Journal of Postgraduate Current Business Research (JPCBR)
e-ISSN 2504 - 8449, Volume 10 Issue 2 2025

Forensic Practices and Investigation Effectiveness: The Mediating Role of Competency

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Abstract

The growing reliance on forensic science in contemporary justice systems underscores the need to understand how organizational practices translate into effective investigative outcomes. While previous studies have examined the role of individual forensic elements such as technology adoption or training programs, there remains a lack of integrative frameworks that explain how multiple practices jointly shape investigation effectiveness. This conceptual paper addresses this gap by developing a model that links forensic procedures, technology application, and training programs to investigation effectiveness, mediated by forensic competency. Drawing on the Resource-Based View (RBV) and Competency-Based Theory (CBT), the framework positions competency as the strategic mechanism through which organizational resources are transformed into reliable, admissible, and timely forensic outcomes. The paper reviews recent empirical evidence highlighting the critical role of procedural rigor, technology integration, and structured training in improving forensic performance. However, it argues that these practices alone are insufficient without competent personnel to enact and integrate them. By conceptualizing competency as a mediator, the model offers a nuanced explanation of why similar resource investments yield different performance results across forensic contexts. The study outlines a future empirical agenda employing Partial Least Squares Structural Equation Modeling (PLS-SEM) to validate the proposed relationships. The expected contributions of this work are threefold: advancing theory by integrating RBV and CBT in a forensic science context, providing practical insights for laboratories and investigative agencies seeking to maximize performance, and informing policy on the design of competency-driven forensic standards. This conceptualization emphasizes that sustainable forensic effectiveness arises not from resources alone but from the alignment of practices with practitioner competency.

Keywords:

Forensic practices, investigation effectiveness, forensic competency, technology application, and training programs.

1. Introduction

Forensic science has emerged as a cornerstone of modern criminal justice systems, shaping the ability of law enforcement agencies to deliver evidence that is both scientifically valid and legally admissible. The effectiveness of forensic investigation has increasingly become a subject of global concern as criminal activities become more complex, cross-border, and technology-driven. Effective forensic practices are essential to ensuring accuracy, timeliness, and admissibility of evidence in court, which directly influence judicial outcomes and public trust in policing institutions (Siegel & Mirakovits, 2021). Yet, the quality of forensic outcomes often varies significantly across jurisdictions, with inconsistencies frequently linked to gaps in procedures, uneven adoption of technology, and insufficient training of personnel (Lim & Chua, 2022; Hassan et al., 2021). These variations underscore the importance of examining forensic practices through a structured and integrated conceptual model.

Global trends highlight the increasing reliance on advanced forensic technologies such as digital evidence systems, automated DNA sequencing, and artificial intelligence–driven pattern recognition. While such tools have been shown to reduce case resolution times and enhance evidentiary accuracy, their impact depends heavily on the availability of trained and competent personnel (Zainal et al., 2023; Tan et al., 2023). The human dimension of forensic investigation, often underemphasized in technology-driven narratives, plays a central role in bridging the gap between resource availability and effective outcomes. Forensic competency, encompassing the technical, analytical, and procedural skills of investigators, is therefore positioned as a crucial mediator in understanding how practices influence investigation effectiveness (Taylor & Nicholas, 2023).

Existing literature demonstrates that standard operating procedures (SOPs) are integral in preserving the integrity of evidence and ensuring consistency across forensic units. For instance, empirical studies reveal that institutions adhering to internationally recognized standards such as ISO/IEC 17025 report fewer cases of evidence rejection in courts (Lee & Kim, 2020). Similarly, training programs designed to improve procedural knowledge and courtroom readiness have been associated with lower error rates and improved admissibility of evidence (Zhang et al., 2022). However, the inconsistent application of SOPs and lack of structured training remain prevalent challenges, particularly in developing countries, where forensic practices are often fragmented and under-resourced (Chong & Tan, 2023; Rahim et al., 2021).

Although numerous studies have investigated individual aspects of forensic investigation, there is a lack of integrative models that consider procedures, technology, and training simultaneously in relation to investigation effectiveness. More critically, the mediating role of forensic competency has received limited empirical and conceptual attention, despite evidence suggesting that it significantly explains variance in outcomes such as evidentiary accuracy, courtroom performance, and case resolution speed (Ong et al., 2022; Liu & Zhao, 2021). Theoretical perspectives such as the Resource-Based View (RBV) and Competency-Based Theory (CBT) provide strong justification for positioning competency as a strategic resource that transforms forensic practices into effective outcomes (Barney, 1991; Spencer & Spencer, 1993). Integrating these theories offers a holistic framework to understand better forensic investigation effectiveness beyond technological or procedural determinants alone.

This paper proposes a conceptual model that positions forensic competency as a mediating mechanism linking forensic procedures, technology application, and training programs to investigation effectiveness. The contribution of this study lies in offering a multidimensional

perspective that unites organizational resources and human capital to explain forensic outcomes. By grounding the framework in RBV and CBT, the study addresses a notable gap in forensic science research. It provides a foundation for empirical validation in future studies. The findings are expected to inform theoretical discourse, practical improvements in forensic practice, and policy interventions aimed at strengthening forensic capacity. Ultimately, this conceptualization seeks to enhance global forensic standards and ensure that investigative systems can adapt to the complexities of modern crime.

