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Challenges of Expertise and Organizational Learning during the Digital Transformation of Forensic Fingerprint Investigation

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For my children

Satu and Anu

Lapsilleni

Satulle ja Anulle

Abstract

The focus of the present dissertation is on personal and collaborative expertise in fingerprint examination, and the carrying out of interventions supporting the organizational transformation of forensic practices of learning and working. The study took place in the context of the digital transformation of fingerprint examination that involved moving from individuals working with real physical samples and analogical documentation to collective processes of analyzing digital fingerprint data. Internal and external criticism is forcing forensic communities to make improvements in terms of further harmonizing criteria, processes and competence requirements. The aim is to improve the quality of forensic investigation at the Fingerprint Laboratory of the Finnish National Bureau of Investigation (NBI) by creating a culture of collectively sharing and enhancing professional knowledge and competence among investigators. A further aim is to deepen understanding of forensic expertise on the personal, collective and organizational level. The conceptual foundations of the research lie in sociocultural frameworks such as adaptive expertise, professional vision, and collective knowledge creation.

The assessment of personal and collaborative expertise in fingerprint examination is based on multiple case studies and action-research methods. The dissertation comprises this summary and three sub-studies published as internationally refereed articles. Study A traces the development of adaptive expertise in fingerprint examination in two apprentices across a two-year training program. The program was designed by the present researcher to support the acquisition of more reflective, collaborative and development-oriented professional competences. Study B addresses critical aspects of collectivized fingerprint-investigation practices that involve distributing analyses of fingerprints across several independent examiners. The study involved organizing, documenting, and analyzing "discrepancy" meetings between examiners who had ended up with conflicting judgments and decisions regarding challenging latents, i.e., fingerprints found from a crime scene. Study C reports discourse interaction in a series of developmental seminars in which the fingerprint laboratory reflected on the transforming of fingerprint-investigation methods and operational guidelines, and worked out new analytic criteria and guidelines for using digital instruments. The multi-faceted data consisted of audio-recorded interviews and group discussions, reflective learning diaries, fingerprint analyses and their written and visual documentation, the results of fingerprint examinations, delayed self-assessments, and jointly constructed PowerPoint notes and quality documentation. The data was iteratively analyzed by

means of qualitative content analysis.

The findings from the studies were as follows. First, the new training methods enabled the apprentices to acquire sophisticated professional competences although their personal ways of reflecting on evolving professional performance differed. Second, the discrepancy meetings revealed how the experienced examiners used partial and limited information in making reconstructive inferences justifying their diverging judgments about the poor-quality latents. The meetings helped with regard to working out more refined criteria for assessing challenging cases and ending up with more coherent decisions. Third, analyses of the developmental seminar discussions revealed that the fingerprint examiners collectively succeeded in verbalizing and constructing their perceptions and interpretations toward a more refined, joint understanding of the criteria of no-value fingerprints, criteria for color-coding and work-out procedures for dealing with discrepant cases, and documentation and other aspects of using the digital instruments. The results of the research were incorporated into some of the NBIFL operational guidelines and quality requirements, as well as guidelines on professional activity in the laboratory.

Keywords: forensic, fingerprint investigation, adaptive expertise, professional vision, discrepancy, decision-making, collective knowledge creation

Tiivistelmä

Digitalisaatio on olennaisesti muuttanut sormenjälkitutkimuksen välineitä, prosesseja ja käytäntöjä. Samaan aikaan kritiikki rikostutkimusyhteisön sisältä ja ulkoa ovat pakottaneet forensiikan palveluiden tuottajat tavoittelemaan toimintansa harmonisoimiseksi yhtenäisiä kriteereitä, prosesseja ja osaamisen pätevyysvaatimuksia. Tämä väitöskirjan tavoitteena on tuottaa syvempää ymmärrystä sormenjälkitutkimuksen asiantuntijuuden kehittämisen haasteista yksilön, yhteisön ja organisaation tasoilla. Väitöstutkimus erittelee adaptiivisen asiantuntijuuden, oppimisen, ammatillisen näkemisen ja kollektiivisen tiedon luomisen käytänteitä sosiokulttuurisesta näkökulmasta.

Tutkimus on luonteeltaan tapaustutkimus ja toimintatutkimus. Väitöskirjan kolmessa osatutkimuksessa kuvataan ja eritellään sormenjälkitutkimusten eritasoisia haasteita. Tutkimuksessa A seurataan kahden harjoittelijan kehittymistä kohti adaptiivista asiantuntijuutta ylitse kaksivuotisen koulutuksen ja harjoittelun. Tutkimuksessa B eritellään haastavien sormenjälkien ristiriitaisiin tulkintoihin liittyvää päätöksentekoa ja tutkimusprosessia. Tutkimuksessa C seurattiin sormenjälkitutkijayhteisön ja yhteisten työprosessien kehittämistä digitaalisen muutosprosessin aikana. Tutkimusaineisto pitää sisällään puhtaaksikirjoitettuja nauhoituksia, reflektiivisiä oppimispäiväkirjoja, itsearviointeja, digitaalisten työkalujen avulla tuotettuja dokumentaatioita, Powerpoint muistiinpanoja ja erilaisia laatudokumentteja. Aineistoon sisältyi suuri joukko analysoituja sormenjälkiä. Tutkimusaineisto analysoitiin laadullisella sisällönanalyysillä.

Tulokset ohjaavat tarkastelemaan forensisen alueen haasteita, jotka liittyvät koulutukseen, sormenjälkitutkimusten tulkintaan ja päätöksentekoon, dokumentointiin, laatuun, jaettujen sääntöjen luomiseen ja myös eri työprosessien ja tutkimusmenetelmien kehittämiseen. Tulokset osoittivat, että harjoittelijat saavuttivat ammatillisen pätevyyden ja heidän yksilöllisen tapansa reflektoida ammatillisesti. Toiseksi, tulokset osoittivat kuinka osallistujat käyttivät rajoittunutta tietoa arvioidessaan heikkolaatuisia sormenjälkiä. Kolmanneksi, tulokset osoittivat kuinka sormenjälkitutkijat tuottivat ja verbalisoivat kollektiivisesti tietoa ja kurottelivat oman pätevyytensä uudelle tasolle, tunnistivat kriittisiä käytänteitä ja löysivät tutkimuksille, prosesseille ja dokumentaatioihin liittyviä yhteisiä ratkaisuja kohti harmonisoidumpia tuloksia.

Avainsanat: forensiikka, sormenjälkitutkimus, adaptiivinen asiantuntijuus, ammatillinen näkeminen, ristiriita, päätöksenteko, kollektiivinen tiedon luominen

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I would like to express my deepest appreciation to everyone who has supported me in conducting this doctoral thesis. The whole PhD journey has been exciting, inspiring, encouraging, enjoyable and rewarding in every way. I have always been intensely curious to learn, understand and find new creative angles for my thinking processes. My aim has been not only to learn facts, but also to train my mind to think and find answers to my endless store of questions.

For over 25 years, I have been privileged to work and develop my expertise in the fascinating world of forensics. Forensic science as a whole became my subject of interest due the variety of "black boxes" there are to encounter and conquer. My PhD studies made it possible for me to open some of these boxes.

I have been working in the midst of organizational and digital change. In addition to finding a balance between new responsibilities, my inspiring research and my demanding work, I have been studying at Helsinki University: I have wavered between exhaustion and feelings of "flow". Feelings of flow have been driving me toward this goal.

During this PhD journey I have been privileged to work with three excellent supervisors whose expertise, knowledge and creative thinking have been quite amazing. They have wisely and patiently guided me on my path toward a new, wider and richer way of understanding and constructing the existing world and its complexity. They have opened up new paths and windows of thinking through which to gaze and wonder.

I owe my deepest and endless gratitude to Professor Kai Hakkarainen for everything. He has always been patient, he has shared his excellent knowledge of theoretical perspectives, and above all he has shared with me his inspiring and creative way of thinking and working. He has affected how I construct the "big picture" more than I could have believed was possible. His personal and collective practices have been part of my learning story during this journey.

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When I started my doctoral studies I became deeply inspired by the lectures and the collective way of working within the doctoral community of Professor Yrjö Engeström, who with his professorial colleague helped me to characterize the world around me in a highly interesting and sense-making way. Their way of sharing knowledge and reflecting on it provided me with an excellent example of how to learn and transfer this kind of activity to my working community. My special, thankful thoughts to all of you.

I will always be grateful to my mother and father, who passed away during the course of my doctoral studies. Their endless, unconditional, encouraging and loving support has meant everything to me. I want them to be proud of me.

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I dedicate this dissertation to my beloved, wonderful daughters Satu and Anu. I want to encourage you just to believe in yourselves. Hold on to your dreams. You both mean everything to me. I love you!

Tuusula, December 2017
Virpi Mustonen

List of original studies

This dissertation is based on the following studies, which are referred to in the text by their corresponding letters A, B and C:

A Mustonen, V., & Hakkarainen, K. (2015). Tracing two apprentices' Trajectories toward Adaptive Professional Expertise in Fingerprint Examination. *Vocations and Learning, 8*:185–211. DOI: 10.1007/s12186-015-9130-7.

B Mustonen, V., Hakkarainen, K., Tuunainen, J. & Pohjola, P. (2015). Discrepancies in expert decision-making in forensic fingerprint examination. *Forensic Science International, 254*, 215–226. DOI: 10.1016/j.forsciint.2015.07.031.

C Mustonen, V., Tuunainen, J., Pohjola, P. & Hakkarainen, K. (2017). Organizational learning in forensic fingerprint investigation: Solving critical challenges with organizational rule construction. *Learning, Culture and Social Interaction, 13,* 75-89. DOI: 10.1016/j.lcsi.2017.03.001.

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Figure 14. The professionals were given a preliminary task in the developmental seminars and were asked to color-code one (the same latent) with all the information analyzed (green stands for good quality, yellow for mediocre quality, red for uncertain, poor quality). The images represent six examiners' divergent ways of coding the same latent. In compliance with NBI safety policy, the images have been manipulated to preserve anonymity.

Glossary of fingerprint terminology

ACE-V	The acronym for a fingerprint investigation method; Analysis, Comparison, Evaluation, and Verification.	
AFIS	The acronym for Automated Fingerprint Identification System of digital fingerprint storage and matching. AFIS is biometric software that uses digital imaging technology to obtain, store and analyze fingerprint data. It provides a list of possible, more likely candidates for the match. Experts examine these possible candidates and determine which one (if any) is an identification.	
Bias	Bias effects are perceptual or mental processes that affect the reliability and validity of observations and the conclusions of the examiner, the tendency to search for data or interpret information in a manner that supports one's preconceptions, or the effect of information or outside influences on the evaluation and interpretation of the data.	
Color-coding	Coding fingerprint information using colors. According to the GYRO system, green dots mean certain, yellow ones uncertain, red ones very uncertain, and orange ones indicate minutiae marked at the comparison stage (see Langenburg & Champod, 2011).	
Distortion	Variances in friction skin captures caused by contact surface, lateral pressure or movement.	
Examination	One single latent in the examination process.	
Fingerprint	An impression of the friction ridges of any part of the finger.	
Fingerprint numbers	Right hand: F1 thumb F2 index F3 middle F4 ring F5 little	Left hand: F6 thumb F7 index F8 middle F9 ring F10 little
Investigation	Overall fingerprint examination processes.	

