baylon, A., Jendly, M., & Rossy, Q. (2015). The polymorphism of crime scene investigation: An exploratory analysis of the influence of crime and forensic intelligence on decisions made by crime scene examiners. *Forensic Science International, 257*, 425-434. doi:10.1016/j.forsciint.2015.10.022

Roux, C., Ribaux, O., & Crispino, F. (2018). Forensic science 2020 – the end of the crossroads? *Australian Journal of Forensic Sciences*, 1-12. doi:10.1080/00450618.2018.1485738

Swofford, H. (2015). The emerging paradigm shift in the epistemology of fingerprint conclusions. *Journal of Forensic Identification, 65*(3), 201.

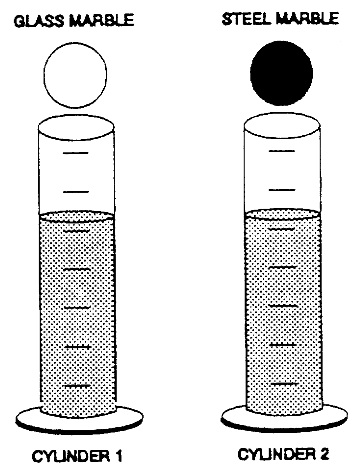
Appendix A: Research Surveys

CTSR and Reasoning Patterns Assessed

1. Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. *Which of these statements is correct?*
a. The pancake-shaped piece weighs more than the ball b. The two pieces still weigh the same
c. The ball weighs more than the pancake-shaped piece

2. *because*
a. the flattened piece covers a larger area. b. the ball pushes down more on one spot.
c. when something is flattened it loses weight. d. clay has not been added or taken away.
e. when something is flattened it gains weight.

3. To the right are drawings of two cylinders filled to the same level with water. The cylinders
are identical in size and shape.



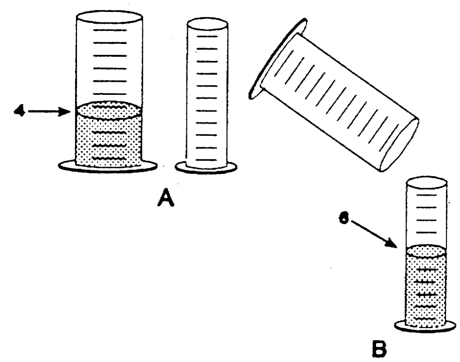
Also shown at the right are two marbles, one glass and one steel. The marbles are the same size but the steel one is much heavier than the glass one.

When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, the water will rise*
a. to the same level as it did in Cylinder 1 b. to a higher level than it did in Cylinder 1 c. to a lower level than it did in Cylinder 1

4. *because*
a. the steel marble will sink faster.
b. the marbles are made of different materials.

c. the steel marble is heavier than the glass marble. d. the glass marble creates less pressure.
e. the marbles are the same size.

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).



Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the
6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*

a. to 8 b. to 9
c. to 10 d. to 12
e. none of these answers is correct

6. *because*

a. the answer cannot be determined with the information given. b. it went up 2 more before, so it will go up 2 more again.
c. it goes up 3 in the narrow for every 2 in the wide. d. the second cylinder is narrower.
e. for every 2 in the wide it goes up 1 more in the narrow.

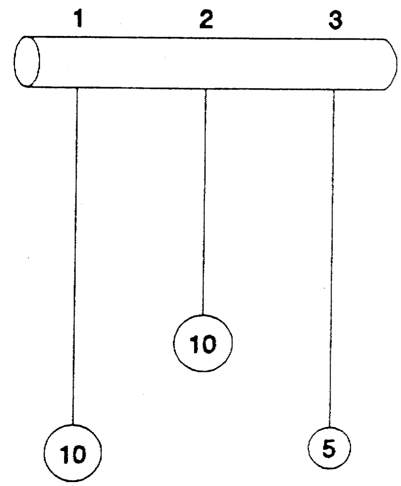
7. Water is now poured into the narrow cylinder (described in Item 5 above) up to the 11th mark. *How high would this water rise if it were poured into the empty wide cylinder?*

a. to 9 b. to 8
c. to 71/2 d. to 7 1/3
e. none of these answers is correct

8. *because*

a. the ratios must stay the same.
b. one must actually pour the water and observe to find out.
c. the answer cannot be determined with the information given. d. it was 2 less before so it will be 2 less again.
e. you subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10-unit weight is attached to the end of String 1. A 10-unit weight is also attached to the end of String 2.
A 5-unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.



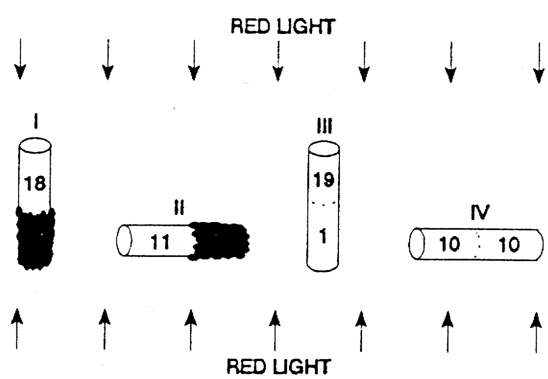
Suppose you want to find out whether the length of the string has an effect on the time it takes to swing back and forth. *Which strings would you use to find out?*

a. only one string
b. all three strings
c. 2 and 3
d. 1 and 3 e. 1 and 2

10. *because*

a. you must use the longest strings.
b. you must compare strings with both light and heavy weights. c. only the lengths differ.
d. to make all possible comparisons. e. the weights differ.

11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed.
Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.

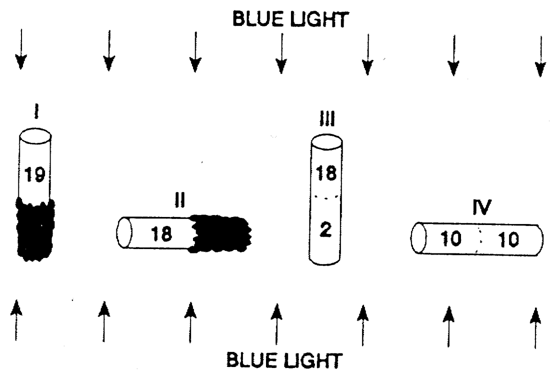


This experiment shows that flies respond to (respond means move to or

away from):
a. red light but
not gravity b. gravity but
not red light
c. both red light and gravity
d. neither red light nor gravity

12. *because*
a. most flies are in the upper end of Tube III but spread about evenly in
Tube II.
b. most flies did not go to the bottom of Tubes I and III.
c. the flies need light to see and must fly against gravity.
d. the majority of flies are in the upper ends and in the lighted ends of the tubes.
e. some flies are in both ends of each tube.

13. In a second experiment, a different kind of fly and blue light was used. The results are shown in the drawing.

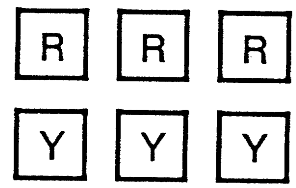


These data show that these flies respond to (respond means move to or away from):
a. blue light but not
gravity b. gravity but not
blue light
c. both blue light and gravity
d. neither blue light nor gravity

14. *because*
a. some flies are in both ends of each tube.
b. the flies need light to see and must fly against gravity.
c. the flies are spread about evenly in Tube IV and in the upper end of
Tube III.
d. most flies are in the lighted end of Tube II but do not go down in

Tubes I
and III.
e. most flies are in the upper end of Tube I and the lighted end of Tube II.

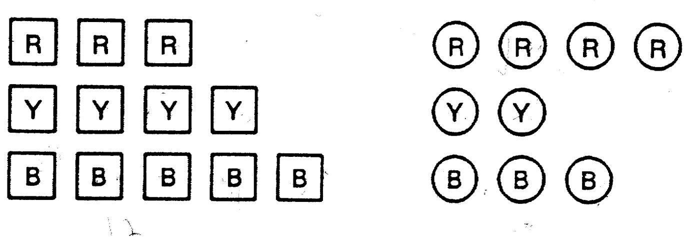
15. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*



a. 1 chance out of 6
b. 1 chance out of 3
c. 1 chance out of 2
d. 1 chance out of 1
e. cannot be determined

16. *because*
a. 3 out of 6 pieces are red.
b. there is no way to tell which piece will be picked.
c. only 1 piece of the 6 in the bag is picked.
d. all 6 pieces are identical in size and shape.
e. only 1 red piece can be picked out of the 3 red pieces.

17. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece.



What are the chances that the piece is a red round or blue round piece?
a. cannot be determined
b. 1 chance out of 3
c. 1 chance out of 21
d. 15 chances out of 21
e. 1 chance out of 2

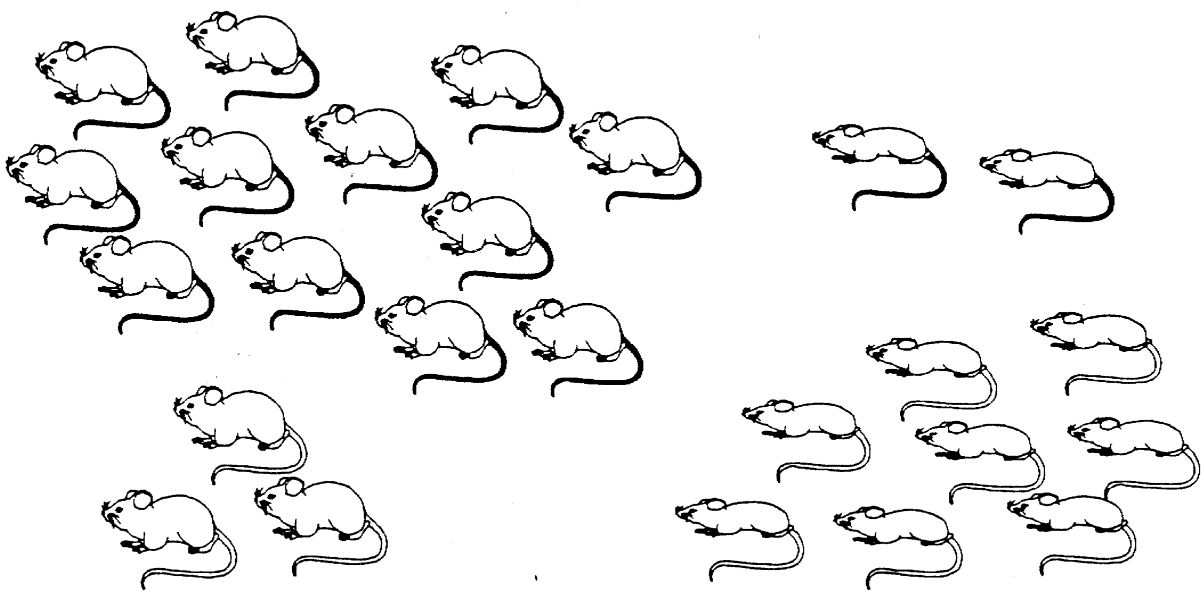
18. *because*

a. 1 of the 2 shapes is round.

b. 15 of the 21 pieces are red or blue.

c. there is no way to tell which piece will be picked. d. only 1 of the 21 pieces is picked out of the bag. e. 1 of every 3 pieces is a red or blue round piece.