2. Literature Review

2.1 Forensic Investigation Effectiveness

Forensic investigation effectiveness (FIE) is widely regarded as the degree to which forensic processes deliver timely, accurate, and legally admissible results that directly contribute to case resolution and judicial integrity. While forensic science has become integral to criminal justice systems worldwide, the definition and measurement of FIE remain contested, with scholars adopting indicators such as case clearance rates, turnaround time, and courtroom admissibility (Chong & Tan, 2023; Mahmood & Ismail, 2021). The centrality of FIE to law enforcement credibility has intensified scholarly interest in how institutional resources and human capital shape outcomes in both advanced and developing forensic systems (Taylor & Nicholas, 2023).

Empirical studies consistently highlight the role of procedural compliance in achieving high levels of forensic effectiveness. Johnson and Fritsch (2020) reported that laboratories strictly adhering to chain-of-custody protocols achieved a significant reduction in evidence rejection rates. Similarly, Lee and Kim (2020) demonstrated that compliance with international standards such as ISO/IEC 17025 enhanced courtroom admissibility, underscoring the link between procedural rigor and judicial outcomes. Beyond compliance, the adoption of forensic technologies has also been associated with faster and more reliable results. McElwain and Taylor (2021) found that digital case management systems reduced average forensic processing times by up to 40 percent.

However, effectiveness is not solely determined by resources or tools; the competency of forensic personnel remains pivotal. Park and Lee (2022) showed that forensic competency mediated the relationship between training interventions and error reduction. This illustrates that personnel skills are essential for translating resources into outcomes. In contexts where training is inconsistent, effectiveness suffers despite the availability of advanced tools (Zulkifli & Tan, 2023). This finding resonates with systems theory, which posits that outcomes emerge from the coordinated functioning of interdependent subsystems, including human actors, technologies, and organizational processes (Meadows, 2008).

Cross-country comparisons also highlight disparities in effectiveness. Lim and Chua (2022) observed that forensic labs in Singapore achieved shorter DNA processing times than their Malaysian counterparts due to standardized procedures and continuous professional development. Similarly, De Vries et al. (2020) noted that European forensic systems with integrated digital platforms experienced fewer appellate reversals, suggesting that institutional integration enhances FIE. These findings highlight the importance of considering forensic investigation effectiveness as a multidimensional construct that extends beyond technical capacity to encompass training, procedural consistency, and personnel competency.

This conceptualization positions FIE not merely as an endpoint of forensic activity but as a system outcome dependent on the alignment of resources, practices, and competencies. Building on the Resource-Based View (RBV) and Competency-Based Theory (CBT), this study treats FIE as the performance indicator through which the value of forensic practices can

be assessed, with competency acting as the mechanism that translates resources into sustainable outcomes.

2.2 Forensic Procedures

Forensic procedures represent the structured methods and standardized practices governing the collection, preservation, analysis, and documentation of evidence within criminal investigations. These procedures are designed to uphold both scientific validity and legal admissibility, ensuring that evidence can withstand judicial scrutiny. Scholars consistently argue that adherence to clear and rigorous procedures is one of the most critical determinants of forensic quality, as errors or inconsistencies in evidence handling can lead to contamination, loss of integrity, and even case dismissals (Harper & Hunt, 2022). The application of well-defined standard operating procedures (SOPs) is therefore critical for maintaining the chain of custody, improving transparency, and enhancing trust in forensic outcomes (Al-Busaidi et al., 2021).

Empirical studies confirm that procedural compliance directly influences investigation outcomes. For example, Lee and Kim (2020) found that forensic units that maintained strict documentation practices achieved significantly higher admissibility rates in court compared to those with less rigorous adherence. Similarly, Ismail et al. (2021) reported that nearly one-quarter of evidence exclusions in Malaysian and Australian courts were attributed to chain-of-custody breaches, reinforcing the importance of procedural fidelity. More recently, Whelan and Nash (2021) demonstrated that forensic teams with well-established workflows resolved cases faster, attributing the efficiency gains to clarity in procedural responsibilities. These findings highlight that procedural adherence is not merely a technical requirement but also a mechanism that improves timeliness and efficiency in investigations.

Despite global recognition of the importance of forensic procedures, challenges remain in achieving universal compliance. In developing contexts, inconsistencies often arise due to resource limitations, fragmented oversight, or lack of standardized frameworks (Rahim et al., 2022). Teo et al. (2021) observed that forensic officers in rural districts frequently relied on undocumented or outdated practices, leading to gaps in evidence quality. This fragmentation is compounded by inter-agency collaboration challenges, where unclear submission protocols contribute to sample mislabeling or contamination (Goh & Idris, 2022). These procedural gaps ultimately compromise both investigative accuracy and public confidence in forensic institutions.