Latent	Friction ridge details (e.g., fingerprint) found from the scene of the crime.
LIMS	The acronym for Laboratory Information Management System. A Laboratory Information Management System is software that records, manages and stores data in the NBIFL. It enables investigated cases to be recorded, traced, and tracked.
Minutiae	Features in fingerprint ridges; bifurcations, ending ridges, and dots. Minutiae are also known as Galton details.
NBIFL	National Bureau of Investigation Forensic Laboratory.
OSAC	Organization of Scientific Area Committees (OSAC) for Forensic Science in the National Institute of Standards and Technology (NIST) See for details: https://www.nist.gov/topics/forensic-science/organization-scientific-area-committees-osac.
Pattern type	The fundamental patterns of the fingerprint are arch, loop, and whorl.
Ridge	Morphology of friction-ridge skin.
Ridge flows	The direction of one or more friction ridges in a fingerprint.

Contents

1 Introduction

Forensic fingerprint investigation and forensics in general are facing major challenges because of globalization and digitalization. Such drivers of change have resulted in turbulence in working life, and have transformed professional practices (Palonen, Boshuizen & Lehtinen, 2014; Hakkarainen et al., 2011; Mustonen et al., 2015). Forensic investigators have to engage in immediate and instant, local and global interactions, and to work in extended professional networks adapting to rapid changes and functioning in heterogeneous networks of technologies, instruments, and experts. Forensic institutions have also had to develop new ways of learning and innovating, and to cope with pressures of time to save costs through mass production.

Coping with rapid nonmonotonic changes requires that professionals cultivate collaborative expertise across many domains. Novel, digitally mediated workflows allow the social distribution of many tasks that were traditionally carried out individually, leading to new transparency, quality, and accountability requirements. Professionals making decisions and justifying suggested changes in operational practices have to rely on more rigorous criteria based on established national and international standards (Jensen, 2012; Jensen & Nerland, 2015; Lahn & Christiansen, 2012). Coping with these changes requires new forms of expertise, institutional efforts supporting competence development, and the pursuit of organizational improvement (Lehtinen, Hakkarainen & Palonen, 2014; Tynjälä & Newton, 2014). Closer integration of professional and scientific knowledge is needed to solve emerging complex problems and to improve examination practices (Lehtinen, Hakkarainen & Palonen, 2014; Tynjälä & Newton, 2014; Tynjälä, & Gijbels, 2012).

Forensic service providers in Finland have been aware for years of the necessity to develop the National Bureau of Investigation Forensic Laboratory's (NBIFL) methods and processes to adapt to the modern and digital age. The NBIFL has been determined to develop such processes, and at the same time has actively implemented new technical solutions and introduced new services. This developmental work has been challenging for the laboratory, but has also provided novel opportunities for improving investigation practices from the training of examiners to complying with real-time operational requirements. These developmental processes and actions gave me the possibility to focus and to look deeply into one area of forensic specialism.

The focus of this dissertation is on the personal practices, interpretations and judgments of fingerprint examiners on the one hand, and the emerging, socially shared

and collective processes and practices among forensic research teams on the other. Fingerprint examination in this context refers to personal interpretative processes of analyzing fingerprints, whereas fingerprint investigation means the overall forensic-investigation process of fingerprinting.

My purpose in this dissertation is to deepen understanding of fingerprint investigation and the various processes it involves, as well as to enhance knowledge and provide models for developing professional competences and supporting organizational learning during a major digital transformation of practices. The aim is to integrate various theoretical perspectives that elaborate the concept of adaptive, professional expertise in the context of fingerprint examination. The resulting knowledge and understanding will facilitate the advancement of fingerprint-investigation practices through a novel training program and in the working out of collectively improved operational and decision-making practices. In pursuit of this aim I collected comprehensive data covering individual, collective, and organizational aspects of fingerprint investigation. The dissertation focuses on developing methods for analyzing processes of making interpretations, judgments and decisions related to fingerprint examination, and documenting the decisions.

The overall objective of the present investigation was to investigate the personal and organizational challenges involved in developing professional expertise in fingerprint investigation that emerge from the digitalized instruments, processes and practices of forensic investigation. To that end, I conducted a series of studies and published three original articles in international, refereed, scientific journals. Each of these studies had specific focuses and research questions related to: 1) apprentices' personal trajectories toward adaptive professional expertise in fingerprint examination; 2) examiners' judgement and decision-making in challenging fingerprint cases; and 3) organizational learning connected with resolving critical challenges arising from organizational rule-construction in collective knowledge creation. I address fingerprint investigation in relation to scientific research on expertise, professional vision, and organizational transformation.

1.1 Challenges related to forensic fingerprint investigation

It is evident that fingerprint-related processes and practices are among the oldest techniques and most well-known identification methods in forensics. Given its long history, fingerprint identification has been considered the gold standard in forensic investigation because of each fingerprint's uniqueness and the richness of the data.

Fingerprints provide indisputable evidence and constitute a valuable tool for criminal investigation. Professional fingerprint examiners have to meet high expectations regarding the production of accurate and precise results. Professionals are also expected to document their working processes transparently, and to make decisions based on high-quality evidence. When requested, they are expected to go to court to present and defend their decisions. In general, the forensic service provider's results are taken as correct and considered to represent "the truth," and fingerprint identification is seldom questioned at court. Fingerprint identification or non-identification carries a great deal of weight as evidence in court: a single, crucial piece of fingerprint evidence and the resulting identification may have devastating consequences for the accused.

Traditional fingerprint identification has faced crises and a diminished reputation in recent decades because of identification errors in high-profile cases. Fingerprint analyses based on limited and incomplete information have also been criticized on the grounds of opaqueness in the methods of identification and decision-making. Several high-profile cases investigated in the United States and elsewhere during the past 20 years have shown that forensic examiners sometimes make mistakes, and that they might face challenges in reporting their findings to law-enforcement officials or juries. Following various US Supreme Court rulings, fingerprint-examination and identification processes have been questioned and challenged because of embarrassing fingerprint misidentifications: examples include the Mayfield case in the USA in 2004 (see https://oig.justice.gov/special/s0601/exec.pdf), and the Shirley McKie case in the UK in 1999 (see https://locardslab.com/2015/05/12/forensic-fails-the-shirley-mckie-fingerprint-scandal/). Since these cases, forensic service providers have been forced to consider whether the results of fingerprint examination should be assumed, in reality, to represent an infallible, error-free culture of investigation (see Lynch & Cole, 2005). In addition, many forensic studies reveal variances in the basis of judgements, and biased decisions (Dror, 2017; Dror & Charlton, 2006; Mustonen, Hakkarainen, Tuunainen & Pohjola, 2015). Challenging situations also emerge when forensic service providers are required to improve the quality of their investigative activities (e.g., NAS, 2009; Saks & Koehler, 2005). The reliability and credibility stakes are high given the requirements of transparent quality on every level, including the methods, processes, training and competences of forensic experts as well as the changing environment due to digitalization (Mustonen & Hakkarainen, 2015; Mustonen et al 2015).

Behind the misidentification and variance in decisions are significant hidden factors and processes, such as bias effects (Dror et al, 2005; Dror & Stoel, 2014). According to the results of studies in the field of ethnographic science and technology, laboratory work is much more messy, opportunistic and contingent than normative perspectives on

forensic methods and other formal practices indicate (e.g., Latour & Woolgar, 1979; Lynch & Cole, 2005). Fingerprint examination consists of a series of steps involving the analysis, comparison and evaluation of a latent print found at a crime scene in relation to a known print. Risk-related human factors emerge in all phases of the analysis and comparison (Ulery et al. 2015). Potential risks and errors may be attributable to inadequate training, poor judgment, complex digital technology, challenges in the methods and processes, a lack of standards, or inadequate quality control. For instance, the use of the vast databases in the Automatic Fingerprint Identification System (AFIS) to find matching fingerprints for latents involves risks because of infrequent occurrences of highly similar 'random' matches (Dror & Mnookin, 2010). Many studies have also shown wide variations in poor-quality latent results and interpretations of fingerprint casework involving erroneous exclusions, missed identifications, and inappropriate inconclusive and no-value decisions (Black, 2012; Dror & Charlton, 2006; Kruger & Dunning, 1999; Ulery et al, 2012). In addition, there are reported cases showing evidence of biased decisions (Dror & Charlton, 2006; Dror & Mnookin, 2010). Dror's findings indicate that contextual factors play an important role in the analysis and interpretation of fingerprints. Awareness of a colleague's decision tends to confirm rather than disconfirm erroneous judgments of identification. Knowing that a subject was in prison at the time of a crime may affect an examiner's judgment and decision. Nevertheless, these previously mentioned identification errors do not happen on a daily basis, and most interpretation difficulties relate to low-quality fingerprints (Mustonen et al, 2015; Ulery et. al, 2011).

Misidentifications and other challenges mentioned above are forcing forensic institutions to make major changes in the socio-technical systems of fingerprint investigation. Service providers have to pursue a more open culture in which the inevitability of human error is acknowledged and preventative operational procedures are developed. Openness in relation to the potential occurrence of errors will probably lead to improvements in practices. In their efforts to avoid potential errors, forensic laboratories, as well as international actors and institutions, have worked to reduce the risk by improving analysis procedures and practices of latent-print examination, as well as in other forensic disciplines based on comparison. Rapidly changing digital technologies are changing the nature of forensic investigation in many ways, and are making formerly implicit and personal examination processes and workflows more explicit and transparent. Within this development, it is essential to open the "black box" of evaluation relating to service credibility and reliability to improve the quality of fingerprint-investigation processes. The term 'black box' is used to indicate some component (set of unspecified elements) in the process, the specific mechanisms,

elements and sub-processes of which are unknown, unspecified or implicit.

In the past, many international forensic laboratories followed the commonly accepted international quantitative standard that required 12 certain minutiae in a fingerprint to be determined so as to qualify for identification. The consensus about the sufficient number of minutiae was not shared by all countries, and some deviating nations required different numbers of minutiae. Many forensic laboratories have changed their decision criteria in an integrative or synthetic direction, however, which is said to offer a more "holistic" and "scientific" basis for the identification of fingerprints than the "old" method of counting specific minutiae (Anthonioz et al., 2008; Cole, 2001). The National Bureau of Investigation Forensic Laboratory (NBIFL) in Finland also moved to the holistic approach in 2001, which was an international trend at the time. Further, the ACE-V (Analysis, Comparison, Evaluation and Verification) framework used in fingerprint examination has shaped this holistic process, which does not give the fingerprint examiner the tools for producing arguments concerning decisions; but merely provides a frame of reference. The lack of validated and transparent thresholds is a recognized weakness of the ridgeology approach and the ACE-V protocol (NIJ, 2017), hence new methods of fingerprint analysis have to be considered.