19. Farmer Brown was observing the mice that live in his field. He discovered that all of the mice were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



Do you think there is a link between the size of the mice and the color of their tails?

a. appears to be a link

b. appears not to be a link

c. cannot make a reasonable guess

20. *because*

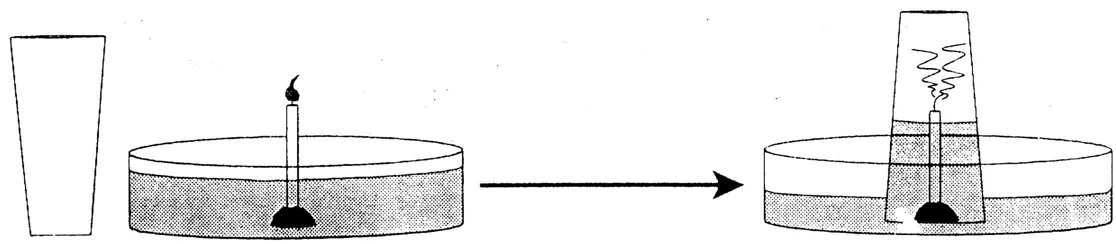
a. there are some of each kind of mouse.

b. there may be a genetic link between mouse size and tail color. c. there were not enough mice captured.

d. most of the fat mice have black tails while most of the thin mice have white tails.

e. as the mice grew fatter, their tails became darker.

21. The figure below at the left shows a drinking glass and a burning birthday candle stuck in a small piece of clay standing in a pan of water. When the glass is turned upside down, put over the candle, and placed in the water, the candle quickly goes out and water rushes up into the glass (as shown at the right).



This observation raises an interesting question: Why does the water rush up into the glass?

Here is a possible explanation. The flame converts oxygen into carbon dioxide. Because oxygen does not dissolve rapidly into water but carbon dioxide does, the newly formed carbon dioxide dissolves rapidly into the water, lowering the air pressure inside the glass.

Suppose you have the materials mentioned above plus some matches and some dry ice (dry ice is frozen carbon dioxide). *Using some or all of the materials, how could you test this possible explanation?*

a. Saturate the water with carbon dioxide and redo the experiment noting the amount of water rise.

b. The water rises because oxygen is consumed, so redo the experiment in exactly the same way to show water rise due to oxygen loss.

c. Conduct a controlled experiment varying only the number of candles to see if that makes a difference.

d. Suction is responsible for the water rise, so put a balloon over the top of an open-ended cylinder and place the cylinder over the burning candle.

e. Redo the experiment, but make sure it is controlled by holding all independent variables constant; then measure the amount of water rise.

22. What result of your test (mentioned in #21 above) would show that your explanation is probably wrong?

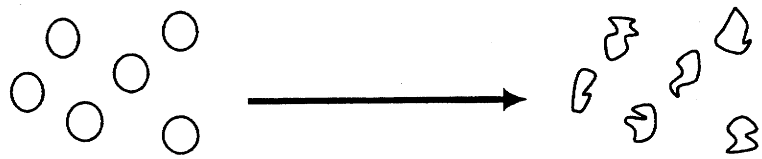
a. The water rises to the same level as it did before.

b. The water rises less than it did before.

c. The balloon expands out.

d. The balloon is sucked in.

23. A student put a drop of blood on a microscope slide and then looked at the blood under a microscope. As you can see in the diagram below, the magnified red blood cells look like little round balls. After adding a few drops of salt water to the drop of blood, the student noticed that the cells appeared to become smaller.



Magnified Red Blood Cells   After Adding Salt Water

This observation raises an interesting question: Why do the red blood cells appear smaller?

Here are two possible explanations: I. Salt ions (Na+ and Cl-) push on the cell membranes and make the cells appear smaller. II. Water molecules are attracted to the salt ions so the water molecules move out of the cells and leave the cells smaller.

To test these explanations, the student used some salt water, a very accurate weighing device, and some water-filled plastic bags, and assumed the plastic behaves just like red-blood-cell membranes. The experiment involved carefully weighing a water-filled bag, placing it in a salt solution for ten minutes, and then reweighing the bag.

What result of the experiment would best show that explanation I is probably wrong?

a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

24. *What result of the experiment would best show that explanation II is probably wrong?*

a. the bag loses weight
b. the bag weighs the same
c. the bag appears smaller

25. You're almost finished, just a few more short questions. Would you please indicate your work affiliation?

- Sworn Police Officer CSI

- Civilian CSI

26. Would you please indicate your highest level of education?

    - Secondary school
    - College (Technical Training)
    - University undergraduate
    - University Masters
    - University PhD

27. Would you provide information on how many years that you have been employed as a CSI?

    - 0-5
    - 6-10
    - 11-15
    - 16-20
    - 21-25
    - More than 25

28. Would you indicate the global region that would best describe your primary place of work?

    - Australia
    - Canada
    - Caribbean Region
    - Hawaii
    - Mercosur (Brazil, Argentina, Paraguay and Uruguay)
    - Middle East
    - New Zealand
    - Philippines
    - South Africa
    - United States of America

Lawson's Classroom Test of Scientific Reasoning - Reasoning Patterns Assessed

Questions	Reasoning Patterns Assessed
1 and 2	conservation of weight
3 and 4	conservation of displaced volume
5 and 6	proportional thinking
7 and 8	advanced proportional thinking
9 and 10	identification and control of variables
11 and 12.	identification and control of variables and probabilistic thinking
13 and 14	identification and control of variables and probabilistic thinking
15 and 16	probabilistic thinking
17 and 18	advanced probabilistic thinking
19 and 20	correlational thinking (includes proportions and probability)
21 and 22	hypothetico-deductive thinking.
23 and 24	hypothetico-deductive reasoning (Lawson, 2000)

A Model for Case-Specific Research in Forensic Science – Friction Ridge Impression Analysis (Mixed Method)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Friction Ridge Impression Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a friction ridge impression analysis. Mixed method research has been conducted on a fingerprint impression that was found at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of mixed method measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

- ☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the following group of images? One image (Figure 1) is of the fingerprint impression that was found within a scene. The following ten (10) images (Figure 2) are of fingerprint impressions that were made in a laboratory by applying 10 lbs./4.54 kgs of pressure on the substrate using the same finger that created the scene fingerprint. Figure 3 contains ten (10) fingerprint impressions that were made in a laboratory by applying 1 lb/.454 kgs of pressure on the substrate using the same finger that created the scene fingerprint.

The case-specific question to be answered is; was the fingerprint placed on the substrate with more than 1 lb/.454 Kgs of pressure?

- ☐ Reviewed the image

Research Project: A Model for Case-Specific Research in Forensic Science – Friction Ridge Impression Analysis Qualitative Data

Figure 1 Crime scene friction ridge impression

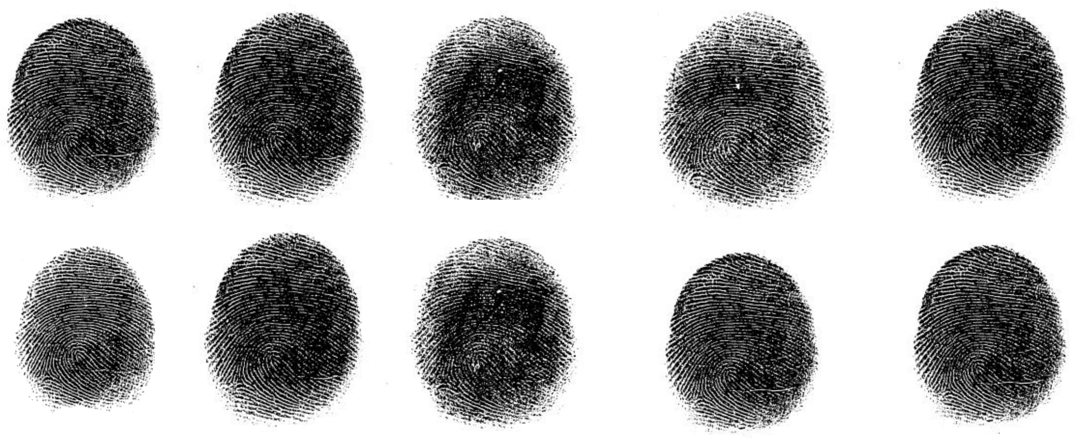


Figure 2 Reproduction of the crime scene friction ridge impression made with 10 lbs./4.54 kgs of pressure.