Theoretical perspectives such as Total Quality Management (TQM) further underscore the need for continuous improvement of forensic procedures. From this standpoint, SOPs should not only codify best practices but also incorporate mechanisms for monitoring, auditing, and feedback to ensure procedural accountability (Bowden et al., 2021). Recent studies suggest that organizations that integrated procedural audits and peer reviews reduced procedural errors by as much as 30 percent (Jamil et al., 2023). However, in many forensic systems, a culture of accountability remains weak, and compliance is treated as a box-ticking exercise rather than a dynamic component of quality assurance (Harper & Hunt, 2022).

Overall, forensic procedures provide the foundation upon which the accuracy and legitimacy of forensic investigations rest. Procedural integrity is critical not only for the preservation of evidence but also for ensuring that the justice system can rely on forensic testimony. In the context of this conceptual model, forensic procedures are expected to exert both a direct influence on investigation effectiveness and an indirect effect through their role in shaping forensic competency. By instilling rigor and consistency, procedures empower forensic

professionals to carry out their duties with greater reliability, ultimately contributing to more effective investigations and stronger judicial outcomes.

2.3 Technology Application

Technology application in forensic investigation refers to the integration of scientific instruments, digital systems, and analytical tools to enhance the accuracy, efficiency, and reliability of forensic evidence. Over the past decade, technological innovation has transformed forensic science, with digital forensics, automated DNA sequencing, biometric systems, and artificial intelligence becoming integral to modern investigations. These technologies provide opportunities to accelerate evidence processing, improve precision, and enable new forms of evidence analysis, such as cyber-forensic imaging and predictive analytics (Tan et al., 2023). However, empirical studies consistently indicate that the successful application of technology in forensic contexts depends not only on access to tools but also on the organizational capacity and personnel competency required to deploy them (Zainal et al., 2023) effectively.

Evidence from advanced forensic systems demonstrates that technology adoption directly influences investigation timeliness and admissibility. For example, Krosch et al. (2020) found that digital case management systems in Australian forensic labs reduced processing time by 35 percent while improving evidentiary accuracy. Similarly, Singh and Ahmed (2021) reported that mobile forensic extraction tools enhanced evidence integrity in cybercrime cases, increasing conviction rates. In Southeast Asia, Tan and Lim (2022) observed that forensic units adopting biometric and digital DNA systems achieved faster case resolutions compared to those relying on manual practices. These findings illustrate the significant potential of technology to enhance forensic effectiveness when appropriately integrated.

Despite these advantages, challenges in technology application remain prevalent. Interoperability issues, inadequate infrastructure, and inconsistent training frequently limit the effective use of forensic technology (Parker & Lee, 2022). Zainal et al. (2023) highlighted that fewer than half of forensic officers in Malaysia had formal training in digital evidence systems, resulting in underutilization of available tools. Similarly, Hassan et al. (2022) noted that while many forensic units had acquired advanced spectrometers and chromatography devices, the absence of maintenance budgets and technical support significantly reduced their operational lifespan. These findings emphasize that investment in technology without parallel investment in training and organizational readiness often yields limited returns.

Theoretical frameworks such as the Technology-Organisation-Environment (TOE) model and the Unified Theory of Acceptance and Use of Technology (UTAUT) explain variations in technology adoption. Chong et al. (2020) demonstrated that user acceptance, effort expectancy, and organizational support determine whether forensic officers actively use digital platforms. Moreover, Zhang et al. (2019) found that electronic chain-of-custody systems reduced audit failures by 24 percent but only in units where officers were trained and organizational culture supported accountability. These studies highlight the interconnectedness of technological capacity, user competency, and institutional support.

Ultimately, technology applications in forensic science should be conceptualized as both direct and indirect drivers of investigation effectiveness. Directly, it improves evidence quality, reduces error rates, and shortens processing times. Indirectly, its value is realized when forensic officers are competent in operating complex systems and integrating outputs into judicial processes. In the proposed conceptual model, technology is hypothesized to have a limited direct impact on effectiveness without competency but plays a critical role in shaping

competency itself. This perspective positions technology not merely as infrastructure but as a strategic resource whose effect depends on human and organizational alignment.

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competency itself. This perspective positions technology not merely as infrastructure but as a strategic resource whose effect depends on human and organizational alignment.

2.5 Training Programs

Training programs function as the primary mechanism for converting procedural guidelines and technological investments into day-to-day investigative capability, thereby shaping the consistency, reliability, and legal defensibility of forensic outputs. Contemporary forensic work requires continual upskilling across domains such as contamination control, digital evidence handling, probabilistic reasoning, and expert testimony; consequently, organizations are shifting from ad hoc courses to competency-based, outcomes-oriented curricula that emphasize practice, feedback, and assessment. Recent research shows that structured training produces measurable performance gains, including lower procedural error rates, shorter turnaround times, and improved evidentiary clarity in court reports, with effects most pronounced when programs integrate simulation, scenario learning, and post-course coaching (Bennett & Carter, 2021; Van der Meulen & Smit, 2020). Beyond technical modules, training that targets documentation discipline and courtroom communication improves admissibility and withstands cross-examination more effectively than purely instrument-focused instruction (Davies & Murphy, 2020).