New transparency, productivity, and quality requirements are forcing forensic-science service providers to find new ways of improving their efficiency without lowering the reliability of the investigation. The absence of shared rigorous investigative standards and internationally agreed and shared training requirements makes the situation challenging. These challenges related to the training, the process, and the decision-making, as well as the methodological deficiencies have encouraged forensic-service providers actively to develop the forensic discipline further to reflect the new digital age. Digitalization is playing a major role in these developmental efforts to improve investigation practices. It carries the potential to bring the discipline to the next levels of transparency and scientific knowledge, as well as to collect the "big data" and statistical knowledge that support novel decision-making. Given the history and demands associated with opening the forensic "black box" in terms of specifying sub-processes and documenting how they unfold, this dissertation is intended to help in resolving these challenges.

1.2 Enhancing practices in forensic fingerprint identification in Finland

This dissertation research took place in the context of a major transformation regarding

technological instruments and methods of fingerprint investigation that involved moving from physical samples and analogical documentation to digitalized fingerprint data and processes. Finland's National Bureau of Investigation Forensic Laboratory's (NBIFL) investigative system was transformed in 2011, mediated by the Laboratory Information Management System (LIMS) to ensure consistent compliance with quality requirements and to make the fingerprint-investigation process more explicit, unbiased, and reasoned. In the traditional examination process an individual examiner analyzed all the latents (i.e., fingerprints found at a crime scene) related to a case. The new system under development distributes the fingerprint examination among several independent examiners, thereby replacing the former approach according to which each examiner was individually responsible for his or her "own" cases. The transformed process of the National Bureau of Investigation Forensic Laboratory (NBIFL) changed the division of labor among the examiners, and made the investigation more collective in nature.

In response to the previously mentioned challenges and needs, in 2011 I organized developmental seminars for all fingerprint examiners, and specific meetings concerning discrepancy decisions in fingerprint identification, as part of the broader developmental program of the NBIFL. *The developmental seminars* focused on verbalizing and reflecting on the examiners' different levels of knowledge and collectivizing their practices through joint rule construction; I also sought to renew the examination process mediated in the LIMS. The purpose of the seminars was to organize a set of reflective intervention meetings and collectively to create rules, criteria, and processes and reach a collective understanding of the complex, digitalized environment of fingerprint examination on the personal and the collective level. A further aim was to focus in detail on the challenges of verbalizing interpretations and fingerprint images, as well as the profound justification of decision-making, as well as to pursue some sub-targets. The harmonizing of documentation was also discussed. The developmental seminars thus provided a context and framework within which to facilitate organizational learning and collectivize organizational practices of fingerprint identification.

The practical organization of *discrepancy meetings* between examiners who had ended up with different decisions was also developed during the seminars. After starting to use LIMS and associated practices of having examiners analyze fingerprints independently, discrepant decisions became highly visible, and divergent interpretations and their justifications more explicit. The occurrence of discrepant decisions justified the organization of specific discrepancy meetings with the examiners (see Mustonen et.al. 2015). These meetings focused the reflection of the participating examiners on differences and similarities in perceptions, interpretations and judgment, as well as on the resulting decisions made in fingerprint identification. My aim was to make the

fingerprint examiners' activity more coherent and to share, collectively, the criteria used.

In addition, the NBIFL hired two new apprentices in the spring of 2011. I had devised the novel training program in 2010 (Mustonen & Himberg, 2011), and it was carried out in 2011-2012, during the *two apprentices' training process*. The NBIFL set high expertise requirements and expectations for future fingerprint examiners, and it was considered necessary to improve training practices to meet the new quality, reliability, and transparency standards called for in the collectivized and digitalized practices of forensic investigation. Accordingly, adaptive expertise came to be considered critical for investigative working. To that end, sophisticated conceptual competences together with flexible procedural skills supported by the laboratory's professional learning environment needed to be cultivated in a more expansive direction. The pedagogic structure of the novel training program supported the activity carried out during the NBIFL developmental actions.

The training of the new apprentices, the discrepancy meetings and the developmental seminars were overlapping, and influenced all the developmental actions pursued in the NBIFL fingerprint laboratory at the time. The further development of instructions covering documentation processes and methodological guidelines continued (Mustonen et al., 2017; Mustonen & Hakkarainen, 2015; Mustonen et al, 2015). The NBIFL aim was to respond to challenges and proactively to develop fingerprint investigation to meet the requirements of the emergent digital operating environment.

1.3 Research aims

The overall research aim was to improve the quality of forensic investigation at the Fingerprint Laboratory by creating a culture of collectively sharing and creating professional knowledge and competence among examiners. The objective of the developmental efforts was to challenge the fingerprint community to engage in reflective interaction, the creation of novel criteria and the development of innovative work practices. The present dissertation traces the development of forensic fingerprint expertise and examines the influence of digitalization on the collectivization of fingerprint-research methods, processes, and decision-making practices. It also addresses the tensions and discrepant relations between the developmental paths of personal expertise and the historically learned and socially constructed collective practices that emerged in the course of facing the challenges of digitalization in the context of the NBIFL organization in Finland.

The investigation was socio-cultural in nature. I was influenced by socio-cognitive theories of expertise (Bereiter & Scardamalia, 1993; Hakkarainen, Palonen, Paavola, & Lehtinen 2004; Hatano & Inagaki, 1992; Lin, Schwartz & Bransford, 2007), the theory of professional vision (Goodwin, 1994), theories of learning through participating in professional practices (Wenger, 1998; Nonaka & Takeuchi, 1995; Lave & Wenger, 1991; Engeström, 1999; 2016), and activity theory, particularly concerning the collective construction of mediating criteria and rules (Engeström, 1987; Heritage, 1984). My aims were to expand socio-cognitive theories of expertise in a sociocultural direction, as well as to adapt activity-based and participatory theories of learning to the examination of personal and social developmental trajectories of professional learning in forensics. The activity-theoretical background inspired and shaped my studies, and led me to see the signs of challenges, tensions and contradictions, as well as the potential in the investigation process.

To meet the needs mentioned above I carried out research on the development and socialization of the new fingerprint apprentices hired at the NBIFL (National Bureau of Investigation Forensic Laboratory), and conducted a series of developmental seminars and discrepancy meetings. The main objective of this dissertation is to trace the development of adaptive personal and collective expertise in fingerprint investigation, and to make explicit the process and sub-processes of the collective learning and construction of knowledge to meet the challenges inherent in the new transparency and quality requirements. I focused my efforts on examining the reasons for the divergent interpretations, justifications and associated decisions, and discuss the examiners' perceptions and impressions of the latents, especially where there was disagreement. I also documented associated processes in which tensions and challenges related to past, current, and future work in this field arose, and used the findings to improve the quality of fingerprint-investigation practices.

Figure 1 summarizes the three sub-studies included in the present dissertation, pointing out the specific respective main focuses, theoretical foundations, methodological approaches and contributions.

	Study A	Study B	Study C
Main focus	The process of adopting fingerprint-investigation knowledge and competence	Decision-making in the context of conflicting interpretations and judgments	Organizational learning and the construction of rules
Theoretical foundations	Adaptive expertise Professional vision	Elements of developmental work research Professional vision	Collective knowledge creation Studies on organizational learning
Methodological approach	Multiple case study of two apprentices' trajectories toward becoming professional fingerprint experts	Analyzing a series of discrepancy meetings in which professional fingerprint examiners negotiated diverging interpretations and judgments	Analyzing developmental-seminar interventions in the fingerprint examiners' community Action research; Multiple case study
Contribution	Reports new pedagogical approaches in the training of two apprentices, and describes the trajectories of their development toward acquiring the necessary adaptive expertise to meet professional competence requirements	Making contradictions in the fingerprint-examination process visible, setting up a new social mechanism for negotiating diverging interpretations, and contributing to novel operational guidelines	Carrying out a series of developmental seminars for reflecting on and transforming examination practices and working out new guidelines and rules for using instruments, documenting examinations, and making decisions

Figure 1. Conceptual dimensions in the framework of this dissertation.

The overall contribution of this dissertation is to provide forensic laboratories with tools to develop and implement organizational learning. It examines elements of personal and social learning and analyses collective knowledge-creation processes across the organization, concurrently analyzing the expansion of the tools and instruments along with the enhancement of processes and rules. I take a social approach to apprentices' training and provide an implemented and documented training program for forensic laboratories. In addition, I offer a new social mechanism for negotiating diverging interpretations and building knowledge according to operational guidelines constructed with professionals.

Figure 2 gives an overview of the dimensions within the framework of this dissertation. It illustrates the reflective nature of the dissertation in researching organizational learning on the personal, collective, and organizational levels, and reveals the dialogical nature of developmental actions related to rule construction, the integration of tools and instruments, and the development of processes.

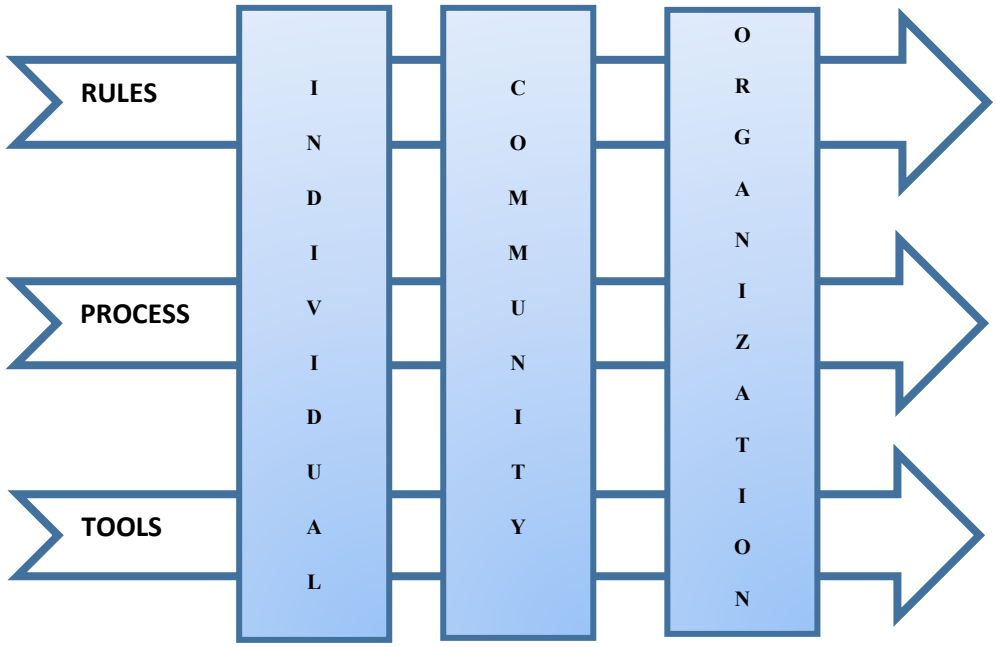


Figure 2. An overview of the research framework.

