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Forensic epistemology: A need for research and pedagogy

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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.

1. Introduction

This study synthesizes the results from two primary studies, *“Forensic Epistemology: Testing the reasoning skills of crime scene experts”* [1] *and “Forensic Epistemology: Exploring Case-Specific Research in Forensic Science”* [2] 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 [3–6]. 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-specialization, where practitioners are “siloed” into one discipline diminishes the generalist approach [7–10]. Research has shown that cumulative knowledge and experience in different domains provide a better depth and breadth of knowledge [11]. 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 [12,13] yet in the field of forensic science, practitioners over the past decade have moved increasingly toward specialization [8,14]. This may have caused the unintended outcome of a division between practice and theory [8,15]. 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 [10,16].

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 [17] 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 [18] 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.

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Subsequently, in 2014 Swan [19] 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 [20,21] 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. [22] 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. [16] 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.

2. 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 [1].

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 [2].

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.

3. Three key themes

3.1. The epistemic state of forensic science

In our first paper *"Forensic Epistemology: Testing the reasoning skills of crime scene experts"* [1] 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"* [2] the percentage 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.

3.1.1. 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 [11,23]. Hogarth [24] 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 [11] 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. [25] 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 [26]. 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 [27,28]. Our research supports this need for treating forensic scenes as ill-structured. Unfortunately many forensic classroom lessons are designed as well-structured problem solving [29] at this time.

Pattern recognition relies on experience and a guarantee that there is a repetitive structure [11]. 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 [30–32]. Amos Tversky and Daniel Kahneman's [33] 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 [34]. Unfortunately, in this type of wicked environment experience reinforces the wrong lessons and decisions [11,23,29]. 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 [27,35–38]. Forensic science curriculum needs to focus on teaching ill-structured problem-solving skills and the following strategies offer direction in accomplishing this task [39].

3.1.2. 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 [1]. 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 [40,41] (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 [42]. 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.

3.2. 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 [1,2]. 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 [43,44]. 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 [45]. Researchers such as Dolmans et al. Andersen et al. and Larmer [44,46,47] 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. Fig. 1 provides a summary of the interface between project-based, problem-based and experience-based learning followed by detailed reviews of each.

3.2.1. Problem-based learning

There has been a shift in tertiary education from a teacher-to a student-centred model of teaching [49]. Considering the nature of forensic science work, this shift should have a positive impact in pedagogy at the university and college level [50,51]. 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" [52]. 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 [53]. Since that time its use has spread into tertiary and K-12 learning environments on a global level [53].

The literature on PBL is extensive and validation research has provided evidence of its efficacy [41,44,52,53]. 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 [54] 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) [55]. 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 [56]. Similarly, Kennedy [57] describes how a team of forensic educators reconfigured "The Pale Horse" model by Belt et al. [58], 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 practises. In a different type of study, Pringle et al. [59] 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.