The durability of training effects depends on transfer—whether learners apply what they learned on the job. Studies in policing and forensic laboratories indicate that transfer is amplified by supervisory reinforcement, opportunities to practice in real cases soon after training, and alignment between course content and local standard operating procedures (Gopal & Singh, 2021; Rahman & Ismail, 2021). Institutions that pair formal instruction with checklists, peer review, and coaching networks report sustained reductions in sample handling errors and stronger chain-of-custody documentation months after course completion (Mahmood, Zain & Koh, 2022). Immersive methods appear especially effective: randomized trials show that virtual or augmented reality crime-scene simulations improve contamination avoidance and evidence recognition accuracy relative to lecture formats, while also increasing learner self-efficacy—an antecedent of transfer (Van der Meulen & Smit, 2020; Kim, Park & Cho, 2022).

Nonetheless, capacity gaps persist. Surveys across mixed-resource jurisdictions reveal uneven access to recertification, limited budgets for instrumentation refresher courses, and scarce opportunities to practice courtroom testimony, all of which constrain the impact of technology investments (Hassan, Rahman & Yeo, 2021; Farid, Noor & Hamzah, 2022). Where training occurs without maintenance support, equipment downtime erodes learning gains; similarly, when course assessment focuses on attendance rather than demonstration of competencies, organizations see minimal change in audit findings (Al-Mansoori & Harun, 2021). Frequency and recency matter: units offering modular micro-learning and quarterly refreshers show fewer procedural deviations than those relying on annual workshops, suggesting that spaced reinforcement is critical in high-stakes laboratory and scene workflows (Tan & Roslan, 2021; Parker & Gomez, 2020).

A growing thread in the literature argues for competency frameworks that map observable behaviors to roles, from scene technicians to reporting scientists, and tie promotion and licensing to demonstrated capability rather than tenure. Where implemented, such frameworks are associated with higher retention, clearer training priorities, and improved peer-review quality (Taylor & Nicholas, 2023; Farid, Noor & Hamzah, 2022). For the present conceptual model, training programs are expected to exert both direct and indirect effects on investigation effectiveness. Directly, they reduce errors and improve reporting quality; indirectly, they

enhance the knowledge, skills, and professional judgment that constitute forensic competency—the mediating mechanism through which procedures and technologies translate into reliable case outcomes. Framing training as a strategic investment in human capital, therefore, aligns with the view that forensic effectiveness emerges from the interaction of resources, routines, and people, with competency at the core of that translation process.

2.6 Forensic Competency (Mediator)

Forensic competency encapsulates the integrated set of technical, procedural, analytical, and communicative capabilities that enable practitioners to convert laboratory methods and scene protocols into evidence that is scientifically sound and legally persuasive. Contemporary scholarship treats competency as a multidimensional construct comprising instrument proficiency, contamination control, inferential reasoning with uncertainty, documentation discipline, and courtroom communication, each of which is consequential for downstream admissibility and case resolution. Recent empirical studies demonstrate that competency is not merely an attribute co-varying with experience; instead, it operates as a mechanism that channels organizational inputs—procedures, technologies, and training—into measurable improvements in investigation effectiveness. In multi-lab surveys, laboratories that pair SOP standardization with competency-oriented assessment report fewer nonconformities and lower rework, suggesting that procedures enhance outcomes primarily when enacted by competent personnel (Bucchi & De Biase, 2021). Competency also shapes the uptake and correct use of technology: identical digital platforms yield divergent performance gains depending on users' calibration skills and error management strategies, underscoring that human capability conditions technology's value (Martire, Growns, & Navarro, 2020).

A robust line of research links competency to decision quality. Studies of evaluative judgment in pattern and DNA interpretation show that trained experts exhibit superior reliability, better likelihood-ratio reporting, and more transparent reasoning trails, reducing the risk of confirmation bias and unwarranted certainty (Thompson, Vuille, & Biedermann, 2022; Scurich & Dror, 2020). Competency development is also associated with improved chain-of-custody documentation and exhibit tracking, two recurrent sources of legal challenge in appellate review (Evett & Berger, 2021). Importantly, competency is learnable and testable: organizations that adopt criterion-referenced competency frameworks with periodic revalidation document sustained gains in scene processing accuracy, contamination avoidance, and report clarity over 6–12 months (Brooks & McKinzey, 2021; Towler, Kemp, & White, 2022). Beyond technical skill, soft-skill components—clarity under cross-examination, defensible explanation of uncertainty, and responsive peer-review behavior—predict evidentiary endurance in court (Cooper & Illes, 2021; Morrison & Thomson, 2021).

Conceptually, positioning competency as a mediator aligns with resource-based and capability-building perspectives. Organizational resources—SOPs, instruments, software, and training budgets—have effects on performance to the extent that individuals can absorb, apply, and adapt them in variable case contexts. Mediation studies in adjacent domains show that training effects on investigative quality are transmitted through gains in self-efficacy, metacognition, and procedural fluency, constructs that are constitutive of competency (Wells, Kassin, & Redlich, 2020; Ashbaugh & Kerr, 2021). In predictive terms, competency explains a substantive share of variance in turnaround time and error rates even after controlling for case mix and workload, indicating an independent contribution over and above material resources (Sauerland, Krix, & Rispens, 2021). For the present model, competency is theorized to transmit the influence of procedures, technology, and training onto investigation effectiveness because competent practitioners are better at maintaining evidential integrity, exploiting tool

capabilities, and articulating conclusions in ways that meet legal thresholds. Treating competency as the central capability that converts resources into reliable outcomes thus provides both an explanatory mechanism and a practical target for interventions.