The aims of the present dissertation are thus to create a coherent and critically evaluated synthesis suggesting how expertise in fingerprint investigation may best be developed on the personal, community and organizational levels to facilitate productive and transformative coping with current challenges.

2 New challenges related to forensic fingerprint expertise

Forensic research is based on sophisticated skills. To preserve high levels of competence, integrity and credibility it is necessary for institutional providers of forensic services to have experts who are able to integrate conceptual knowledge into their everyday practice (Markauskaite & Goodyear, 2017), and have the capability as well as the willingness continuously to improve their professional expertise. The present investigation took place after digitalization had radically transformed the socio-material basis of forensic investigation, in other words the technologies, work flows, and social organization (Fenwick & Nerland, 2014). As a consequence of such changes, fingerprint examiners work with digital fingerprints rather than physical samples, share their expertise socially rather than working alone, and follow national and international quality standards and guidelines rather than mere personal judgment.

Digitalized instruments and methods give rise to new kinds of skill and competency requirements, and a need to cultivate new kinds of collaborative, dynamic expertise. The challenge is to utilize bodies of expert research to develop coherent forensic methods, practices and programs for training fingerprint experts. The findings of expert research provide guidance for improving many aspects of the forensic laboratory's procedures and facilitating the development of associated expertise. My aim is to integrate such findings with efforts to develop methods of fingerprint investigation, and to offer workable solutions for cultivating future forensic expertise.

In the following sections I briefly review the research on expertise that is relevant to fingerprint investigation from three partially overlapping perspectives: 1) individual problem-solving capability, 2) the social nature of professional expertise, and 3) the transformative processes involved in expertise.

2.1 Expertise as cultivated problem-solving capability

Expertise has traditionally been examined in terms of exceptional individual capabilities to effectively solve complex problems, developed through sustained training and practice. It could be defined as the individual mastery of a well-organized body of usable knowledge that the person employs to focus selectively on the critical aspects of complex problems in a given domain, and thereby achieves an exceptionally high level of

performance in his or her trained domain of activity (Ericsson 2006; Ericsson & Pool, 2016). Professional expertise is, to a large extent, based on tacit or implicit knowing: experts know more than they can tell and often cannot provide a reliable verbal description of their reasoning processes (Polanyi, 1966). This is especially true in visualization-rich disciplines of expertise such as interpreting x-ray images or analyzing fingerprints, in which pattern recognition plays a crucial role.

Generally, people learn throughout the waking hours of their lives. However, there is a difference between experts and non-experts in terms of professional activity. Skillful performance depends on the professional's level of knowledge, how well it is integrated and how effectively it is geared to performance (Bereiter & Scardamalia, 1993). However, dynamic problem-solving processes are key elements of expert performance. Experts need knowledge, but they also effectively solve problems that may be complex and interconnected with the social environment. They tackle problems more efficiently than non-experts, which also adds to their expertise over time. There is always a higher level from which a problem can be approached, taking more variables into account, reaching a higher standard of accomplishment or meeting a larger and more subtle range of requirements, continually incorporating already-mastered skills into more advanced procedures. This kind of expert capacity is called progressive problem-solving. Non-experts, in turn, tend to tackle problems that do not require them to extend themselves; they work routinely and are skeptical of most innovations (Bereiter & Scardamalia 1993).

Bereiter and Scardamalia (1993) point out in their discussion of medical expertise that the majority of medical doctors' cases are unchallenging and can be solved by relying on routine procedures. However, 5-10 percent of the cases are very challenging and require doctors to work at the edge of their own expertise. It appears to me that these observations also apply to forensic fingerprint investigation. Most of the cases can be solved by relying on routines, and here forensic expertise is not highly challenged. Then there are complex cases with limited and partial information, when forensic expertise is challenged in an especially demanding way. In such cases, experts have to go beyond routine solutions toward higher-level problem-solving procedures that stretch their own capabilities. Various reasoning strategies and iterative knowledge-building efforts enable experts, who also use critical self-reflection, to find workable solutions to complex problems in spite of human cognitive limitations. Experts invest resources released from accumulating experience to work at the edge of their competence, acquiring progressively higher levels of competence in return.

Hatano and Inagaki (1992) characterize *adaptive expertise* as a continuous, active search for opportunities to develop one's professional knowledge and understanding.

The knowledge of the adaptive expert derives from his or her formal, procedural and self-regulative knowledge. Formal knowledge comprises theoretical, conceptual, and professional understanding, on which experts' reflecting-in-practice (during activity) and reflecting-on-practices (retrospective reflection) within the social environment is based (Schön, 1987). Procedural knowledge builds on practical activity, which generates valuable experience, "know how" and reflective, tacit knowledge. Self-regulative knowledge relies on metacognition, reflection, planning, observation and evaluation within elements of the social environment (Hatano & Inagaki, 1992). Metacognitive capabilities have an important role in professional development and advancement. Novices as well as professional fingerprint examiners use metacognitive strategies in planning, controlling, observing and adapting their investigative processes. In the present study, metacognitive processes were in evidence in the training of apprentices as well as in discussions at discrepancy meetings, when experienced examiners justified their decisions.

Within Hatano's framework, professional routines could be described as highly specific, cultural tools, the unreflective application of which in seemingly usual cases could easily lead to errors (Cole, 2007). Adaptive experts are characterized by their deliberate efforts to understand the meaning of professional practices and associated inventive and flexible performance, rather than their direct assimilation of established routines (Hatano & Inagaki, 1992). Adaptive expertise entails procedural flexibility in terms of adapting existing procedures according to the cases encountered, and critically reflecting on mistakes and errors (Rittle-Johnson, Star & Durkin, 2012). The flexible and adaptive use of procedures requires the integration of formal and informal knowledge. Successful analysis of complex cases requires fingerprint examiners to integrate conceptual, visual and procedural knowledge in the context of application. To cultivate such competences, it is essential to work with varied cases, to apply multi-faceted procedures, and to enact diverse reflective practices (Lin, Schwartz & Bransford, 2007).

Furthermore, competent experts make decisions in highly specialized domains by mutually negotiating disagreements between diverging views and investing cooperative efforts in reaching reliable, joint conclusions. As described earlier, the reliability of forensic experts has been challenged in many ways, and this does not only concern fingerprint decisions (Dror & Hampikian, 2011; Mustonen et al. 2015). The reliability of forensic investigation is connected to the broader issue of how unbiased decisions are reached. The exclusion of irrelevant contextual information, countering the human tendency to confirmation, and expected-frequency biases are challenges to forensic expertise (Dror, 2016). Such contextual information could indicate that another expert has identified the fingerprint or that a suspect has already confessed to the crime, for

instance. Forensic experts have to be trained to identify different kinds of bias effects, and to be consciously aware when they are in the "bias danger zone".

In sum, expertise could be described as a personally cultivated, problem-solving capability. Adaptive efforts to continuously improve professional expertise, instead of merely mastering prevailing routines, are critical in rapidly transforming professional environments. Indeed, expertise is not only a matter of personal professional competence but also, to a significant degree, represents shared practices and methods of expert cultures and networks (Bereiter & Scardamalia, 1993; Hakkarainen et al., 2004). Consequently, it would seem necessary to expand the examination of expertise beyond the individual cognitive approach to incorporate socially shared or distributed aspects. In the following sections I consider expertise in terms of socially shared learning, competence and practices in forensic communities.

2.2 Socially shared aspects of expertise

Although cultivated individual competences truly matter (Billett, 2006), professional expertise is embedded in social practices of organized professional communities and networks, and in the broader institutional environment regulating experts' activities (Lave & Wenger, 1991; Wenger, 1998). Expert knowledge represents the cultural-historical evolution of the professional disciplines, and is embodied in the social practices of expert communities and networks (Hakkarainen et al., 2004; Lave & Wenger, 1991). Socio-culturally-oriented researchers examine expertise in terms of socializing and growing into a professional culture, appropriating its shared practices, norms, values and, further, developing an associated professional identity. As I see it, personal competences are embedded in the socially shared competences of expert cultures (Billett, 2006).

Learning to do fingerprint analysis requires the acquisition of sophisticated expertise through in-depth socialization during years of training and practical experience. Fingerprint examiners have traditionally been trained in a mentor-apprentice setting (Lave & Wenger, 1991) by the forensic institutions themselves, which rely strongly on experience or seniority. The scientific forensic community has criticized such experiential training practices. According to these critics, the trainee's knowledge of modern professional educational and training methods as well as of quality requirements has been too strongly dependent on the idiosyncratic personal preferences of the senior mentors. Many of these persons are highly qualified, but their work has not always met desirable quality standards, such as transparency in terms of the criteria and

documentation of examination processes. The process has undoubtedly produced competent routine experts, but more effort should be invested in the development of reflective forensic experts with a high level of self-regulative skills who can adaptively respond to the challenges of the continuously changing and digital working environment (NAS, 2009; NIJ, 2010, 2017).

From the socio-cultural perspective, expert competences are thoroughly mediated by cultural knowledge and practices, including visual-recognition and interpretation capabilities. The internalized professional knowing of examiners provides the psychological tools (Vygotsky 1978) for separating, within a visual field, significant cues and signs from a non-significant background. Such capabilities allow experts to make well-justified inferences relying only on partial and limited information, which are therefore crucially dependent on all aspects of their visual and visual-processing capabilities. The task of analyzing fingerprints is very challenging, especially in poor-quality latents, because each fingerprint is unique. Latents collected from crime scenes are often partial and distorted, and examiners have to be able to determine in uncertain circumstances whether the latents and prints on ten print-cards found in the archives indeed come from the same person.

Expertise in fingerprint examination relies to a great extent on pattern recognition, particularly on the visual level (Dror & Cole, 2010). Similar to how radiologists and fighter pilots operate, fingerprint examiners use the powerful human visual system as their main instrument for making judgments. Professional fingerprint examiners have to be able to combine their vision, speech, gestures, and other embodied resources to make sense of the fingerprint images (Styhre, 2010). Rather than being a one-directional flow of information from the outside to the inside, pattern recognition is a constructive process driven by the participant's own culturally mediated schemes and expectations (D'Andrade, 1992; Neisser, 1976). A key aspect of expertise in fingerprinting is a deliberately cultivated professional vision (including interpretation) capability (Goodwin, 1994), meaning the experience-based and socially organized visual capabilities needed for "seeing" (perceiving, recognizing, comprehending, and interpreting) signals and events of fingerprint images relevant to the interests and purposes of the fingerprint-examination community. Goodwin (1994) categorized professionals' visual activity in terms of three practices: coding, highlighting, and producing and articulating material representations. Coding by marking minutiae in latents enables one to make AFIS database searches and comparisons with the suspect's fingerprints. By highlighting disturbances and color-coding ridge flows (i.e., details) or minutiae, the examiner makes his or her perceptions visible to other experts. Constructing external material representations involves manipulating fingerprint images

in various ways by means of AFIS software and Photoshop, and also by producing written annotations that ground and justify one's interpretations.