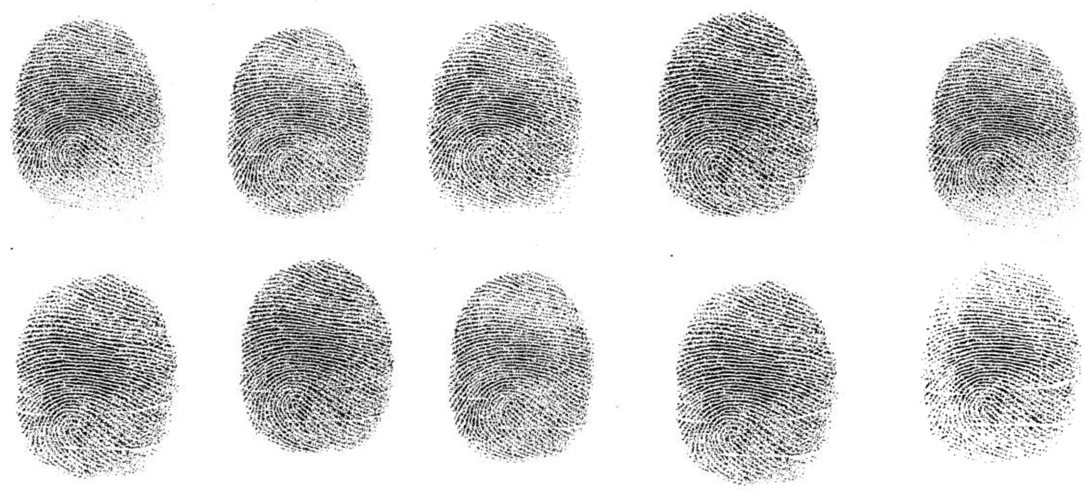


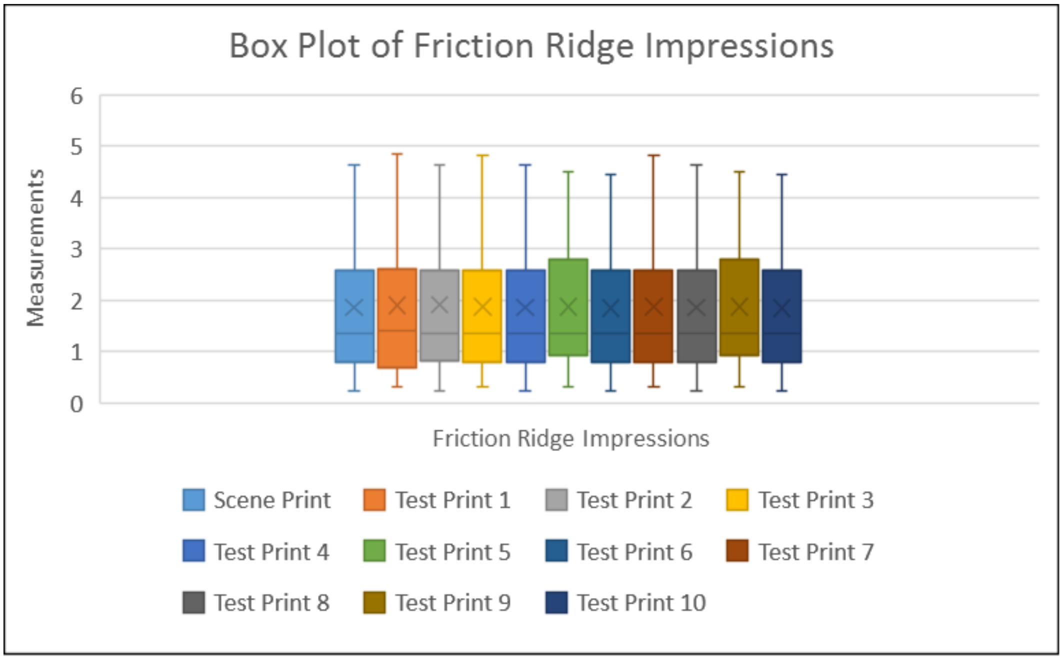
Figure 3 Reproduction of the crime scene friction ridge impression made with 1 lb/.454 kgs of pressure.

3. What preferred research method of analysis would you choose to answer this case-specific question?

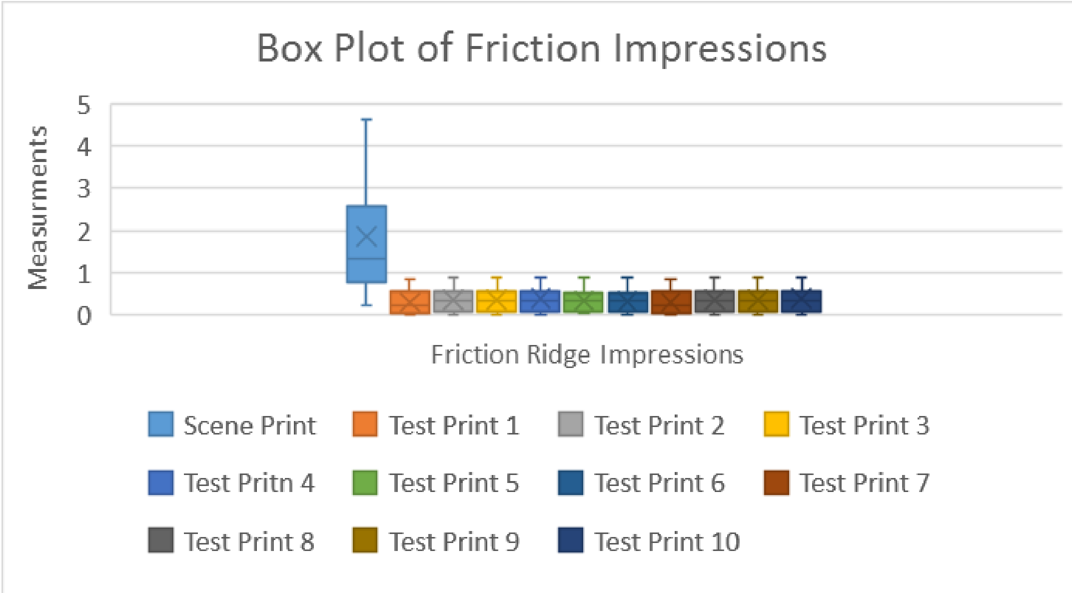
4. In addition to the above qualitative study what would you say if provided with the following quantitative study where measurements of the size of the ridges from the scene fingerprint impression were statistically compared to

measurements taken from the size of the ridges of multiple test impressions (n=300). An ANova test indicated that there was no significant difference between the size of the ridges from the impression (Figure 1 above) and other test impressions made with 10 lbs/4.54 Kgs of pressure (Figure 2 above). A second ANova test indicated a significant difference between the size of the ridges from the scene impression (Figure 1 above) and other test impressions (Figure 3 above) that were made with 1 lb/.454 Kgs of pressure. These quantitative data suggest that the fingerprint was placed on the substrate with more than 1 plb/.454 Kgs of pressure. Those data are presented below for your review.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Scene	15	27.837	1.8558	1.780379		
1	15	28.476	1.8984	1.831843		
2	15	28.749	1.9166	1.646365		
3	15	28.096	1.873067	1.83758		
4	15	27.856	1.857067	1.780995		
5	15	28.106	1.873733	1.71652		
6	15	27.641	1.842733	1.709587		
7	15	28.096	1.873067	1.83758		
8	15	27.856	1.857067	1.780995		
9	15	28.106	1.873733	1.71652		
10	15	27.641	1.842733	1.709587		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.07567	10	0.007567	0.004302	0.99999	1.892653
Within Groups	270.8713	154	1.758905			
Total	270.947	164				



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Scene	15	27.837	1.8558	1.780379		
1	15	4.7192	0.314613	0.074659		
2	15	5.4855	0.3657	0.060429		
3	15	5.3645	0.357633	0.07664		
4	15	5.9084	0.393893	0.074216		
5	15	5.1964	0.346427	0.076174		
6	15	4.9842	0.33228	0.062272		
7	15	4.7192	0.314613	0.074659		
8	15	5.4855	0.3657	0.060429		
9	15	5.3645	0.357633	0.07664		
10	15	5.9084	0.393893	0.074216		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30.85244	10	3.085244	13.62569	5.47E-17	1.892653
Within Groups	34.86999	154	0.226429			
Total	65.72243	164				



In this study it is assumed that all the variables are controlled and constant. The only variable that has been changed is the pressure (10 lbs/4.54 kgs and 1 lb/.454 Kgs) when the fingerprints were placed on the substrate. The sample set is accepted as scientifically sufficient and robust.

- ☐ Reviewed those data

5. When you review those mixed method data from both studies within this research, how would the amount of scientific information impact you for providing a conclusion that the suspect fingerprint was made with more than 1 lb/.454 kgs of pressure?

- ☐ No impact
- ☐ Minor impact
- ☐ Neutral
- ☐ Moderate impact
- ☐ Major impact

6. Would you offer an expert opinion in court based on the information provided in this mixed methods study that the suspect fingerprint was made with more than 1 lb./.454 Kgs of pressure?

    - ☐ Yes
    - ☐ No

7. If no, what further research evidence would you suggest to strengthen this opinion?

8. If yes, use the sliding scale to provide your percent confidence level in this opinion.

9. Please provide additional information or comment.

10. You're almost finished, just a few more short questions. Would you please indicate your highest level of education?

    - ☐ Secondary school
    - ☐ College (Technical Training)
    - ☐ University undergraduate
    - ☐ University Masters
    - ☐ University PhD

11. Would you provide information on the number of years that you have been employed as a friction ridge examiner?

- ☐ 0-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ 21-25
- ☐ More than 25

12. Indicate the global region that would best describe your primary place of work.
    - ☐ Australia
    - ☐ Canada
    - ☐ Caribbean Region
    - ☐ Hawaii
    - ☐ Mercosur (Brazil, Argentina, Paraguay and Uruguay)
    - ☐ Middle East
    - ☐ New Zealand
    - ☐ Philippines
    - ☐ South Africa
    - ☐ United States of America

13. Thank you for taking the time to complete this survey. I truly value the information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Friction Ridge Impression Analysis (Qualitative)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Friction Ridge Impression Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a friction ridge impression analysis. Qualitative research has been conducted on a fingerprint impression that was found at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of qualitative measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the following group of images? One image (Figure 1) is of the fingerprint impression that was found within a scene. The following ten (10) images (Figure 2) are of fingerprint impressions that were made in a laboratory by applying 10 lbs./4.54 kgs of pressure on the

substrate using the same finger that created the scene fingerprint. Figure 3 contains ten (10) fingerprint impressions that were made in a laboratory by applying 1 lb/.454 kgs of pressure on the substrate using the same finger that created the scene fingerprint.

The case-specific question to be answered is; was the fingerprint placed on the substrate with more than 1 lb/.454 Kg of pressure?

In this study it is assumed that all the variables are controlled and constant. The only variable that has been changed are the pressures (10 lbs/4.54 Kgs and 1 lb/.454 Kgs) when the fingerprints were placed on the substrate. The sample set is considered scientifically sufficient and robust.

- ☐ Reviewed the images

Figure 1 Crime scene friction ridge impression

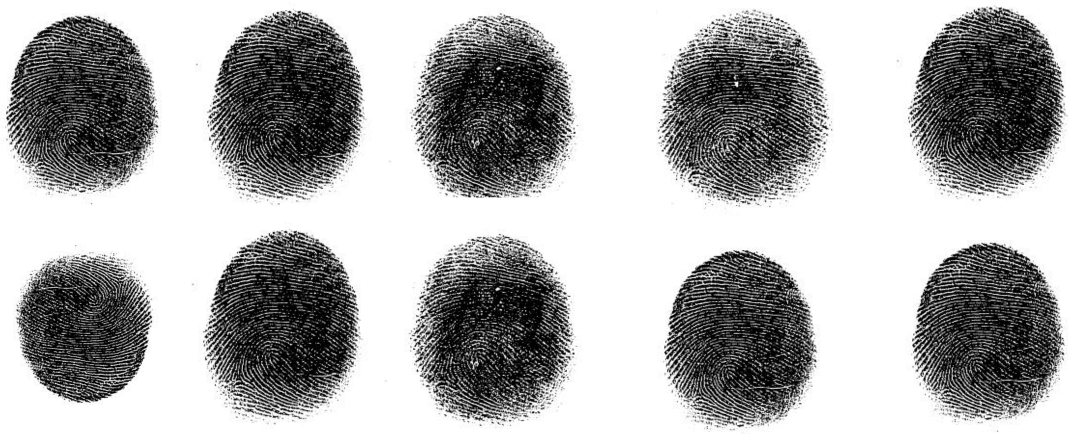


Figure 2 Reproduction of the crime scene friction ridge impression made with 10 lbs./4.54 kgs of pressure.