3. Methodology

This study adopts a quantitative, cross-sectional survey design to develop and subsequently validate a theory-driven model explaining investigation effectiveness from forensic practices through the mediating role of competency. A conceptual paper ordinarily foregrounds theoretical development; however, to support future empirical testing and replicability, the present section specifies a rigorous operational plan covering population, sampling, instrumentation, procedures, and data analysis choices consistent with variance-based structural equation modeling.

The target population comprises practicing forensic professionals involved in crime scene processing, laboratory analysis, digital forensics, or reporting, drawn from public laboratories and law-enforcement affiliated units. Because forensic personnel are distributed across organizational tiers and specializations, a nonprobability, stratified purposive sampling strategy is proposed to ensure coverage of key roles (e.g., scene examiners, laboratory analysts, reporting scientists, digital forensic specialists) and unit types (biology/DNA, toxicology, trace, digital). Purposive selection is justified on the grounds that respondents must possess role-specific knowledge to meaningfully evaluate procedural adherence, technology usage, training exposure, and competency. To curb selection bias and approximate representativeness, strata quotas will be set proportional to workforce composition reported by participating agencies, and invitations will be disseminated via professional associations and laboratory quality managers, supplemented by controlled snowballing limited to within-stratum referrals. This approach balances feasibility and coverage in a specialized workforce where sampling frames are often restricted.

Sample size planning follows contemporary guidance for PLS-SEM. Rather than relying on the outdated "10-times rule," the minimum sample is determined using power-analytic procedures such as the inverse square root and gamma-exponential methods that account for maximum arrowheads pointing at a latent variable, anticipated path coefficients, and desired statistical power (Kock & Hadaya, 2018). Assuming a maximum of four predictors per endogenous construct, medium effect sizes ($f^2 \approx 0.15$), $\alpha = .05$, and power = .80, a minimum of approximately 150–200 cases is expected to be sufficient; nonetheless, a target of 300 responses is set to enable robust bootstrapping, multi-group comparisons by role, and assessment of measurement invariance.

Data will be collected using a structured questionnaire comprising validated reflective measures adapted to the forensic context. Forensic procedures will capture SOP adherence, chain-of-custody discipline, and documentation rigor; technology application will assess availability, frequency, and depth of use of digital and laboratory systems; training will capture recency, frequency, modality, and perceived alignment; competency will measure technical, procedural, analytical, and communicative capabilities; investigation effectiveness will operationalize timeliness, accuracy, and perceived admissibility support. Items will use five- or seven-point Likert scales and undergo expert review for content validity and cognitive pretesting with 15–20 practitioners to refine wording, followed by a pilot study ($n \approx 50$) to assess reliability and item performance.

Partial Least Squares Structural Equation Modeling (PLS-SEM) will be conducted in SmartPLS due to its strengths for prediction-oriented models with complex mediation, non-

normal indicators, and moderate sample sizes (Hair, Hult, Ringle, & Sarstedt, 2022; Benítez, Henseler, Castillo, & Schuberth, 2020). The analysis proceeds in two stages. The measurement model assessment will examine indicator reliability via outer loadings targeting ≥ .708 (retaining .60–.70 if theoretically essential and AVE is adequate), internal consistency reliability with composite reliability between .70 and .95, convergent validity with average variance extracted (AVE) ≥ .50, and discriminant validity via HTMT with thresholds < .85 for conceptually distinct constructs or < .90 for related constructs (Henseler, Ringle, & Sarstedt, 2015). Collinearity will be checked using full collinearity VIFs targeting < 3.3 to minimize bias and common-method concerns (Kock, 2015). If necessary, cross-loadings and HTMT-inference will inform item pruning while preserving content coverage.

The structural model assessment will test direct and indirect paths using bias-corrected and accelerated bootstrap confidence intervals with at least 5,000 resamples. R^2 values will judge explanatory power for endogenous constructs with benchmarks of ≈ .25 (weak), .50 (moderate), and .75 (substantial). At the same time, effect sizes will be evaluated using f^2 at ≈ .02 (small), .15 (medium), and .35 (large) to quantify the incremental contribution of exogenous constructs (Hair et al., 2022). Predictive relevance will be examined using Stone-Geisser's Q^2 via blindfolding ($Q^2 > 0$ indicates out-of-sample predictive capability). Model fit will be described using standardized root mean square residual (SRMR) with values < .08 indicative of acceptable fit in PLS contexts (Henseler et al., 2014; Hair et al., 2022). Out-of-sample predictive performance will be evaluated with PLSpredict comparing PLS and linear benchmark errors (RMSE/MAE) at the indicator level; superior or at least non-inferior prediction supports practical utility (Shmueli et al., 2019; Shmueli et al., 2021). Mediation will be assessed by estimating the size and significance of indirect effects and by computing variance accounted for (VAF) to characterize partial versus full mediation, while ensuring that collinearity and confounding are ruled out (Nitzl, Roldán, & Cepeda, 2016). Robustness checks will include common method variance diagnostics (marker variable or unmeasured latent method factor if feasible), multi-group analysis by role/specialty (MICOM for measurement invariance), and sensitivity analyses excluding influential cases.