Professional coding represents the transformation of observed phenomena into concepts and categories that are relevant to the profession (Goodwin, 1994). Accordingly, examiners' visual cognition is socio-culturally shaped by deliberate and sustained training to recognize normatively determined meaningful patterns (Fleck, 1979). Extended deliberate training gradually builds the required visual competences that allow professionals to recognize meaningful patterns in spite of partial, noise-laden, and distorted information. Professional vision emerges through this noise, and is embedded in practices of systematic coding, the highlighting of fingerprint images, and producing and articulating associated material representations (e.g., documentation). Producing and articulating material representations, and marking and highlighting them in some fashion, make phenomena in this complex perceptual field salient. My studies address many aspects of the professional visual capability of fingerprint examiners, revealing the value of this theoretical framework for forensic investigation.

As Schatzki (1996, 2002) notes, practices of fingerprint examination could be understood as rule-governed forms of repeated social actions based on shared practices. Fingerprint examination as such appears to rely on internalized and often unconsciously followed local, personal, and social rules. Organizational efforts are needed to collaboratively agree on examination norms and regulations, and to create policies and standards of appropriate practices that support investigators' shared efforts and guide the justification of their decisions. It is therefore critical in a digitalized environment for communities of fingerprint examiners to work out shared norms and standards that individual examiners will deliberately follow, even in complex cases. The problem, however, is that any rule can be followed in an infinite number of ways in practice (Wittgenstein, 1953). Professional conduct is thus challenging because even agreed rules do not provide actors with specific instructions regarding how they are to be followed in a given situation. Instead, rules (as used) appear to be context-dependent, meaning that professionals utilize them interpretatively to construct their sense of appropriate behavior in any concrete situation (Heritage 1984; Leiter 1980).

Expert decisions, despite their sophistication, are not infallible. Critique of such decisions has been severe: they are reportedly affected by irrelevant biases, inconsistent rules and criteria in organizational guidelines, and fingerprint examiners' procedures (see Dror, 2017). Fingerprint examiners carry out a whole series of AFIS searches that result in similarity scoring of potentially relevant fingerprints from huge archives. A particular result of AFIS scoring, even if irrelevant, may affect subsequent analyses by creating expectations (i.e., expected frequency bias), and along with other irrelevant

information influence expert decision-making (Dror, 2013; Dror & Stoel, 2014; Houses of Parliament, 2015a, 2015b).

Responding to this critique, many forensic laboratories are trying collectively to define practical rules and criteria for improving the coherence of investigation processes and harmonizing decision-making. When decisions are made by several independent examiners without knowing what the other examiners decided, contextual bias may be encountered. That said, knowing one's colleague has made an identification may result in confirmation bias. The collective and digitalized examination process has challenged expertise by embedding individual examination in socially shared rules and distributed activities. Through the making of varying decisions, highly visible, digital practices support and require the transformation of examiners' personal and social activities.

The focus in the present dissertation is on the rules for examining fingerprints in the context of moving to a digitalized examination process, which is inherently more transparent and collective in nature. Socially and culturally mediated elements of self-regulative knowledge and processes will help to deepen the discussion on adaptive expertise embedded in transforming organizational practices.

2.3 Expertise as a process of personal and social transformation

Many investigators argue that social transformation and the deliberate pursuit of novelty and innovation characterize the professional expertise found to be characteristic of our time (Engeström, 1987; Hakkarainen et al., 2004; Paavola et al., 2004). This approach was already anticipated by Bereiter and Scardamalia (1993), who examined expertise as a process that could be realized through the careers of an individual, a team, a corporation or a whole society functioning in an expert way (Bereiter & Scardamalia 1993). Experts who apply sophisticated skills to meet broader social needs and use talents in other areas of value to the community are developing the whole community at the same time. The expert who shares his or her knowledge and experience effectively is taking part in creating an innovative knowledge community (Hakkarainen et al., 2004): the expert needs the community to develop his or her expertise and, further, to advance the community's capabilities.

Given the introverted and organizational tradition of training individuals in fingerprint examination there have been few opportunities for collective knowledge creation and collaboration, for structured efforts that go beyond the best prevailing practices. The conservative nature of the traditional mentor-apprentice training system

used in forensic organizations has been criticized by the highly respected National Academy of Science (NAS, 2009). Traditionally, a fingerprint examiner's work has been individualistic in nature: he or she chooses the case to be examined, analyzes all the latents found at a crime scene, and works alone on the case until a research report is produced. Because of the idiosyncratic and opaque nature of the examiner's local analytical and interpretative practices, it has been very hard to make his or her work more transparent and subject to quality assessment. The investigation process has embodied a great deal of tacit knowledge, as well as potentially hidden confirmation bias (Dror et al., 2005). The examiner's perceptions, interpretations, and rationale in making decisions have not, in general, been systematically documented.

Digitalization has transformed many aspects of forensic investigation. Investigators rely increasingly on information-management systems in terms of mediating working with professional objects, structuring work flows, making them transparent, and providing sophisticated instruments for searching for and analyzing information (Fenwick & Nerland, 2014; Nerland, 2012). Digitally mediated workflows allow for the social distribution of work tasks, which were traditionally carried out individually. Simultaneously, digital work processes appear to lead to new kinds of transparency and accountability requirements, transforming many personal and social aspects of work in the forensic domain. Furthermore, fingerprint experts have to learn to reflect on their professional practices and to share their professional knowledge with their colleagues. It is necessary to reflectively evaluate and compare one's interpretations with those of one's colleagues. Moreover, coping with the new challenges that emerge in rapidly changing environments of professional activity necessitates the building of internal and external networks that give support in terms of solving problems, sharing knowledge and competences, and fostering the development of expertise. It is essential to create a culture of sharing expertise and to build learning organizations.

As the above analysis reveals, forensic experts' activities in global professional environments offering digital-technological solutions are becoming more and more complex. These experts have to have flexible and transformative as well as expansive, higher-level socio-cognitive skills, collaborative professional capabilities, and the ability collectively to share professional knowledge. Naturally, norms and values play an important role in expert work. I understand adaptive expertise in forensics as a socio-epistemic practice that shapes the everyday work of examiners, and their relationships with other examiners. It involves second-order activity eliciting proactive adaptation to fingerprint work. Professional development also entails negotiation between collective norms and practices, as participants evolve in their subjectivities and identities (Billett, 2011). Appropriate practices of adaptive expertise cultivate examiners' epistemic agency

(Billett, 2011), in other words their interest, motivation, and capability of learning and deepening participation in the expansive activities of the fingerprint community.

Given the transforming technologies and practices of fingerprint investigation, this dissertation addresses the social, collective and networked aspects of expertise. Frameworks put forward by Hakkarainen and his colleagues (2004; 2016), Edwards (2011) and Stetsenko (2008) facilitate consideration of the socially distributed, relational, transformative and expansive aspects of expertise. An understanding of the socially and culturally mediated nature of self-regulative knowledge and processes serves to deepen the discussion on adaptive expertise. An adaptive expert's continuous internal and collegial dialogues provide him or her with the opportunity to improve his or her personal expertise and to contribute to the expert community. With its shared practices that guide experts deliberately to reflect on their interpretations and judgements and compare them to those of colleagues, a transformative approach to professional practices could become a habit and a continuous process. Adaptive expertise is considered a critical aspect of investigative working habits and sophisticated conceptual competences. A professional learning environment supports the development of expertise in an expansive direction with flexible and cultivated procedural skills.

The present investigation also draws upon cultural-historical activity theory (Engeström, 1987), according to which one would consider expert work in terms of activity systems that mediate the participants' work by means of tools, objects, shared norms, and a certain division of labor. The transformation of professional activity is seen as a process of expansive learning cycles (Engeström, 1999) that involves 1) questioning current activities, 2) analyzing past and current activities, 3) envisioning and modelling new solutions, 4) examining and testing the new model, 5) implementing the new model, and 6) reflecting on the process. Engeström created a well-elaborated change-laboratory approach to systematically support organizational transformation processes. Activity theory functioned as a general inspirational background or epistemic resource for the present dissertation, and helped me to understand the systemic changes in the process of fingerprint investigation.

Efforts to conceptualize new challenges to expertise in the age of digitalization and globalization have shown results in recent discourse related to professional epistemic cultures (Knorr Cetina & Reichmann, 2015). Expert work in knowledge-intensive domains cannot be understood merely in terms of practices because local and global knowledge plays such a central role. Studies on the development of expertise in professional fields have focused on complex knowledge-intensive disciplines, human-automation collaboration, and network communities, as well as on workplaces. The notion of professional epistemic cultures highlights the dynamic role of knowledge in

overcoming the challenges of multi-disciplinary work that requires collaboration across the boundaries of academic and professional organizations (Knorr Cetina & Reichmann, 2015; Nerland, 2012; Edwards, 2012). Dealing with emerging complex problems requires non-monotonic learning that makes radically new innovations possible, and leads to a reconfiguration of the role of science in society and technology (Brown & Duquid, 2001; Kastenhofer, 2007). Objects of professional work are becoming increasingly complex and messy, and require advanced problem-solving, expansive learning and the creation of new knowledge. Coping with these rapid changes requires new forms of learning and innovation, as well as the closer integration of professional and scientific knowledge (Lehtinen, Hakkarainen & Palonen, 2014; Tynjälä & Newton, 2014; Tynjälä & Gijbels, 2012). Given the increased accessibility of scientific knowledge, methods, and practices, academic epistemic cultures are "spilling over" to the professions (Knorr Cetina & Reichmann, 2015). Consequently, professional expert systems may increasingly incorporate scientific instruments, methods or practices. There are higher expectations of creative and transformative rather than mere operational competences. Within this development, it is critical to improve the training of forensic examiners and to create advanced professional learning opportunities. Recent research on knowledge and expert networks (Hakkarainen et al., 2004; Phelps, Heidl & Wadhwa, 2012), mutual trust, and the creation of knowledge (Ellonen, Blomqvist & Puumalainen, 2008) as well as collaborative knowledge (Bereiter, 2002; Nonaka & Takeuchi, 1995; Paavola, Lipponen, & Hakkarainen, 2004) has revealed the importance of providing opportunities for communication and collaboration across organizational boundaries. Extended professional communities and networks play a crucial role in the productivity as well as the creativity of professional communities.