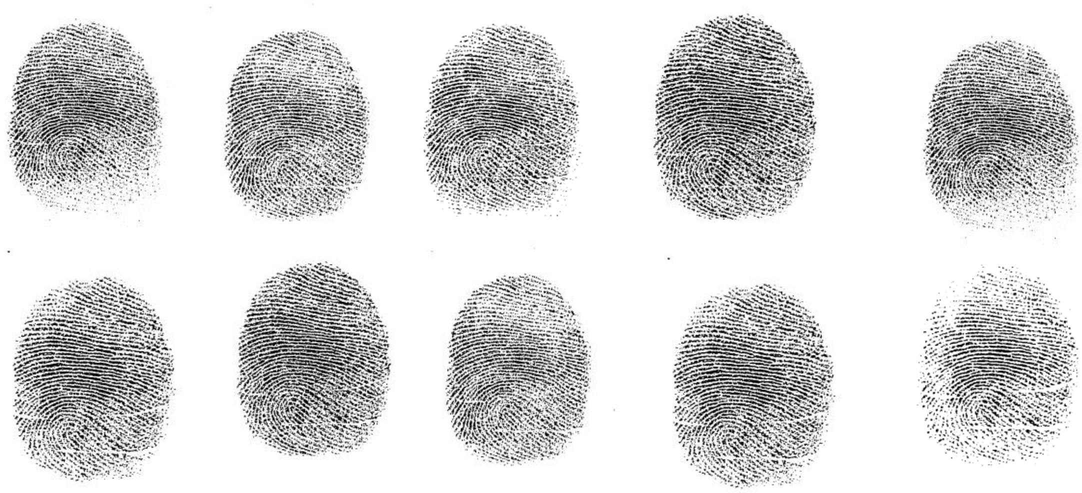


Figure 3 Reproduction of the crime scene friction ridge impression made with 1 lb/.454 kgs of pressure.

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. When you review those qualitative data within this research, how would the amount of scientific information impact you for providing a conclusion that the suspect fingerprint was made with more than 1 lb/.454 Kgs of pressure?

   ☐ No impact

   ☐ Minor impact

   ☐ Neutral

   ☐ Moderate impact

   ☐ Major impact

5. Would you offer an expert opinion in court based on the information provided in this quantitative study that the suspect fingerprint was made with more than 1 lb./.454 Kgs of pressure?

- Yes
- No

6. If no, what further research evidence would you suggest to strengthen this opinion?

7. If yes, use the sliding scale to provide your percent confidence level in this opinion.

8. Please provide additional information or comment.

9. You're almost finished, just a few more short questions. Would you please indicate your highest level of education?

    a. Secondary school
    b. College (Technical Training)
    c. University undergraduate
    d. University Masters
    e. University PhD

10. Would you provide information on the number of years that you have been employed as a friction ridge examiner?

    a. 0-5
    b. 6-10
    c. 11-15
    d. 16-20
    e. 21-25
    f. More than 25

11. Would you please indicate the global region that would best describe your primary place of work?

    a. Australia
    b. Canada
    c. Caribbean Region
    d. Hawaii
    e. Mercosur (Brazil, Argentina, Paraguay and Uruguay)
    f. Middle East
    g. New Zealand
    h. Philippines
    i. South Africa
    j. United States of America

12. Thank you for taking the time to complete this survey. I truly value the

information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Friction Ridge Impression Analysis (Quantitative)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Friction Ridge Impression Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a friction ridge impression analysis. Quantitative research has been conducted on a fingerprint impression that was found at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of quantitative measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the image of a fingerprint pattern that was located within a scene? The case-specific question to be answered is; was the fingerprint placed on the substrate with more than 1 lb/.454 Kg of pressure?

☐ Reviewed the image

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. What would you say if provided with the following quantitative study where measurements of the size of the ridges from the scene fingerprint impression were statistically compared to measurements taken from the size of the ridges of multiple test impressions (n=300). An ANova test indicated that there was no significant difference between the size of the ridges from the impression and other test impressions made with 10 lbs/4.54 Kgs of pressure. A second ANova test indicated a significant difference between the size of the ridges from the scene impression and other test impressions that were made with 1 lb/.454 kg of pressure. These quantitative data suggest that the fingerprint was placed on the substrate with more than 1 lb/.454 kg pound of pressure. Those data are presented for your review.

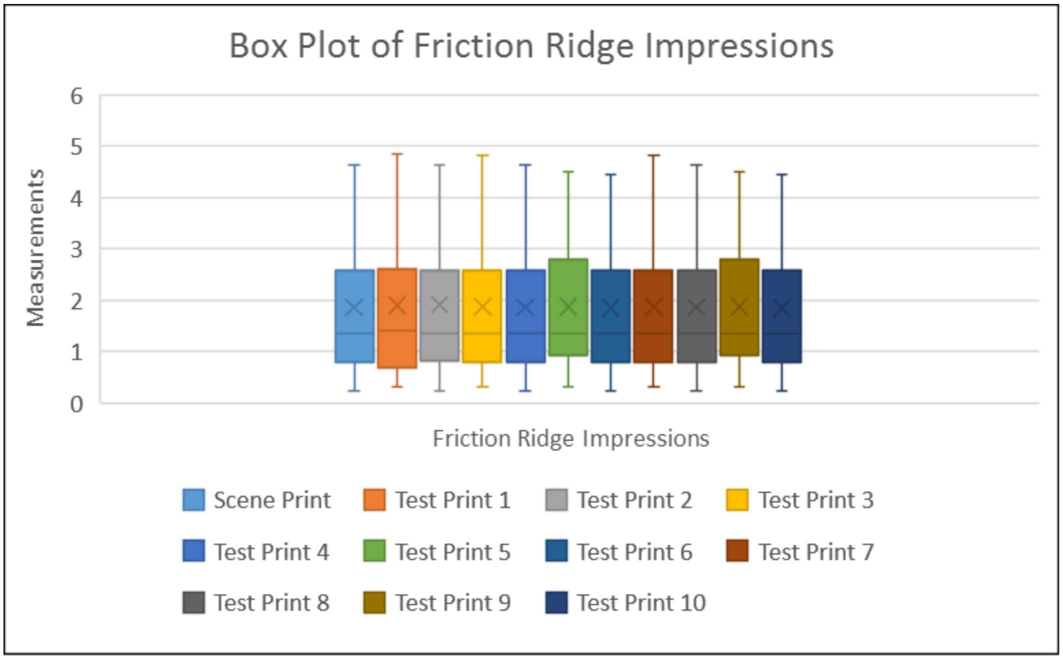
Anova: Single Factor

SUMMARY

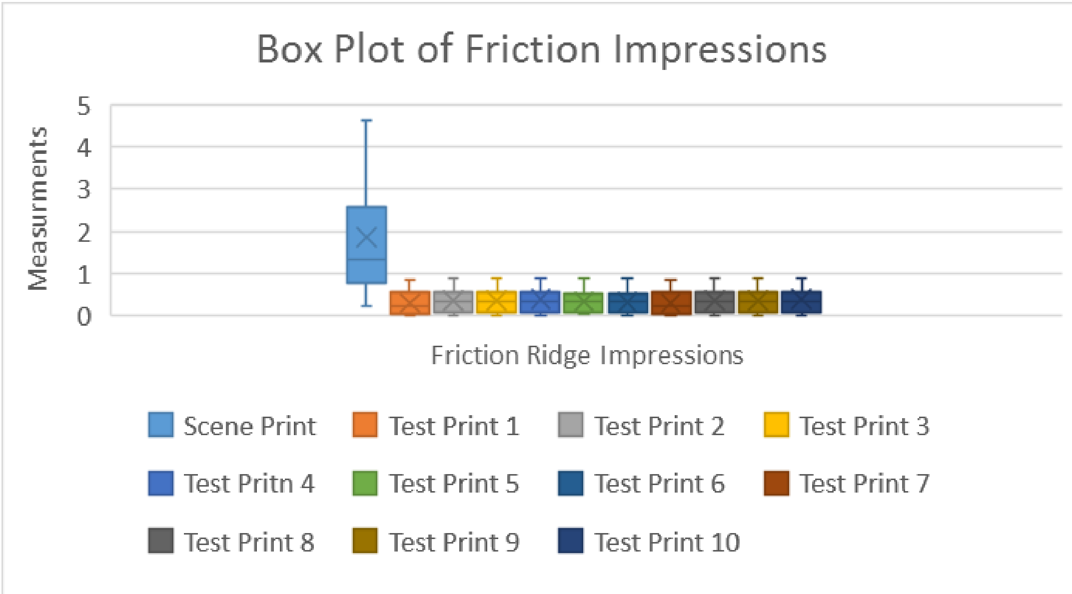
Groups	*Count*	*Sum*	*Average*	*Variance*
Scene	15	27.837	1.8558	1.780379
1	15	28.476	1.8984	1.831843
2	15	28.749	1.9166	1.646365
3	15	28.096	1.873067	1.83758
4	15	27.856	1.857067	1.780995
5	15	28.106	1.873733	1.71652
6	15	27.641	1.842733	1.709587
7	15	28.096	1.873067	1.83758
8	15	27.856	1.857067	1.780995
9	15	28.106	1.873733	1.71652
10	15	27.641	1.842733	1.709587

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.07567	10	0.007567	0.004302	0.99999	1.892653
Within Groups	270.8713	154	1.758905			
Total	270.947	164				



Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Scene	15	27.837	1.8558	1.780379		
1	15	4.7192	0.314613	0.074659		
2	15	5.4855	0.3657	0.060429		
3	15	5.3645	0.357633	0.07664		
4	15	5.9084	0.393893	0.074216		
5	15	5.1964	0.346427	0.076174		
6	15	4.9842	0.33228	0.062272		
7	15	4.7192	0.314613	0.074659		
8	15	5.4855	0.3657	0.060429		
9	15	5.3645	0.357633	0.07664		
10	15	5.9084	0.393893	0.074216		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30.85244	10	3.085244	13.62569	5.47E-17	1.892653
Within Groups	34.86999	154	0.226429			
Total	65.72243	164				



In this study it is assumed that all the variables are controlled and constant. The only variable that has been changed is the pressures (10 lbs/4.45 Kgs and 1 lb/.454 kg) when the fingerprints were placed on the substrate. The sample set is considered scientifically sufficient and robust.

☐ Reviewed those data

5. When you reviewed those quantitative data within this research, how would the amount of scientific information impact you for providing a conclusion that the suspect fingerprint was made with more than 1 lb/.454 kg of pressure?