Ethical procedures will emphasize informed consent, role-appropriate anonymization, and secure data handling consistent with laboratory confidentiality. Participation will be voluntary with the option to withdraw; no case-specific information will be collected. Together, these design choices are aligned with best practices for modeling complex capability-performance relationships in specialized professional settings and provide a replicable blueprint for future validation studies across jurisdictions.

4. Expected Outcomes and Discussions

The proposed conceptual framework anticipates several significant outcomes that advance theoretical development, inform forensic practice, and shape policy directions. The central expectation is that forensic procedures, technology application, and training programs will exert positive effects on investigation effectiveness, both directly and indirectly through forensic competency. Competency is hypothesized to serve as the key mechanism translating institutional resources into sustainable improvements in forensic outcomes such as timeliness, admissibility, and reliability of evidence. This mediating role will help explain why some organizations with comparable resources achieve stronger outcomes than others, highlighting competency as the missing link in prior models of forensic performance.

4.1 Theoretical Outcomes and Implications

From a theoretical standpoint, the study is expected to extend the Resource-Based View (RBV) by demonstrating that organizational resources in forensic contexts—such as standardized

procedures, advanced technologies, and training programs—do not automatically create performance advantages. Instead, these resources require the development of forensic competency to become strategically valuable, rare, inimitable, and non-substitutable (Barney, 1991; Teece, 2014). This argument reinforces the RBV's claim that resources only generate sustained advantage when they are effectively mobilized and embedded within organizational capabilities.

Furthermore, Competency-Based Theory (CBT) is expected to be strengthened through this model. CBT posits that individual and organizational competencies form the foundation for superior performance by aligning skills, knowledge, and attitudes with organizational demands (Spencer & Spencer, 1993; Taylor & Nicholas, 2023). By empirically testing competency as a mediator, the study highlights how individual-level capabilities function as conduits between organizational-level resources and system-level outcomes, thereby providing multi-level validation of CBT. These outcomes contribute to the broader theoretical discourse by bridging RBV and CBT, showing that resource investments in forensic practices are filtered through the competence of practitioners before influencing performance outcomes (Towler, Kemp, & White, 2022).

4.2 Practical Outcomes and Implications

On a practical level, the study expects to show that forensic procedures directly improve investigation effectiveness by enhancing evidence admissibility and case resolution speed. However, the effect of procedures will be amplified when officers possess the competency to apply them consistently under real-world pressures (Bucchi & De Biase, 2021). Similarly, while investments in forensic technologies may reduce processing times and expand analytical possibilities, their practical benefits are contingent on users' competence in calibration, interpretation, and maintenance (Martire, Growns, & Navarro, 2020). Training programs, meanwhile, are expected to produce immediate improvements in practitioner performance, but their long-term impact depends on the extent to which competency is reinforced through ongoing professional development and organizational support (Bennett & Carter, 2021; Kim, Park, & Cho, 2022).

These expected outcomes suggest that forensic organizations must reorient their strategies from resource acquisition to resource activation. For example, rather than investing solely in advanced instruments, laboratories should integrate competency-based training and audits to ensure technologies are appropriately utilized. Similarly, procedural manuals should be complemented by continuous competency assessment, enabling organizations to identify gaps and tailor interventions to address them. Practically, the framework advocates for embedding competency evaluation into recruitment, training, and performance management systems, ensuring that forensic effectiveness is systematically developed rather than assumed.

4.3 Policy Outcomes and Implications

At the policy level, the expected outcomes highlight the need for regulatory bodies and forensic oversight agencies to establish competency frameworks that define minimum standards across technical, procedural, and communicative domains. Policies that emphasize resource provision without corresponding investments in competency risk producing underutilized or ineffective systems (Hassan, Rahman, & Yeo, 2021). International bodies such as the United Nations Office on Drugs and Crime (UNODC) and the European Network of Forensic Science Institutes (ENFSI) have already recommended competency-based accreditation models, which focus not only on laboratory infrastructure but also on practitioner capability (Thompson, Vuille, & Biedermann, 2022). Adoption of such models could ensure greater harmonization of

forensic standards across jurisdictions, enhancing cross-border collaboration and mutual recognition of forensic results.

In developing contexts, policies informed by the present framework would prioritize competency development as a strategic resource. For instance, funding models should allocate resources not only for procuring advanced technologies but also for establishing recurring competency-based training, recertification, and performance audits. Policymakers could further institutionalize competency by embedding it in accreditation standards and legal admissibility criteria, ensuring that evidence presented in court meets both technical and competency thresholds. These outcomes are particularly relevant in an era of increasing reliance on digital and scientific evidence, where public trust in forensic results is directly tied to perceptions of practitioner expertise and reliability (Scurich & Dror, 2020).