Fuller and Unwin (2004) argued that "restrictive" professional learning environments transmitted rigid routines and narrow practices, and provided limited opportunities for the development of the highest levels of expertise. Expansive environments, on the other hand, constantly engage professionals in deliberate acts of learning, professional reflection, and competence stretching. Expansive professional communities may establish shared and collective practices and routines that push experts to function in a more sophisticated and critical manner. Because of the introverted tradition of the investigative professions, it has been challenging to determine the best investigative practices and to cultivate shared national and international investigative norms. Such organizations invest efforts in engaging all employees in critically assessing their personal and shared activities, identifying problems and challenges, and promoting change. Such practices characterize learning organizations and innovative knowledge communities (Edwards, 2000; Paavola et al., 2004). In connection with the present

dissertation I organized developmental seminars that engaged a whole community of fingerprint examiners in reflecting on and transforming their professional practices, and thereby in implementing practices of organizational learning in present-day institutions of forensic investigation.

2.4 Concluding remarks

Professionals alter their thinking processes to ease their memory burdens and extend their socio-cognitive powers, relying on socially accumulated knowledge structures and mediating instruments that transform difficult cognitive and learning problems. If one wishes to cultivate future expert competence at workplaces one must have an in-depth understanding of the personal and social nature of expertise. Learning and using expert knowledge are intertwined within an object-oriented process of incidental and intentional knowledge building. Learning could be seen in terms of situated dialogue and the socially mediated efforts of expert communities. Collective participation occurs in work practices and networks in different types of developmental and implementation projects: organizations engage in multidisciplinary developmental projects or other reflective boundary-crossing processes that turn them into a learning entity. However, working in an expert community does not guarantee the personal development of a competent, adaptive expert with a high level of cognitive capacity and continuously expanding flexible skills and knowledge: one must consider the trainee's degree and type of engagement, among other things.

It is clear from the above that professional expertise in fingerprint examination is embedded in the institutional practices of forensic organizations based on certain legislation, regulations and rules, as well as on operational guidelines, ISO standards, and associated quality systems. Forensic expertise is exceptional in nature, specifically in terms of acting and making decisions as part of the societal rule of law. This requires high levels of ethics and morality. There needs to be constructive reflection on what constitutes the basis of knowledge and on the significance of attitudes, perceptions, ideas, practices and historically constructed policies. Cultivating expertise requires dynamic and critical reflection on novel knowledge and work practices. Self-directed learning processes play an important role in professional learning. Dynamic efforts to pursue expansive and innovative ways of working, combined with good dialogical skills, foster novel knowledge production and the development of both expert and organizational learning. It is necessary critically to review organizational policies, collective research policies, and approaches and methods of organizational training to

support both personal and organizational learning. It is impossible to cope with digitalization and other global changes in the absence of systematic efforts to bring about organizational transformations that support the development of personal and social expertise.

Methods of fingerprint investigation have to be improved to meet the challenges related to globalization: one sees the emergence of more rigorous standards and collective knowledge creation. Developmental aims toward adaptive expertise and a learning organization require major changes and modifications in social activity. Forensic institutions have a constant need to apply modern educational methods in the training of a new generation of fingerprint experts. Digitalization is providing modern tools with which to meet these requirements (e.g., Laboratory Information Management System). By developing shared concepts, methods, and practices of fingerprint analysis, and having the same fingerprints examined independently by several examiners (to reach concordant judgements), criminal-investigation communities could facilitate critical thinking whereby more rigorous shared investigative norms may emerge. Professionals aiming collectively to share various aspects of expertise need to cultivate skills and competences enabling them to reflect on their professional activity on a meta-cognitive level, relate their own specialized expertise to the broader field of forensic investigation, and engage in critical professional discourse to improve their competences (Collins & Evans, 2002, 2007). If the NBIFL is to succeed in responding to such requirements, it has to be aware of these possibilities and the need to transform individualistic perspectives on professional expertise into a socially mediated, adaptive professional vision and the collegial cultivation of expertise.

In what follows, I will give a more detailed description of the specific context of forensic investigation in which the present doctoral study was conducted. I will start by describing the training of fingerprint examiners, and efforts made to develop a new training system in response to the above-mentioned challenges. I will then go on to describe the process of collecting and analyzing evidence in fingerprint examination.

3 Research setting: The Finnish system of fingerprint examination

This chapter introduces the area of this study and the relevant practices of forensic fingerprint investigation in the NBIFL. In the first section I describe the traditional training of fingerprint examiners as well as the new training program developed at the time I started my dissertation process. The focus in the second section is on the traditional investigation process as well as the new digitally mediated process that constituted the starting point of my studies. This will help the reader to understand the context of the studies reported in the dissertation.

3.1 The training of fingerprint examiners

The cultivation of adaptive personal and collaborative expertise to cope with the challenges arising from the transformation of fingerprint examination and investigation requires improvement in the training of forensic experts such as fingerprint examiners. These experts have traditionally relied on individual and subjective working practices, and it has been quite challenging to make this work more transparent to facilitate quality assessment. The NBIFL (National Bureau of Investigation Forensic Laboratory) identified these challenges and decided proactively to develop its training methods and examination processes.

There are no educational programs in Finland leading to a university degree in forensics: almost all the required training has to be carried out and organized inside the NBIFL. The NBIFL modernized the training program for fingerprint experts in 2009, introducing features such as apprenticeships and a social approach to expertise (see Mustonen & Himberg, 2011). The training was intended to promote transparency and collaboration in terms of encouraging experienced examiners to share their knowledge and skills with novices, flexibly connecting and adapting learning across time and space (Fuller & Unwin, 2011; Guile, 2011; Lave & Wenger, 1991).

The development of the novel training program was one of the outcomes of my developmental actions in the NBIFL when I started the dissertation process. The objective was to train adaptive experts to acquire a high level of conceptual knowledge and advanced metacognitive skills, who would actively seek opportunities to develop

their professional knowledge and understanding, and to solve new, challenging problems. My efforts focused on developing experts who were willing continuously to improve their professional skills, albeit with an awareness of their personal limitations and the associated risks. A further aim of the training program was to support the career-long developmental path of novice examiners.

Fingerprint apprentices have traditionally been trained in organizational in-house mentor-apprentice settings based on seniority and long-standing practical case-work activity. This kind of experience-based training has attracted criticism from the forensic science community. This traditional training was a product of its time, but it does not meet the current requirements for forensic expertise.

The structures and practices of the training of fingerprint examiners are based on the pedagogy of adult education, focusing on high-quality and transparent documentation, and increased efficiency. The mentor-apprentice training has undoubtedly produced good routine examiners, but overcoming challenges related to the changing environment requires more. The training of the competent adaptive expert is expected to equip trainees with a deep conceptual understanding, advanced reflective, self-regulatory and problem-solving capabilities, sophisticated learning skills, a preference for challenges over routine, and a readiness to rely on collective and shared expertise rather than introverted individualism. Experts should also develop advanced interaction skills, appreciate the importance of continuous self-development, and show knowledge-based respect for professional values and ethics. They should be oriented toward actively seeking new knowledge from professional and scientific sources.

As mentioned above, Finland offers no academic degree programs in fingerprint examination. The novel training program in the NBIFL was created to simulate an academic program designed to foster adaptive expertise. It was decided that the new apprentices to be recruited should have a multidisciplinary background, varying scientific training and at least a Bachelor's degree. The program comprises six (6) modules worth 120 European credits and with an estimated duration of 1-2 years. Figure 3 depicts the structure of this new training program.

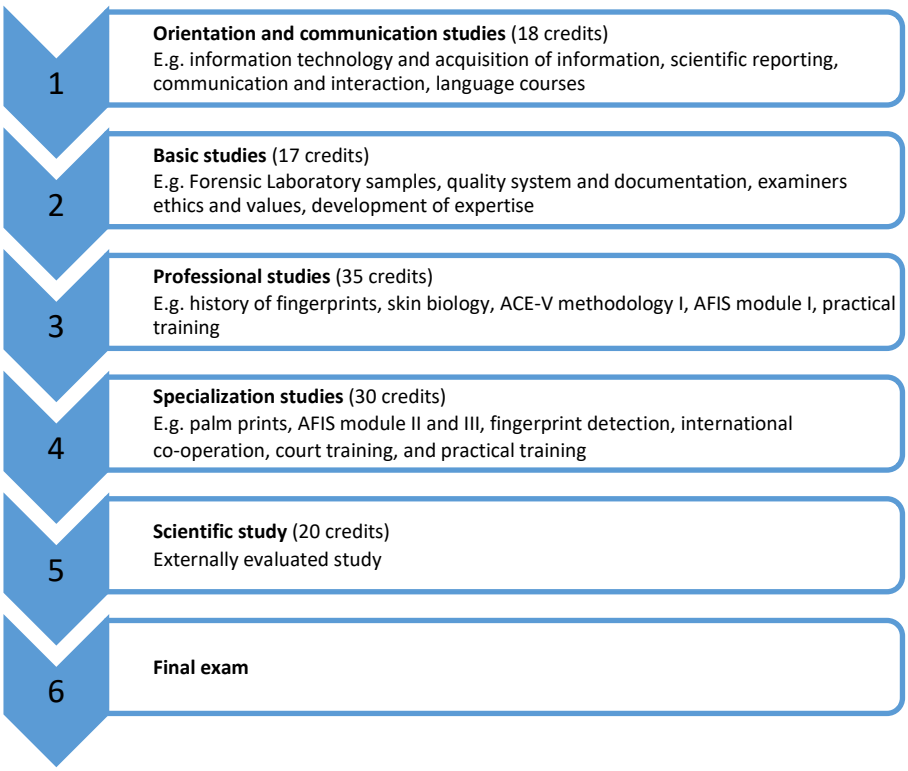


Figure 3. The structure of the program for training fingerprint experts

The training program is flexible in nature. To ensure flexibility in the schedules and a meaningful social structure the modules may be partly overlapping, although at the same time they are organized so as to have apprentices progress from basic to more specialized and integrative studies.

The quality documentation follows carefully described guidelines, and includes descriptions of the scope of the program, the means of implementation, evaluation and competence criteria, a list of required literature as well as a generic description of the study modules in a separate, detailed documentation package. Evaluation, implementation, and competence criteria are systematically structured and described, covering aspects such as roles, responsibilities, feedback, and measures of performance.

Internal and external evaluations are essential parts of the program. The NBIFL will invite academic experts from a local university to give external evaluations of the apprentices' scientific theses. It also organizes evaluation board meetings among laboratory supervisors, quality managers and managers to assess the apprentices' final examination and establish proper, internal certification. During the board meetings, the

supervisor gives a summary of the measurements of the apprentices' performance (portfolio, tests, writing tasks, reflection reports, learning day books) and a written assessment of the training results. Following a vote of acceptance from the board, the apprentice will be certified to work as a qualified fingerprint examiner (see Mustonen and Himberg, 2011 for more detailed information).