☐ No impact

☐ Minor impact

☐ Neutral

☐ Moderate impact

☐ Major impact

6. Would you offer an expert opinion in court based on the information provided

in this quantitative study that the suspect fingerprint was made with more than 1 lb/.454 kg of pressure?

- ☐ Yes
- ☐ No

7. If no, what further research evidence would you suggest to strengthen this opinion?

8. If yes, use the sliding scale to provide your percent confidence level in this opinion.

9. Please provide additional information or comment.

10. You’re almost finished, just a few more short questions. Would you please indicate your highest level of education?

    a. Secondary school

    b. College (Technical Training)

    c. University undergraduate

    d. University Masters

    e. University PhD

11. Would you provide information on the number of years that you have been employed as a friction ridge examiner?

    a. 0-5

b. 6-10

c. 11-15

d. 16-20

e. 21-25

f. More than 25

12. Would you indicate the global region that would best describe your primary place of work?

a. Australia

b. Canada

c. Caribbean Region

d. Hawaii

e. Mercosur (Brazil, Argentina, Paraguay and Uruguay)

f. Middle East

g. New Zealand

h. Philippines

i. South Africa

j. United States of America

13. Thank you for taking the time to complete this survey. I truly value the information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Bloodstain Pattern Analysis (Mixed Method)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Bloodstain Pattern Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a bloodstain pattern analysis. Mixed method research has been conducted on a suspected impact pattern at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of mixed method measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the following group of images? One image (Figure 1) is of the suspect pattern that was found within a scene. The pattern consists of several directional stains that appear to form one pattern. The following nine (9) images (Figures 2-10, Patterns A-I) are of impressions that were made in a laboratory from an impact into a liquid blood source. The case-specific question to be answered is; was this pattern created by an impact event into wet blood?

- Reviewed image

Figure 1 Pattern from crime scene.

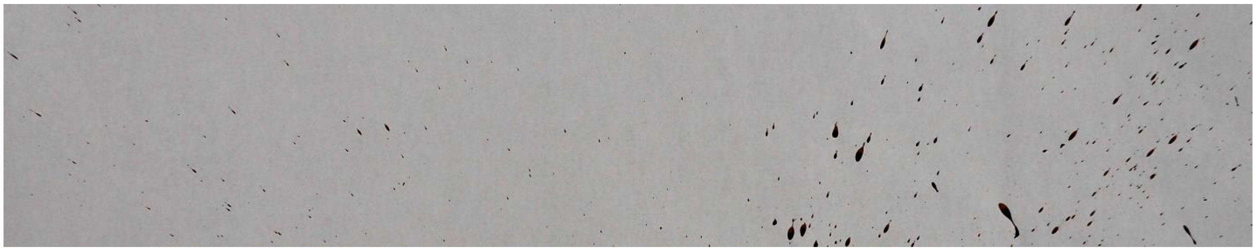


Figure 2 Impact test pattern A.

Figure 3 Impact test pattern B.

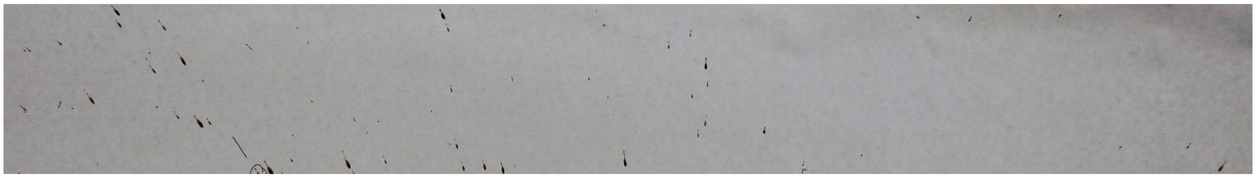


Figure 4 Impact test pattern C.

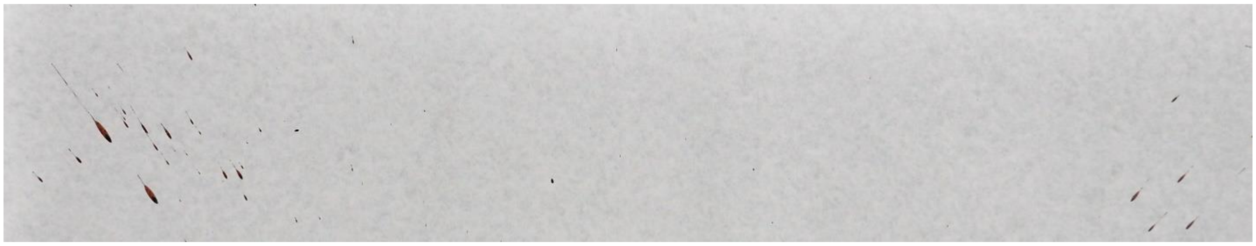


Figure 5 Impact test pattern D.

Figure 6 Impact test pattern E.

Figure 7 Impact test pattern F.

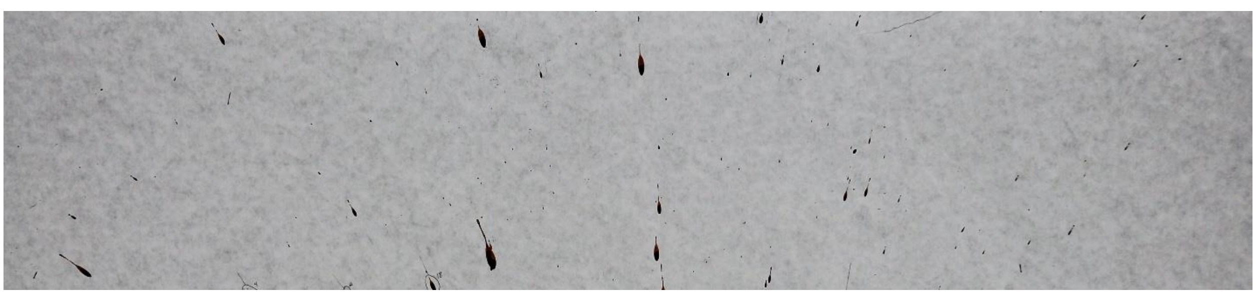


Figure 8 Impact test pattern G.

Figure 9 Impact test pattern H.

Figure 10 Impact test pattern I.

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. In addition to the above qualitative study what would you say if provided with the following quantitative measurements showing Convergent Points (CP) x, y and z straight line trajectory estimations of the area of origin for ten patterns. These were calculated from the pattern in question (Figure 1 scene) and from nine patterns (A-I, figures 2-10) created in a controlled laboratory setting by an object striking a liquid blood source. All patterns show that there is an area of origin suggesting the pattern was made by an impact mechanism.

Click to choose the diagram and proceed to the next question.

Pattern	CPx (cm)	Cpy (cm)	CPz (cm)
Scene	**17.7**	**54.3**	**72.6**
Test A	**19.8**	**52.5**	**69.1**
B	**20.4**	**59.5**	**71.3**
C	**23.1**	**62.5**	**65.1**
D	**19.6**	**55.6**	**56.3**
E	**14.6**	**53.6**	**63.9**
F	**11.5**	**53.3**	**64.3**
G	**20.6**	**56.3**	**67**
H	**18.8**	**57.1**	**62.6**

I	**28.9**	**53.5**	**67.8**

In this study it is assumed that all the variables are controlled and constant. It is confirmed that all patterns were created with human blood at normal body temperature.

5. When you review this mixed method research of the patterns, how would the amount of scientific information impact you for providing a conclusion that the suspect pattern type was created by an impact event into a wet blood source?

   - ☐ No impact
   - ☐ Minor impact
   - ☐ Neutral
   - ☐ Moderate impact
   - ☐ Major impact

6. Would you offer an expert opinion in court based on the information provide in this mixed methods study that the partial bloodstain pattern was created by an impact event into a wet blood source?

   - ☐ Yes
   - ☐ No

7. If no, what further research evidence would you suggest to strengthen this opinion?

8. If yes, use the sliding scale to provide your percent confidence level confidence level in this opinion.

9. Please provide additional information or comment.

10. You’re almost finished, just a few more short questions. Would you please indicate your highest level of education?

- ☐ Secondary school
- ☐ College (Technical Training)
- ☐ University undergraduate
- ☐ University Masters
- ☐ University PhD

11. Would you provide information on the number of years that you have been employed as bloodstain pattern analyst?

- ☐ 0-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ 21-25
- ☐ More than 25

12. Would you please indicate the global region that would best describe your primary place of work?

- ☐ Australia
- ☐ Canada

- ☐ Caribbean Region
- ☐ Hawaii
- ☐ Mercosur (Brazil, Argentina, Paraguay and Uruguay)
- ☐ Middle East
- ☐ New Zealand
- ☐ Philippines
- ☐ South Africa
- ☐ United States of America

13. Thank you for taking the time to complete this survey. I truly value the information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Bloodstain Pattern Analysis (Qualitative)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Bloodstain Pattern Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a bloodstain pattern analysis. Qualitative research has been conducted on a suspected impact pattern at a crime scene. The expert participant will be asked to provide information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University

Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of qualitative measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

- ☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the following group of images? One image (Figure 1) is of the suspect pattern that was found within a scene. The pattern consists of several directional stains that appear to form one pattern. The following nine (9) images (Figures 2-10) are of impressions that were made in a laboratory from an object impacting into a liquid blood source. The images depict the upper area of the created patterns. The case-specific question to be answered is; was this pattern created by an impact event into wet blood?