5. Integrative Discussion

Overall, the expected outcomes emphasize that forensic investigation effectiveness emerges from the alignment of resources, practices, and competencies. Theoretically, the framework integrates RBV and CBT, offering a multi-level explanation of how resources transform into outcomes. Practically, it underscores the centrality of competency as the lever through which procedures, technology, and training translate into reliable forensic performance. At the policy level, it calls for a paradigm shift towards competency-driven standards and investments. Collectively, these outcomes highlight the transformative potential of positioning competency at the heart of forensic practice, ensuring that justice systems are equipped to meet the challenges of contemporary crime with credibility, reliability, and efficiency.

References

Al-Busaidi, R., Al-Zadjali, A., & Khan, F. (2021). Chain of custody practices and evidence reliability in forensic investigations. *Forensic Science International: Reports, 3*(4), 100–112.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management, 17*(1), 99–120.

Bennett, A., & Carter, L. (2021). Simulation-based training for forensic practitioners: Effects on error reduction and report quality. *Science & Justice, 61*(4), 412–421.

Bowden, A., Carter, J., & Wilson, R. (2021). Quality assurance frameworks in forensic practice: A TQM perspective. *Science & Justice, 61*(3), 267–276.

Brooks, D., & McKinzey, R. (2021). Competency-based evaluation and sustained gains in forensic scene processing. *Science & Justice, 61*(6), 745–754.

Bucchi, M., & De Biase, F. (2021). Quality nonconformities and competency management in forensic laboratories: A multi-site study. *Forensic Science International: Reports, 3,* 100206.

Chong, K. H., & Tan, L. W. (2023). Digital evidence management and forensic effectiveness: Challenges in interoperability. *Journal of Policing and Criminal Justice, 45*(2), 189–207.

Chong, K., Lee, W., & Idris, N. (2020). User acceptance of forensic digital platforms: An application of UTAUT. *International Journal of Digital Crime and Forensics, 12*(4), 23–38.

Cooper, C., & Illes, J. (2021). Communicative competence and evidentiary endurance in expert testimony. *Forensic Science Policy & Management, 12*(3), 165–176.

Davies, P., & Murphy, E. (2020). Expert testimony readiness: Training interventions and evidentiary clarity. *Forensic Science International: Reports, 2*(3), 200–208.

De Vries, G., Janssen, H., & Peters, M. (2020). Integrated forensic systems and judicial outcomes in Europe. *Science & Justice, 60*(4), 345–354.

Evett, I., & Berger, C. (2021). Managing chain-of-custody through competence: Implications for appellate review. *Forensic Science International, 325*, 110978.

Farid, R., Noor, S., & Hamzah, N. (2022). Competency-based progression and retention in forensic laboratories. *Forensic Science Policy & Management, 13*(2), 95–109.

Goh, C., & Idris, N. (2022). Procedural consistency in forensic submissions: An inter-agency perspective. *Asian Journal of Criminology, 17*(2), 198–214.

Gopal, R., & Singh, A. (2021). Transfer climate and post-training performance in forensic teams. *Policing: An International Journal, 44*(6), 1011–1027.

Harper, D., & Hunt, S. (2022). Procedural accountability in forensic science: Strengthening compliance culture. *Forensic Science Policy and Management, 13*(1), 33–45.

Hassan, N., Rahman, Z., & Yeo, P. (2021). Recertification access and performance gaps in public forensic labs. *Journal of Forensic Sciences, 66*(5), 1583–1594.

Hassan, R., Rahim, N., & Tan, S. (2021). Forensic training gaps and their implications for evidence admissibility. *International Journal of Forensic Science, 12*(3), 245–259.

Hassan, R., Zulkifli, M., & Tan, H. (2022). Technology readiness and operational sustainability in forensic laboratories. *Forensic Science International, 330,* 111–123.

Ismail, R., Tan, J., & Mahmood, N. (2021). Chain-of-custody breaches and their implications for evidence admissibility. *Forensic Science International, 325*, 110–121.

Jamil, A., Rahman, Z., & Yusuf, K. (2023). Forensic procedural audits: Improving compliance through peer reviews. *Journal of Forensic Sciences, 68*(2), 211–223.

Johnson, D., & Fritsch, E. (2020). The role of SOPs in enhancing forensic admissibility. *Journal of Criminal Justice Research, 38*(4), 411–429.

Kim, J., Park, S., & Cho, H. (2022). Augmented reality simulations and contamination control in scene processing. *Forensic Science International: Reports, 4,* 100289.

Krosch, T., Hughes, S., & Brown, A. (2020). Digital case management systems and forensic performance outcomes. *Science & Justice, 60*(5), 456–465.

Lee, H., & Kim, J. (2020). Standardised forensic documentation and court admissibility in Asia. *Journal of Forensic Sciences, 65*(6), 1823–1832.

Lim, H., & Chua, C. (2022). Comparative analysis of forensic readiness in Southeast Asia. *Asian Journal of Criminology, 17*(4), 423–441.

Liu, X., & Zhao, Y. (2021). Competency mediation in forensic toxicology performance. *Forensic Chemistry, 23,* 100–114.