The competent fingerprint examiner will operate in the fascinating world of forensics, in a collective network of qualified experts working for different organizations nationally and internationally. Decisions have to be reliable, valid and based on transparent and well-documented high-quality criteria. In the next section I describe the forensic examination process from the crime scene to the court.

3.2 The process of fingerprint examination

Citizens rarely confront criminality. When a crime takes place, according to official police strategy, the Finnish police begin to examine the case seeking to find out what happened and to identify possible suspects. The crime-investigation process usually starts when a civilian contacts the police and reports an offence. The first police patrol and specialized crime-scene investigators collect material evidence such as fingerprints, blood, secretion marks, fibers, paint, glass, gunpowder, and shoe prints, if available. Specialized crime-scene investigators in Finland process this evidence and attach relevant material to an official request for the services of the NBIFL. Nowadays, the police send the case request and relevant case material, including digitalized fingerprints, to the NBIFL's headquarters electronically (or by mail). The request is then forwarded electronically to the examiners. NBIFL examiners analyze and process the evidence, and send a report to the police electronically. Eventually, the police (or the head of the investigation along with the prosecutor) evaluate the evidence and bring it to court to be used in any proceedings. Figure 3 (below) depicts a very simplified model of the whole process of investigation, and describes the role of the NBIFL in the overall forensic investigation process.

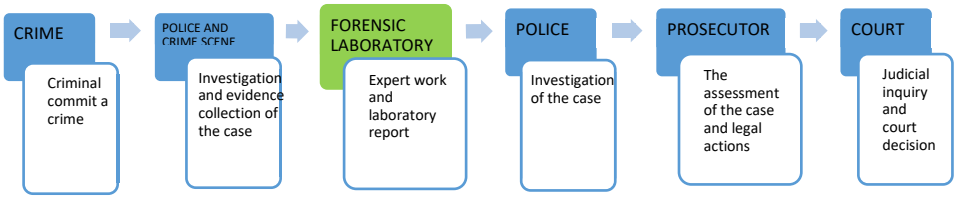


Figure 4. The overall police forensic investigation process.

The processing of fingerprint material has been digitized in the past decade and no longer relies only on paper, ink, photographs, and tapes. Sometimes, although very rarely nowadays, fingerprint requests include concrete physical objects such as tapes and papers. This physical evidence is processed and transformed into a digital format. It is clear that digitalization has had a dramatic influence in crime-scene units. Whereas fingerprint experts previously worked with concrete, physical evidence and instruments (such as a magnifying glass), they now work almost exclusively with digital tools and images: in other words, all the work is done with the assistance of computers and imaging technology. The Automatic Fingerprint Identification System (AFIS) facilitates this electronic transmission of case material.

The traditional fingerprint expert's work was an individual endeavor, each expert taking responsibility for his or her own analysis and identification. The old process was sometimes experienced as quite heavy on individual experts, who had to investigate many fingerprints from a crime scene, personally manage the case procedures, and meet the required quality of documentation (see Figure 5). The process also leaned on tacit knowledge and confirmation bias, the effects of which were hidden behind the daily work load (Hutchins, 1995).

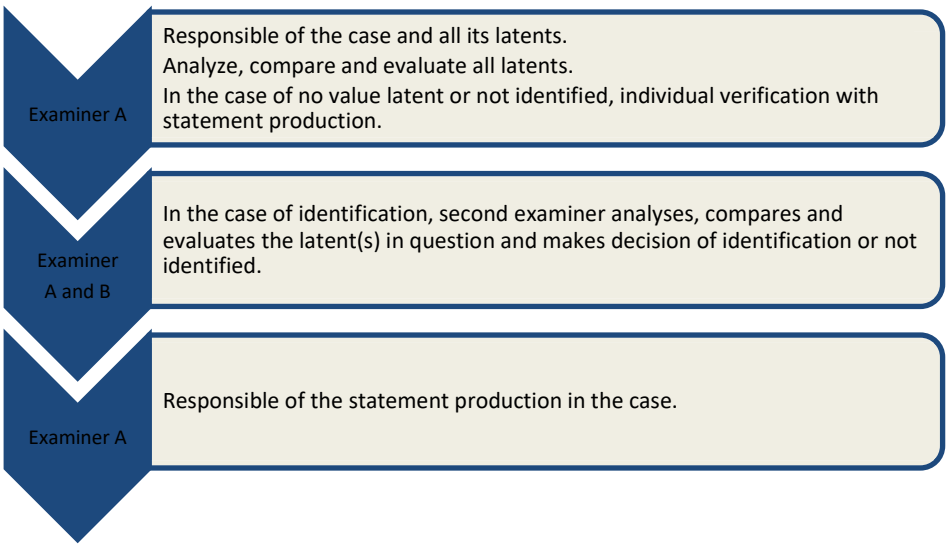


Figure 5. The old fingerprint-examination process.

Other experts became involved if the examiner needed a second opinion, regarding the identification of results or solving complicated fingerprint cases, for instance. In cases of lacking identification the examiner signed the report alone. If a second examiner was called in, he or she checked, accepted or rejected the identifications and no-value decisions of the first examiner as part of his or her own work process and practice. In cases of identification, the reports were signed by two examiners. Moreover the first examiner was able personally to select the second examiner who would give a second opinion and offer consultation. This increased the likelihood of producing non-transparent analyses based on locally developed criteria. What were documented as "facts" tended to be information about the technical actions and decisions made, such as a note to photocopy the identified person's name and the number of the identified finger. Documentation about perceptions, interpretations and the basis of decisions was missing, and identification discrepancies between examiners were not documented in any way. Moreover, the AFIS did not provide sufficient or supportive tools to document the latents, which were investigated but not saved in the unsolved-latent database.

The old process did not always provide sufficient possibilities for doing the required quality work, either, but it did have some strengths. The examiner worked with the same case (one case with many latents) and knowing and remembering the high quality of latent features, he or she usually found it possible efficiently to exclude or identify the high-quality latent from the suspects' fingerprints and to continue working with the case. Remembering the features and patterns did have its challenges and restrictions related to

bias effects, and there were other potentially sensitive issues to do with worrisome, dangerous errors, including simple errors in documentation.

The NBIFL developed many proposals about documentation (organizational reports) during the 2000s, without achieving its ambitious target of making decisions more explicit, unbiased and reasoned. A new kind of fingerprint-examination process was introduced that was intended to fulfill quality requirements (standards). This new procedure has its roots in the ACE-V method of fingerprint examination adopted by the NBIFL in the early 2000s.

The investigative system was altered in 2010 to comply with the new quality requirements (Mustonen & Himberg, 2011). The NBIFL transformed case management and documentation by moving from analogical to digital fingerprint data mediated by a Laboratory Information Management System (LIMS). The aim was to increase the transparency of forensic processes and change fingerprint examination from an individual to a collective work practice. The new investigative work process involved the independent examination and extensive documentation of fingerprints by several examiners, according to a certain division of labor, instead of one individual processing all the latents related to a case. Every fingerprint is examined and documented individually, and the result of the request is processed according to a division of labor. The new process comprises four steps: registration, screening, identification, and statement production (see Figure 6).

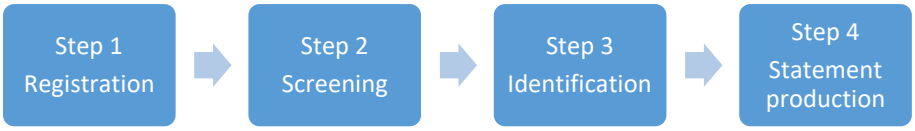


Figure 6. The NBIFL's new phases of fingerprint work.

In the registration phase (step 1) the customer-service worker checks the information entered and stored in LIMS, and a fingerprint expert checks the AFIS information as well as the quality of the fingerprints. If all the samples have the fingerprint quality "no value," the case will go straight to the statement-production stage. If the quality is good enough to warrant further investigation, the fingerprints are delivered to experts for screening.

During the screening phase (step 2) the fingerprint examiner examines one fingerprint at a time, and does a pre-analysis in accordance with the fingerprint-quality instructions and methods. The fingerprint analysis is based on the ACE-V methodological framework. The expert analyzes each fingerprint according to the following characteristics: clarity, deposition pressure, lateral pressure, tolerance and other anatomical aspects (for details, see Ashbaugh 1999). At this stage the expert also decides whether the fingerprint carries enough information to be possibly identified later. The analysis and the decision-making related to the fingerprint are documented in the LIMS system. If the quality turns out to be good enough the fingerprint goes further in the process. Next, the examiner excludes the fingerprints of people who had permission to touch the material, such as the police. After this, the examiner compares the suspect's fingerprints to those in the fingerprint register and carries out the AFIS searches, if possible. Sometimes the examiners do this in reverse order. As the examiner does the work he or she enters all the required documentation for each fingerprint into the LIMS system.

If the examiner's verdict at this stage is "no identification", the fingerprint goes to the statement-production stage. If, on the other hand, the expert finds two identical fingerprints, that of the suspect and a "hit" from the AFIS system, the former is sent for identification (step 3). At this stage, two examiners independently carry out complete analyses of the fingerprint in question, and also do the documentation and make the decision about the case individually, without knowing each other's findings. When both examiners are ready, the decision progresses to statement production (step 4). In most cases, a statement is produced and sent to the police almost immediately with the help of the LIMS system.

If there are discrepancies in two examiners' decisions the case will be reported to both of them as well as to the fingerprint-group quality manager, and a discrepancy meeting will be organized. These three people then compare each other's documentation, discuss the discrepancies in the identification, and make a decision. All this is documented in LIMS. Study B included discrepancy meetings, the aim being to find out how examiners presented and concluded their judgements and decisions.

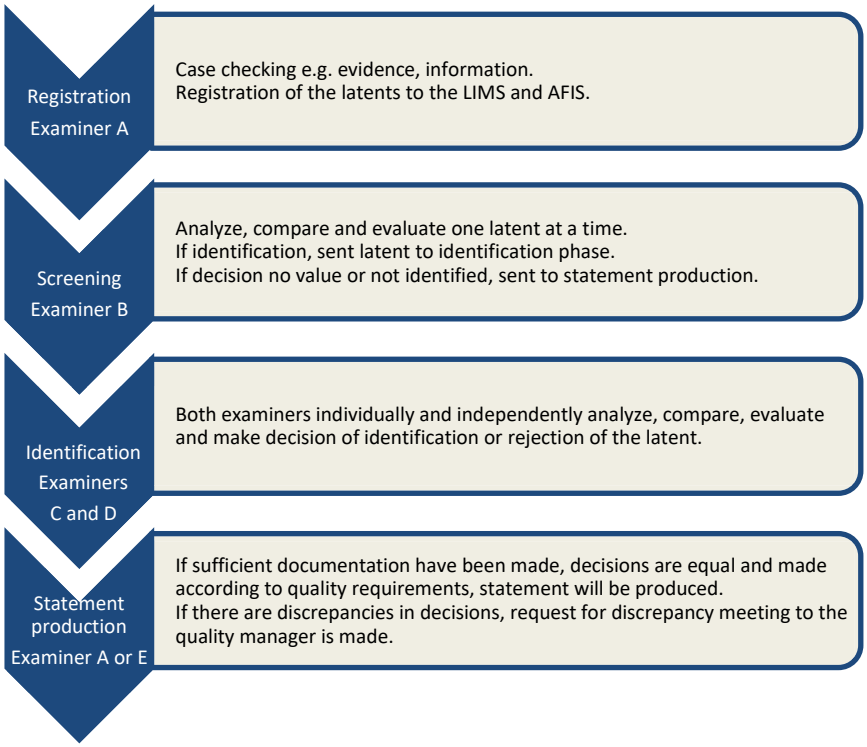


Figure 7. An overall description of the novel examination process.