Figure 1 Pattern from crime scene

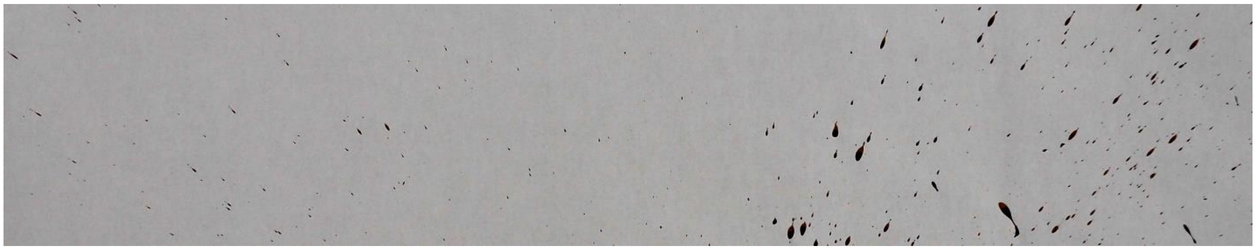


Figure 2 Impact test pattern

Figure 3 Impact test pattern

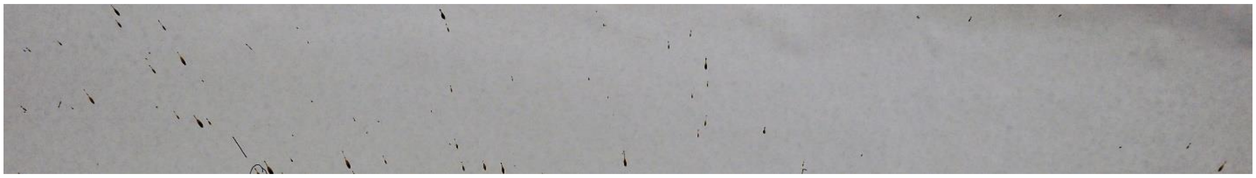


Figure 4 Impact test pattern

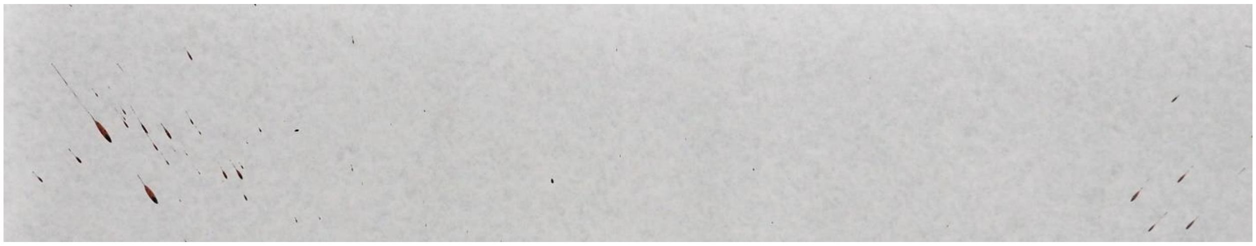


Figure 5 Impact test pattern

Figure 6 Impact test pattern

Figure 7 Impact test pattern

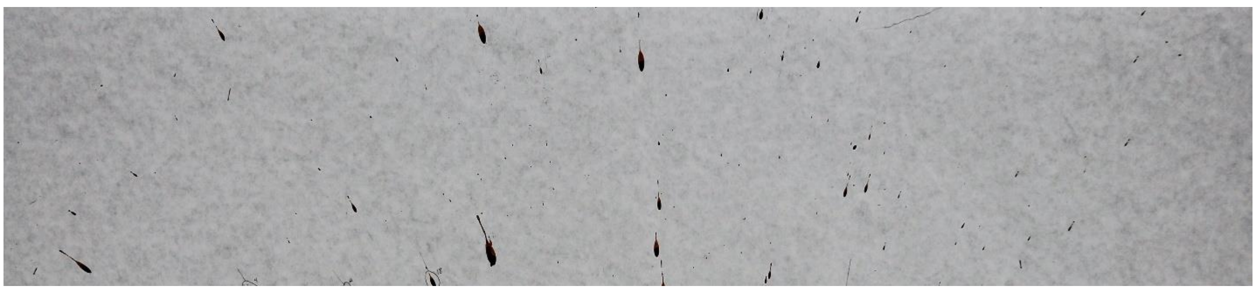


Figure 8 Impact test pattern

Figure 9 Impact test pattern

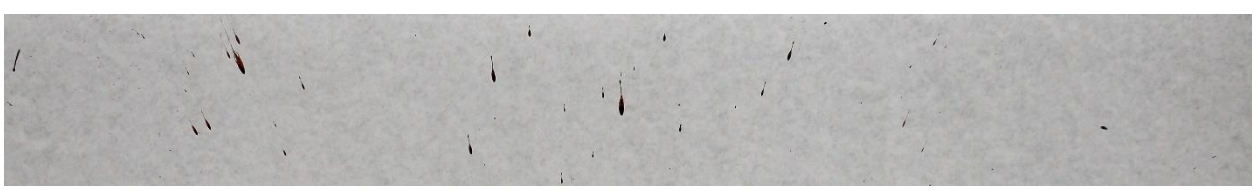


Figure 10 Impact test pattern

a. Reviewed image

In this study it is assumed that all the variables are controlled and constant. It is confirmed that all patterns were created with human blood at normal body temperature. The sample set is considered to be scientifically sufficient and robust.

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. When reviewing the qualitative observations within this research how would the amount of scientific information impact you for providing a conclusion that the suspect pattern was created by an impact event into a wet blood source?

   a. No impact
   b. Minor impact
   c. Neutral
   d. Moderate impact
   e. Major impact

5. Would you offer an expert opinion in court based on the information provide in this qualitative study that the partial bloodstain pattern was

created by an impact event into a wet blood source?

a. Yes
b. No

6. If no, what further research evidence would you suggest to strengthen this opinion?

7. If yes, use the sliding scale to provide your percent confidence level confidence level in this opinion.

8. Please provide additional information or comment.

9. You're almost finished, just a few more short questions. Would you indicate your highest level of education?
    a. Secondary school
    b. College (Technical Training)
    c. University undergraduate
    d. University Masters
    e. University PhD

10. Would you provide information on how many years have you been employed as bloodstain pattern analyst?

    a. 0-5
    b. 6-10
    c. 11-15

d. 16-20

e. 21-25

f. More than 25

11. Would you indicate the global region that would best describe your primary place of work.

    a. Australia
    b. Canada
    c. Caribbean Region
    d. Hawaii
    e. Mercosur (Brazil, Argentina, Paraguay and Uruguay)
    f. Middle East
    g. New Zealand
    h. Philippines
    i. South Africa
    j. United States of America

12. Have you provided expert opinion evidence in court on bloodstain pattern analysis?

    a. Yes
    b. No

13. Thank you for taking the time to complete this survey. I truly value the information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Bloodstain Pattern Analysis (Quantitative)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Bloodstain Pattern Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a bloodstain pattern analysis. Quantitative research has been conducted on a suspected impact pattern at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of quantitative measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the enclosed image of the suspect pattern that was found within a scene? The pattern consists of several directional stains that appear to form one pattern. The case-specific question for you to answered is; was this pattern created by an impact event into wet blood?

Click to choose the diagram and proceed to the next question.

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. What would you say if provided with the following quantitative measurements showing the Convergent Point (CP) x,y and z straight line trajectory estimations of the area of origin for ten patterns? These were calculated from the pattern in question (scene) and from nine patterns (A-I) that were created in a controlled laboratory setting by an object striking a liquid blood source. All patterns show that there is an area of origin suggesting the pattern was made by an impact mechanism.

Click to choose the diagram and proceed to the next question.

Pattern	CPx (cm)	Cpy (cm)	CPz (cm)
Scene	**17.7**	**54.3**	**72.6**

Test A	**19.8**	**52.5**	**69.1**
B	**20.4**	**59.5**	**71.3**
C	**23.1**	**62.5**	**65.1**
D	**19.6**	**55.6**	**56.3**
E	**14.6**	**53.6**	**63.9**
F	**11.5**	**53.3**	**64.3**
G	**20.6**	**56.3**	**67**
H	**18.8**	**57.1**	**62.6**
I	**28.9**	**53.5**	**67.8**

In this study it is assumed that all the variables are controlled and constant. It is confirmed that all patterns were created with human blood at normal body temperature. The sample set is considered to be scientifically sufficient and robust.

5. When you reviewed those quantitative data within this research, how would the amount of scientific information impact you for providing a conclusion that the suspect pattern was created by an impact event into a wet blood source?

    a. No impact

    b. Minor impact

    c. Neutral

    d. Moderate impact

    e. Major impact

6. Would you offer an expert opinion in court based on the information provide in this quantitative study that the partial bloodstain pattern was created by an impact event into a wet blood source?

    a. Yes
    b. No

7. If no, what further research evidence would you suggest to strengthen this opinion?

8. If yes, use the sliding scale to provide your percent confidence level in this opinion.

9. Please provide any additional information or comment.

10. You're almost finished, just a few more short questions. Would you please indicate your highest level of education.

    a. Secondary school
    b. College (Technical Training)
    c. University undergraduate
    d. University Masters
    e. University PhD

11. Would you provide information on the number of years that you have been employed as bloodstain pattern analyst?

    a. 0-5
    b. 6-10

c. 11-15

d. 16-20

e. 21-25

f. More than 25

12. Would you indicate the global region that would best describe your primary place of work?

   a. Australia

   b. Canada

   c. Caribbean Region

   d. Hawaii

   e. Mercosur (Brazil, Argentina, Paraguay and Uruguay)

   f. Middle East

   g. New Zealand

   h. Philippines

   i. South Africa

   j. United States of America

13. Have you provided expert opinion evidence in court on bloodstain pattern analysis?

   a. Yes

   b. No

14. Thank you for taking the time to complete this survey. I truly value the

information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Footwear Impression Analysis (Mixed Method)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Footwear Impression Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a footwear impression analysis. This mixed method research has been conducted on a suspected footwear impression at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of mixed method measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

- ☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the following group of images? One image (Figure 1) is of the suspect pattern that was found within a scene. The pattern consists of a small area from a shoe tread. The following six (6) images (Figure 2, test impressions 1-6) are of impressions that were made in a laboratory from a Converse shoe. The case-specific question to be answered is; was the partial crime scene footwear impression made by a Converse shoe?