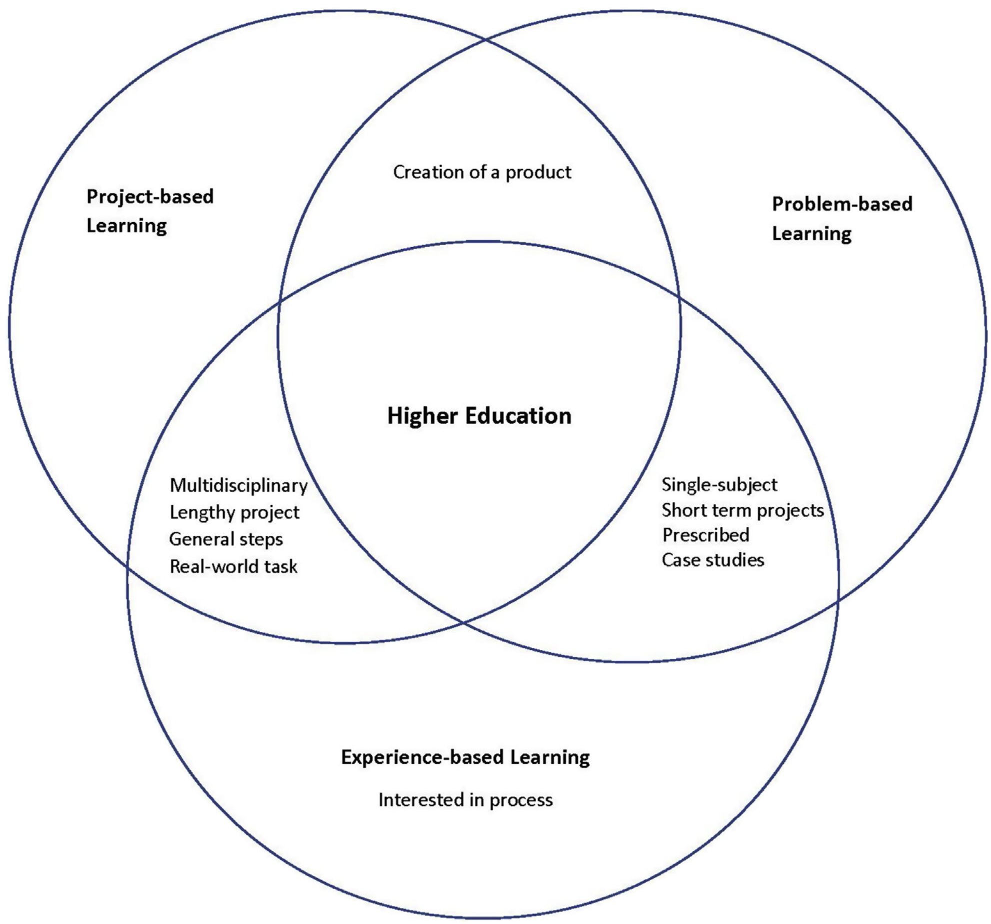

Fig. 1. Interface between project-, problem- and experience-based learning in higher education [46–48].

3.2.2. Case or experience-based learning

Experiential learning has a long history dating to its development by Kolb [60] 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 [60]. 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 [60,61]. 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. [62] 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 [63], 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 [64–67]. 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 [68–70]. Experiential learning has also been presented as one way of sustaining the development of higher education on a global level [71].

This model has been reinforced in forensic science by Rogers [72] 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 [73]. 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 [73]. Further studies that concentrated on a bloodstain pattern analysis course and a crime scene investigation course completed by Illes et al. [74,75] 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 [76] 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 [76]. Likewise, a 2018 study conducted by David Byrne [77] 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 [29,51]. 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 [78,79].

3.2.3. Project-based learning

Project-based learning (PjBL)as defined by Larmer et al. [80], 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 [81]. PjBL has been extensively supported for used in K-12 education. For instance, in 2015 the Ministry of Education in Ontario, Canada identified PBL as the future of education providing a deeper learning environment [81]. PjBL has also been described as a way to "prepare students to master their new role as a global citizen with greater responsibilities" [82]. Subsequently, the use of PjBL has emerged in higher education with research supporting its use in science, technology, engineering and mathematic (STEM) subjects [48]. In fact, the use of PjBL in secondary education has increased the number of students who pursue a post-secondary STEM education [83].

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 accomplished by focussing on an interdisciplinary project (involving the crime scene, police, forensic laboratory, scientists and justice system) over a longer period of time [82,84]. The projects are ill-structured where students work in small groups, taking the focus from traditional teacher learning to a student-centred learning process [84]. 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 [48,85].

3.2.4. 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 1 provides an example of the model.

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

3.2.5. Teaching research design

Research indicates that one pedagogic approach to increase formal reasoning skills is directly connected with experimental research design education [23,86]. Especially important, is a history of research studies showing that participating in scientific investigations increases student capacity to conduct inquiries [87–89]. 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 [88,90,91].

Research by Bryce et al. [51] 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 [1,2]. 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 [92]. 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 [2].

Our research on case-specific methods suggests that forensic practitioners are more confident using a mixed-methods data approach [2]. 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 [93,94]. 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

Table 1
Example of project-based learning for forensic practitioners (PrBLFP) model [84].

Model Structure	Forensic Science Example
Ill-structured Problem	A complex ill-structured problem consisting of four crime scenes within one over arching 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.

contrast, qualitative methods involves an exploration that can lead to understanding a problem [95]. The combination of both methods can strengthen conclusions by providing research triangulation and capability to explore greater problem complexity [96]. 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.

3.2.6. 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"* [97] 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.

3.3. A call for research

Scholarship of Teaching and Learning (SoTL) is research studying the impact of teaching on student learning [98]. 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 [99]. 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 [100,101]. 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 [102]. Policy making is innately political with researchers and practitioners having different perspectives that can impede the impact of scientific research on the policy makers [103]. A recent example is the heated debate between scientist and politicians on the agreement of the existence of climate change [104]. 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.

4. 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 [105] 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.

4.1. 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 maybe 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 [8].

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 forensics careers as practitioners [10,16]. The implementation of ill-structure problem-solving education that contains “domain knowledge, justification skills, science attitudes, and regulation of cognition” [25] 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.

4.2. 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.

Declaration of competing interest

None.

CRediT authorship contribution statement

Mike Illes: Writing - review & editing, Writing - original draft. **Paul Wilson:** Supervision, Writing - review & editing. **Cathy Bruce:** Supervision, Writing - review & editing.

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