Mahmood, R., & Ismail, N. (2021). Evidence admissibility and forensic effectiveness in Malaysia. *International Journal of Forensic Science, 13*(1), 78–89.

Mahmood, T., Zain, R., & Koh, C. (2022). Peer-review checklists and sustained training effects in toxicology units. *Forensic Chemistry, 30*, 100423.

Martire, K., Growns, B., & Navarro, D. (2020). Decision-making competencies and accuracy in forensic evaluations. *Journal of Forensic Sciences, 65*(6), 1845–1856.

McElwain, R., & Taylor, S. (2021). The role of digital systems in forensic timeliness. *Forensic Science International: Reports, 5*(2), 100–118.

Morrison, G. S., & Thomson, D. (2021). Competency standards and forensic voice comparison: Effects on legal robustness. *Forensic Science International, 318*, 110587.

Ong, S. C., Tan, Z., & Idris, M. (2022). Forensic competency as mediator between procedural clarity and performance. *Journal of Applied Criminology, 14*(3), 199–212.

Park, J., & Lee, S. (2022). Competency as a mediator in forensic investigation quality. *Forensic Science International, 330*, 111–121.

Parker, D., & Lee, M. (2022). Interoperability challenges in digital forensic adoption: A longitudinal study. *Forensic Science Policy and Management, 13*(3), 177–189.

Parker, R., & Gomez, L. (2020). Micro-learning frequency and adherence to SOPs in forensic labs. *Policing and Society, 30*(7), 789–805.

Rahim, A., Sulaiman, R., & Nor, A. (2022). Resource constraints and procedural gaps in forensic practice. *International Journal of Forensic Science, 14*(2), 145–159.

Rahman, F., & Ismail, A. (2021). Supervisor support and on-the-job practice after forensic training. *International Journal of Forensic Science, 13*(2), 120–132.

Sauerland, M., Krix, A., & Rispens, I. (2021). Predictors of forensic processing time and error: The role of practitioner competence. *Law and Human Behavior, 45*(5), 421–433.

Scurich, N., & Dror, I. E. (2020). Cognitive factors in forensic decision making: Competency and bias mitigation. *Legal and Criminological Psychology, 25*(1), 27–43.

Siegel, J. A., & Mirakovits, K. (2021). *Forensic science: The basics* (4th ed.). CRC Press.

Singh, R., & Ahmed, S. (2021). Mobile forensics and evidence reliability: Evidence from cybercrime investigations. *Journal of Forensic Sciences, 66*(3), 854–863.

Spencer, L. M., & Spencer, S. M. (1993). *Competence at work: Models for superior performance.* Wiley.

Tan, C., Lim, H., & Goh, Y. (2023). Forensic technology adoption and effectiveness in Southeast Asia. *Asian Journal of Criminology, 18*(1), 55–73.

Tan, H., & Lim, P. (2022). Biometric adoption and forensic effectiveness in Southeast Asian policing. *Policing and Society, 32*(7), 911–927.

Tan, K., & Roslan, M. (2021). Quarterly refreshers and quality metrics in evidence handling. *Asian Journal of Criminology, 16*(3), 329–346.

Taylor, J., & Nicholas, R. (2023). Competency frameworks for forensic professionals: A systematic review. *Forensic Science Policy and Management, 14*(2), 99–112.

Teece, D. J. (2014). The foundations of enterprise performance: Dynamic and ordinary capabilities in an (economic) theory of firms. *Academy of Management Perspectives, 28*(4), 328–352.

Teo, L., Yusof, H., & Nasir, A. (2021). Procedural practices in rural forensic units: An empirical study. *Forensic Science International: Reports, 4*(1), 100–115.

Thompson, W. C., Vuille, J., & Biedermann, A. (2022). Likelihood ratios and competence: Improving interpretive practice in forensic science. *Forensic Science International: Synergy, 4,* 100236.

Towler, A., Kemp, R. I., & White, D. (2022). Face identification competency frameworks and performance in forensic settings. *Cognitive Research: Principles and Implications, 7*(1), 45.

Whelan, K., & Nash, P. (2021). Workflow clarity and case resolution efficiency in forensic investigations. *Policing: An International Journal, 44*(5), 765–781.

Zainal, M., Yusof, R., & Idris, N. (2023). Barriers to digital forensic adoption: Insights from developing economies. *International Journal of Digital Crime and Forensics, 15*(2), 44–61.

Zhang, Q., Wu, H., & Li, Y. (2019). Electronic chain-of-custody systems in forensic science: Improving compliance and accountability. *Forensic Science International: Reports, 2*(1), 90–99.

Zhang, Y., Liu, L., & Chen, W. (2022). Training interventions and cybercrime case outcomes in China. *Forensic Science International: Digital Investigation, 42,* 301–312.

Zulkifli, A., Hassan, F., & Rahman, S. (2021). The diffusion of forensic technologies in developing contexts: Opportunities and barriers. *Journal of Policing Studies, 34*(2), 201–217.

Zulkifli, H., & Tan, A. (2023). Procedural compliance and investigation outcomes: Evidence from Southeast Asia. *Journal of Forensic Sciences, 68*(1), 78–89.