   a. Reviewed the images

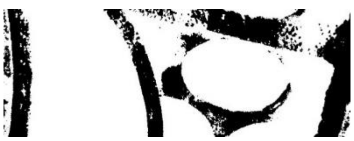


Figure 1 Partial crime scene impression

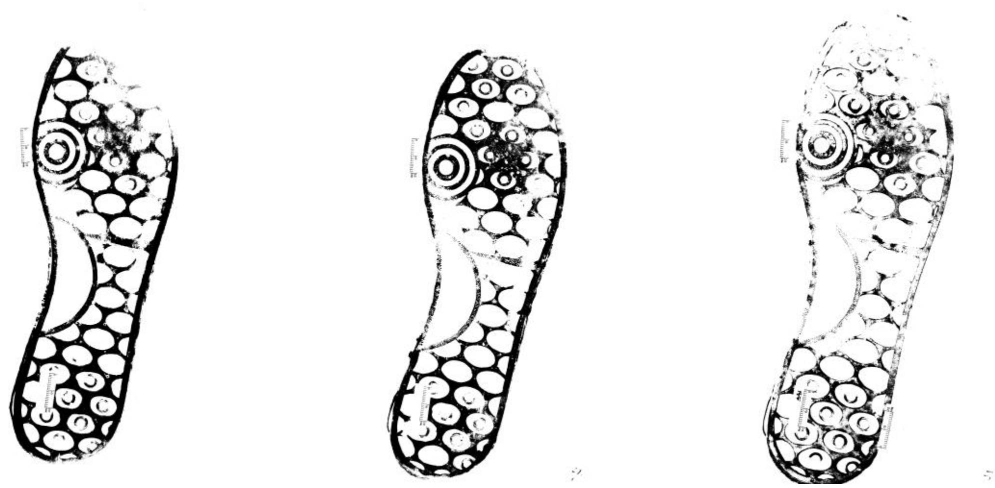
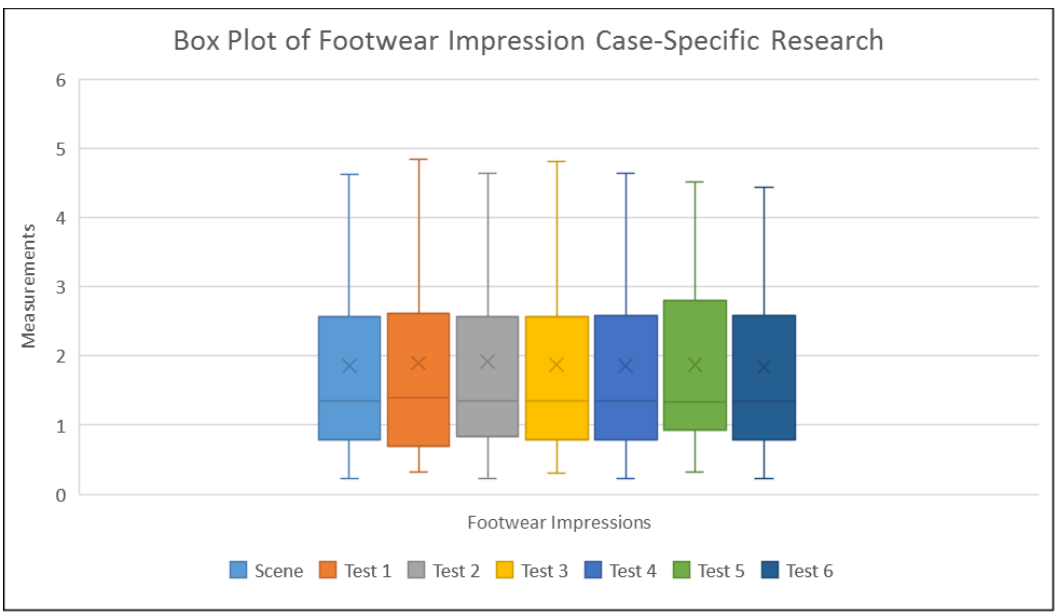


Figure 2 Test impression #1-6 made from a Converse shoe

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. A quantitative study was also conducted where measurements from the partial tread impression were statistically compared to measurements taken from the middle tread area of six (6) converse shoe impressions made in a laboratory environment. An ANova test indicated that there was no significant difference between the partial impression and other six (6) test impressions of a Converse shoe. This quantitative data suggests that the partial impression was created by a Converse shoe. Those data are presented for your review.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Scene	15	27.837	1.8558	1.780379		
1	15	28.476	1.8984	1.831843		
2	15	28.749	1.9166	1.646365		
3	15	28.096	1.873067	1.83758		
4	15	27.856	1.857067	1.780995		
5	15	28.106	1.873733	1.71652		
6	15	27.641	1.842733	1.709587		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.060099	6	0.010016	0.005699	0.999999	2.192518
Within Groups	172.2458	98	1.75761			
Total	172.3059	104				



In this study it is assumed that all research variables have been controlled and that the shoe tread of the test impressions is only related to one Converse shoe make and no other known shoe make or model. The sample set is accepted as scientifically sufficient and robust.

    a. Reviewed those data

5. When you review those quantitative and qualitative data within this mixed method research, how would the amount of scientific information impact you for providing a conclusion that the partial footwear impression was created by a Converse shoe?

    a. No impact
    b. Minor impact
    c. Neutral
    d. Moderate impact
    e. Major impact

6. Would you offer an expert opinion in court based on the information provide in this mixed methods study that the partial footwear impression was created by a Converse shoe?

    a. Yes
    b. No

7. If no, what further research evidence would you suggest to strengthen this opinion?

8. If yes, use the sliding scale to provide your percent confidence level in this opinion.

9. Please provide additional information or comment.

10. You're almost finished, just a few more short questions. Would you please indicate your highest level of education?

    a. Secondary school

    b. College (Technical Training)

    c. University undergraduate

    d. University Masters

    e. University PhD

11. Would you provide information on the number of years that you have been employed as a footwear examiner?

    a. 0-5

    b. 6-10

    c. 11-15

    d. 16-20

    e. 21-25

    f. More than 25

12. Would you please indicate the global region that would best describe your primary place of work?

    a. Australia

b. Canada

c. Caribbean Region

d. Hawaii

e. Mercosur (Brazil, Argentina, Paraguay and Uruguay)

f. Middle East

g. New Zealand

h. Philippines

i. South Africa

j. United States of America

13. Thank you for taking the time to complete this survey. I truly value the information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Footwear Impression Analysis (Qualitative)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Footwear Impression Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a footwear impression analysis. Qualitative research has been conducted on a suspected footwear impression at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office

Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of qualitative measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

- ☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate

2. Would you please review and analyze following group of images? One image (Figure 1) is of the suspect pattern that was found within a scene. The pattern consists of a small area from a shoe tread. The following six (6) images (Figure 2, test impressions 1-6) are of impressions that were made in a laboratory from a Converse shoe. The case-specific question to be answered is; was the partial crime scene footwear impression made by a Converse shoe?

Figure 1 Partial crime scene impression

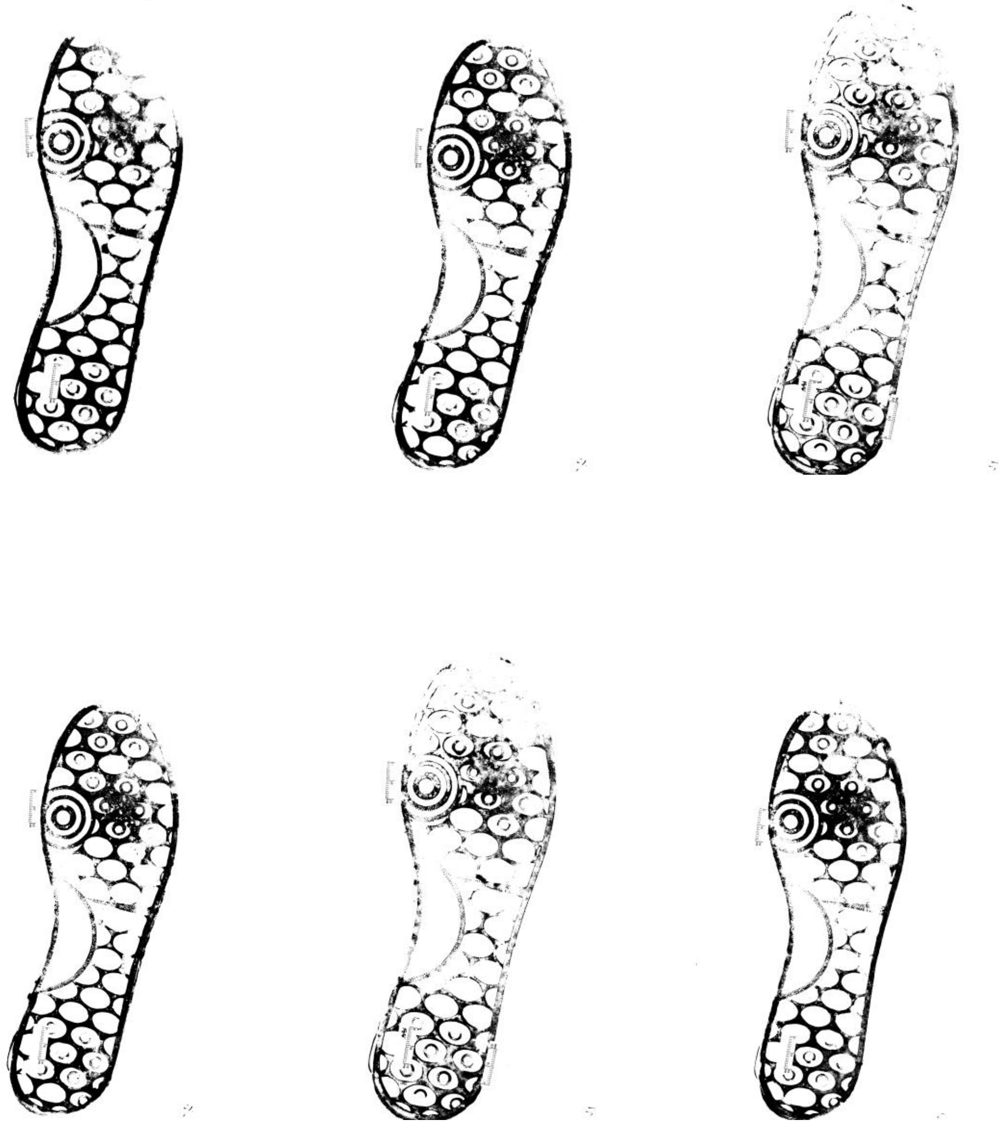


Figure 2 Test impression #1-6 made from a Converse shoe

a. Reviewed the images

In this study it is assumed that all research variables have been controlled and that the shoe tread of the test impressions is only related to one Converse shoe make and no other known shoe make or model. The sample set is accepted as scientifically sufficient and robust.

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. When you review those qualitative data within this research, how would the amount of scientific information impact you for providing a conclusion that the partial footwear impression was created by a Converse shoe?

    a. No impact
    b. Minor impact
    c. Neutral
    d. Moderate impact
    e. Major impact

5. Would you offer an expert opinion in court based on the information provide in this quantitative study that the partial footwear impression was created by a Converse shoe?

    a. Yes
    b. No

6. If no, what further research evidence would you suggest to strengthen this opinion?

7. If yes, use the sliding scale to provide your percent confidence level in this opinion.

8. Please provide additional information or comment.

9. You’re almost finished, just a few more short questions. Would you please indicate your highest level of education.

   a. Secondary school

   b. College (Technical Training)

   c. University undergraduate

   d. University Masters

   e. University PhD

10. Would you provide information on the number of years that you have been employed as a footwear examiner?

    a. 0-5

    b. 6-10

    c. 11-15

    d. 16-20

    e. 21-25

    f. More than 25

11. Would you please indicate the global region that would best describe your primary place of work?

    a. Australia

    b. Canada

c. Caribbean Region

d. Hawaii

e. Mercosur (Brazil, Argentina, Paraguay and Uruguay)

f. Middle East

g. New Zealand

h. Philippines

i. South Africa

j. United States of America

12. Thank you for taking the time to complete this survey. I truly value the information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

A Model for Case-Specific Research in Forensic Science – Footwear Impression Analysis (Quantitative)

1. **Participant Consent**

Research Project: A Model for Case-Specific Research in Forensic Science – Footwear Impression Analysis

Researcher: Mike Illes, mikeilles@trentu.ca

Description: This research study will examine and suggest best practices from the use of existing research models that should be used in forensic science case-specific research. The participant will be reviewing information derived from a case-specific question on a footwear impression analysis. Quantitative research has been conducted on a suspected footwear impression at a crime scene. The expert participant will be asked to offer information on tendering evidence and with what level of confidence based on those data provided.

Those data collected will be secured in a Trent University encrypted hard drive and the results will be used in publications and presentations. The survey is completely voluntary, anonymous, and has approval from the Trent University Research Ethics Board (REB # 24765). The Trent University Research Office Compliance Officer is Karen Mauro, (705) 748-1011 ext. 7896 or kmauro@trentu.ca.

Sessions: This will be a one session questionnaire on the use of quantitative measures in case-specific research. The survey will take approximately 10 minutes to complete. Feel free to discontinue the survey at any time.

Sessions: This will be a one session questionnaire on the use of quantitative measures in case-specific research.

- ☐ I have been informed of the nature of this study as described above and freely give my informed consent to participate.

2. Would you please review and analyze the enclosed image of the suspect pattern that was found within a scene? The pattern consists of a small area from a shoe tread pattern. The case-specific question to be answered is; was the partial crime scene footwear impression made by a Converse shoe?

- ☐ Reviewed the image

3. What preferred research method of analysis would you choose to answer this case-specific question?

4. A quantitative study was conducted where measurements from the partial tread impression were statistically compared to measurements taken from the middle tread area of six converse shoes. An ANova test indicated that there was no significant difference between the partial impression and the other six (6) test impressions of a Converse shoe. This quantitative data suggests that the partial impression was created by a Converse shoe. Those data are presented for your review.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Scene	15	27.837	1.8558	1.780379		
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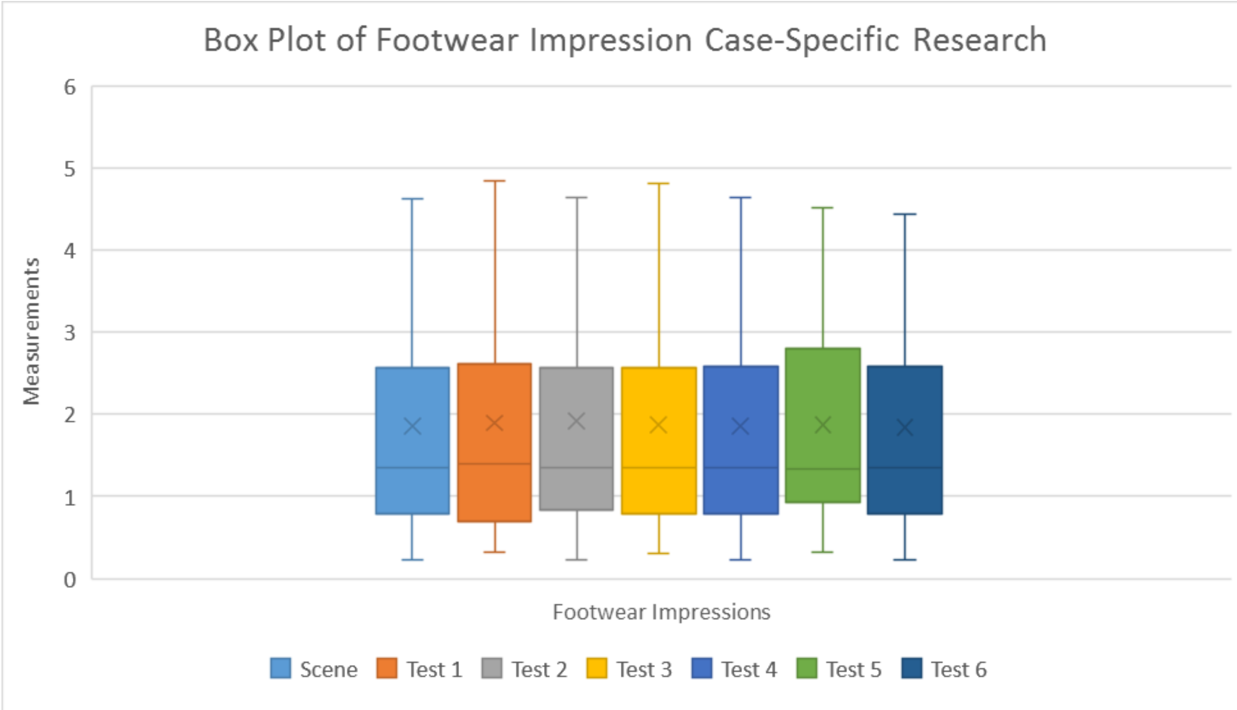
5	15	28.106	1.873733	1.71652		
6	15	27.641	1.842733	1.709587		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.060099	6	0.010016	0.005699	0.999999	2.192518
Within Groups	172.2458	98	1.75761			
Total	172.3059	104				



In this study it is assumed that all research variables have been controlled and that the shoe tread of the test impressions is only related to one Converse shoe make and no other known shoe make or model. Consider the sample set to be scientifically robust.

☐ Reviewed those data

5. When you review those quantitative data within this research, how would the amount of scientific information impact you for providing a conclusion that the partial footwear impression was created by a converse shoe?

   ☐ No impact

   ☐ Minor impact

   ☐ Neutral

   ☐ Moderate impact

- ☐ Major impact

6. Would you offer an expert opinion in court based on the information provide in this quantitative study that the partial footwear impression was created by a converse shoe?

   - ☐ Yes
   - ☐ No

7. If no, what further research evidence would you suggest to strengthen this opinion?

8. If yes, use the sliding scale to provide your percent confidence level in this opinion.

(Scale insert in Qualtric)

9. Please provide additional information or comment.

10. You have almost complete the survey, just a few more questions to answer. Would you please indicate your highest level of education?

    a. Secondary School Diploma
    b. College Diploma (Technical)
    c. University Undergraduate Degree
    d. University Graduate Masters
    e. University Graduate PhD

11. Would you provide information on the number of years that you have been employed as footwear analyst?

   a. 0-5
   b. 6-10
   c. 11-15
   d. 16-20
   e. 21-25
   f. More than 25

12. Would you please indicate the global region that would best describe your primary place of work?

   a. Australia
   b. Canada
   c. Caribbean Region
   d. Hawaii
   e. Mercosur (Brazil, Argentina, Paraguay and Uruguay)
   f. Middle East
   g. New Zealand
   h. Philippines
   i. South Africa
   j. United States of America

13. Thank you for taking the time to complete this survey. I truly value the

information you have provided. Your responses will contribute to this research and suggest new lines of approach to the use of case-specific research.

Appendix B: Research Ethic Board Approvals

TRENT UNIVERSITY

Office of
Research & Innovation

Mike Illes
Forensic Science
DNA

April 25, 2017

File #: 24763
Title: Reasoning in Crime Scene Investigations

Dear Mr. Illes,

The Research Ethics Board (REB) has given approval to your proposal entitled "Reasoning in Crime Scene Investigations".

The committee strongly suggests and encourages you to encrypt any data that is being collected that contains any personal or identifying information. Please add a statement to your consent form concerning this. For help with encryption services, please contact Trent's IT Department.

Please add a running footer to your consent form, with the date of Trent REB approval and consent revisions number (e.g., 01-Jan-12, Version 2), so that the consent form used can be easily identified in future.

When a project is approved by the REB, it is an Institutional approval. It does not undermine or replace any other community ethics process. Full approval depends upon the approval of all other bodies who are named as stakeholders in this research.

In accordance with the Tri-Council Guidelines (article D.1.6) your project has been approved for one year. If this research is ongoing past that time, submit a Research Ethics Annual Update form available online under the Research Office website. If the project is completed on or before that time, please email Karen Mauro in the Research office so the project can be recorded as completed.

Please note that you are reminded of your obligation to advise the REB before implementing any amendments or changes to the procedures of your study that might affect the human participants. You are also advised that any adverse events must be reported to the REB.

On behalf of the Trent Research Ethics Board, I wish you success with your research.

With best wishes,

Dr. Brenda Smith-Chant
REB Chair
Phone: (705) 748-1011 ext. 7780, Fax: (705) 748-1587
Email: bresmith@trentu.ca

c.c.: Karen Mauro
Compliance Officer

1600 West Bank Drive, Peterborough, ON Canada K9L 0G2 | trentu.ca/research | 705.748.1011 ext 7050 research@trentu.ca

Office of
Research & Innovation

Mike Illes
Forensic Science
LHS

May 09, 2017

File #: 24765
Title: A MODEL FOR CASE-SPECIFIC RESEARCH IN FORENSIC SCIENCE

Dear Mr. Illes,

The Research Ethics Board (REB) has given approval to your proposal entitled "A MODEL FOR CASE-SPECIFIC RESEARCH IN FORENSIC SCIENCE".

The committee strongly suggests and encourages you to encrypt any data that is being collected that contains any personal or identifying information. Please add a statement to your consent form concerning this. For help with encryption services, please contact Trent's IT Department.

Please add a running footer to your consent form, with the date of Trent REB approval and consent revisions number (e.g., 01-Jan-12, Version 2), so that the consent form used can be easily identified in future.

When a project is approved by the REB, it is an Institutional approval. It does not undermine or replace any other community ethics process. Full approval depends upon the approval of all other bodies who are named as stakeholders in this research.

In accordance with the Tri-Council Guidelines (article D.1.6) your project has been approved for one year. If this research is ongoing past that time, submit a Research Ethics Annual Update form available online under the Research Office website. If the project is completed on or before that time, please email Karen Mauro in the Research office so the project can be recorded as completed.

Please note that you are reminded of your obligation to advise the REB before implementing any amendments or changes to the procedures of your study that might affect the human participants. You are also advised that any adverse events must be reported to the REB.

On behalf of the Trent Research Ethics Board, I wish you success with your research.

With best wishes,

Dr. Brenda Smith-Chant
REB Chair
Phone: (705) 748-1011 ext. 7780, Fax: (705) 748-1587
Email: bresmith@trentu.ca

c.c.: Karen Mauro
Compliance Officer

Appendix C: Copy Right Permissions

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iii. See attached letter.

CANADIAN SCHOLARS

WOMEN'S PRESS

425 Adelaide Street West
Suite 200
Toronto, ON
M5V 3C1
416-929-2774

September 6, 2019

Dear Mr. Illes,

This letter confirms that you as the author of the textbook (provisionally) titled *The Scientific Method in Forensic Science: A Canadian Handbook* share copyright with the publisher Canadian Scholars and, thus, are permitted to use material (e.g., Chapter 1) from the textbook in your dissertation. The publisher asks that you properly attribute the material in your dissertation to the forthcoming textbook.

Sincerely,

Katherine Kurowski
Editorial/Production Manager
Canadian Scholars | Women's Press
katherine.kurowski@canadianscholars.ca