Inherent in this transformed investigative working process, which was implemented during the present dissertation work, are many opportunities for improving the quality and overall transparency of fingerprint work. The examiners no longer need to rely exclusively on their own tacit knowledge because the new working process is based on a division of labor. Measures taken to overcome subjective bias related to working with one's "own" cases included collectivizing the work process and having different examiners working on different stages. However, these measures do not guarantee the exclusion of unintentional bias influences.

In sum, under the new system, every fingerprint is examined and documented individually, and the result of the request is processed according to a division of labor. The new investigative process was intended to facilitate the production of more transparent, detailed documentation and work descriptions. As well as being based on collective work, this novel process relies on the LIMS system and involves extensive

documentation. As a result, the whole fingerprint-identification process and the separate actions involved are easily traceable afterwards, if necessary.

4 Research questions

The purpose of the present dissertation is to examine personal and collaborative expertise in fingerprint examination based on multiple case studies and using the methods of action research (Lewin, 1946; Noffke & Somekh, 2009). This type of action research with elements of social engineering and management studies facilitates transformation in real social action. Action research is practice-driven in nature, and thus is applicable to the scientific investigation of personal and social transformation in the process of changing the operational methods of fingerprint examination (Lewin, 1946). The present series of studies were carried out in the context of digitalizing fingerprint investigation and the profound transformation of the personal and collaborative processes involved.

The dissertation has theoretical, methodological and practical objectives. The overall objective is to enhance understanding of the major challenges in fingerprint investigation and its quality in the NBIFL context. One of the aims is to elaborate concepts and theoretical perspectives on adaptive, professional expertise, rule construction and organizational learning in fingerprint investigation. A more general aim is to address the personal and organizational challenges involved in developing expertise in fingerprint investigation in the context of digitalized forensic instruments and methods. The research questions were intended to examine: 1) trajectories of developing professional expertise on the personal and social level in the context of the fingerprint training program; 2) judgement and decision-making among experienced fingerprint examiners dealing with conflicting interpretations of complex cases; and 3) the collective transformation of fingerprint-investigation practices in the context of organizational change. These objectives were pursued in three studies that involved working out theoretical conceptions, methodological procedures and specific improvements regarding the practices of fingerprint examination.

In addressing these questions I collected data on the NBIFL fingerprint group focusing on individual, team-level, and organizational activities. The general aim of the study was to examine the processes and practices of forensic fingerprint investigation in terms of the challenges arising from digitalization and the changing quality and transparency requirements. Three separate but interlinked studies were conducted in pursuit of this aim, each of which had a specific research focus. I analyzed the trajectories of apprentices acquiring adaptive professional expertise, examiners' judgements and decision-making, and organizational efforts to develop fingerprinting processes in the midst of major transformation in research technologies.

Table 1 lists the publications consulted, the specific research questions they posed, and their general methodological approaches.

Table 1. The main research questions, the nature of each study and the names of the publications.

Research questions	Methodological approach	Publication
Study A: **How does the new training program socialize newcomers into acquiring adaptive professional expertise in fingerprint investigation?**	Multiple-case study on two apprentices	Mustonen, V. & Hakkarainen, K. (2015). Tracing two apprentices' Trajectories toward Adaptive Professional Expertise in Fingerprint Examination. *Vocations and Learning, 8*:185–211. DOI: 10.1007/s12186-015-9130-7.
Study B: **How do fingerprint examiners make judgements during the fingerprint-identification process?**	Multiple-case study focused on judgment and decision-making	Mustonen, V., Hakkarainen, K., Tuunainen, J. & Pohjola, P. (2015). Discrepancies in expert decision-making in forensic fingerprint examination. *Forensic Science International, 254*, 215–226. DOI: 10.1016/j.forsciint.2015.07.031.
Study C: **How are the challenges related to the digitalization of fingerprint investigation addressed in the developmental seminars organized by fingerprint examiners?**	An intervention aimed at fostering organizational development and learning	Mustonen, V., Tuunainen, J., Pohjola, P. & Hakkarainen, K. (2017). Organizational learning in forensic fingerprint investigation: Solving critical challenges with organizational rule construction. *Learning, Culture and Social Interaction.* DOI: 10.1016/j.lcsi.2017.03.001.

5 Research design

The aim of the research was to improve the quality of forensic services in fingerprint investigation. Toward that end, a series of studies was carried out to make fingerprint processes more transparent and to collectively generate solutions that would assist in meeting present and future challenges.

The focus in this chapter is on the research design and the methods used. The main research strategy was to adopt a case-study approach combined with an action-research perspective. I relied on action research in my efforts to shed light on and enhance understanding of the interrelated individual, collective and organizational activities involved in transforming practices of forensic investigation related to fingerprint examination (Noffke & Somekh, 2009). My research tasks for this dissertation included designing and carrying out interventions that could be considered case studies, which involved training new examiners, organizing a series of discrepancy meetings, and holding developmental seminars. The overall goal was to deepen understanding of the transforming practices of forensic investigation in the age of digitalization. The research strategy was to use the holistic and embedded multiple-case data collection, and to create general explanations that would fit each case and study context (Yin, 2009).

In accordance with the aims of the study I relied on qualitative research with an ethnographic orientation. The data collection focused on the development of professional expertise among the apprentices, the implementation of organizational rules and procedures, and poor-quality, discrepant cases of fingerprint analysis. This chapter describes the research methods in detail.

5.1 Research setting

The present research was carried out in the National Bureau of Investigation's Forensic Laboratory (NBIFL), which operates under Finland's Ministry of the Interior. The National Bureau of Investigation comprises three divisions; criminal investigation, criminal intelligence, and the forensic laboratory. There is also a cyber prevention center, which overlaps in its activity with the three divisions.

In 2017, the NBIFL had approximately 120 experts representing different specializations. Its main mission is to provide a wide variety of forensic services to law-enforcement officials engaged in crime investigation, such as fingerprint analyses, DNA, narcotics, documents, secretion marks, gunpowder, handwriting, fibers, paint, glass, and

chemicals. The Bureau is responsible, overall, for developing the quality of all crime-scene investigation in Finland, and complies with the international standards of forensic laboratories. It is currently engaged in an ongoing process of ensuring the accreditation of all the crime-scene units in Finland, in accordance with the regulations of the European Union.

The NBIFL has a small number (14) of professionally qualified examiners specialized in analyzing fingerprints. The present author, a former fingerprint examiner and forensic scientist, was, at the time of the study, responsible for developing fingerprint-examination practices and quality at the NBIFL.

About 12 examiners working in the Forensic Laboratory's fingerprint group participated in different parts of the study. All of them, except one younger professional and the apprentices, had more than 10 years of experience in fingerprint research. There were approximately as many males as females. Three of the participants had a Master's degree from a university and the others had either a Bachelor's degree or a degree from a vocational college.

5.2 Data collection and analysis

The data were collected in interviews and included recorded, collective discussions among examiners, work descriptions and documentation on actual fingerprint analyses and other work duties. The material comprises documents and physical artefacts, audio recordings of interactive sessions and presentations, records of semi-structured interviews, reflective learning diaries, documentation of professional training, self-assessments, and PowerPoint slides showing digital images of fingerprints, documentation of fingerprint analyses in study reports, and pictures taken from Laboratory Information Management System (LIMS). Automatic Fingerprint Identification System (AFIS) search results with score lists and analyzed digital images were also used as supportive material in the analysis. As explained above, qualitative content analysis was used in each study. Table 2 summarizes the research data.

Table 2. A summary of the research data.

	Study A	Study B	Study C
Methods of data collection	Focused interviews Learning diaries Documentation of fingerprint analyses and training processes	Audio-recordings Documentation of fingerprint analyses	Audio-recordings Documentation of analyzed fingerprints Operational guidelines and quality documents
Participants	2 apprentices and 2 senior fingerprint examiners*	6 discrepancy meetings involving a total of 10 fingerprint examiners	12 fingerprint examiners, supervisors and other community members
Methods of data analysis	Qualitative content analysis of transcribed interviews Qualitative content analysis of reflective textual learning diaries Qualitative analysis of documented fingerprint analyses Qualitative analyses of the documented Practical Training I and II processes CTS and ENFSI tests and results Qualitative analysis of delayed self-assessment (written)	Qualitative content analysis of transcribed conversations during discrepancy meetings Quality reports Qualitative analysis of LIMS and AFIS documentation with quality reports, color-coding and AFIS-screenshots	Qualitative content analysis of transcribed developmental seminar sessions Qualitative content analysis of PowerPoint notes of developmental seminars Qualitative analysis of the pre-task documentation related to the developmental seminars Qualitative analysis of LIMS and AFIS documentation with quality reports, color-coding, and AFIS-screenshots with descriptions of the justifications Quality reports

Note:* Documentation with 2 professional fingerprint supervisors from Practical Training modules.

Study A. Methods of studying: the trajectories of the two apprentices

The focus in Study A was on the development of adaptive expertise in fingerprint examination in two apprentices across a two-year training program. I designed the novel

training program for the fingerprint experts (see Mustonen & Himberg, 2011) and also supervised the application of the training process as a whole.

The analysis focused on the development of adaptive expertise beyond the straightforward adoption and mastery of rigid routines. The study was based on the qualitative analysis of the participants' written and spoken reflections. We traced and identified the principal themes, carefully read the material related to each theme, adjusted and modified the categorization formed on the basis of the data, and used excerpts to illustrate key issues identified in the process under study.

The encoded material included the apprentices' reflections on how the examination practices related to their professional knowledge, the skills and competences required of fingerprint examiners, ideas and reflections concerning how methods of fingerprint examination should be tested, and the various challenges and frustrations encountered. Attention was also paid to the ways in which the apprentices built their personal professional networks within the NBIFL, and how they familiarized themselves with field units working at crime scenes. The categories emerging from the analysis corresponded closely to the instructions given to the participants regarding issues they should address in their learning diaries. Because the diaries were already partially structured according to the corresponding themes, the analysis was rather straightforward, and divergent interpretations were easily identified.

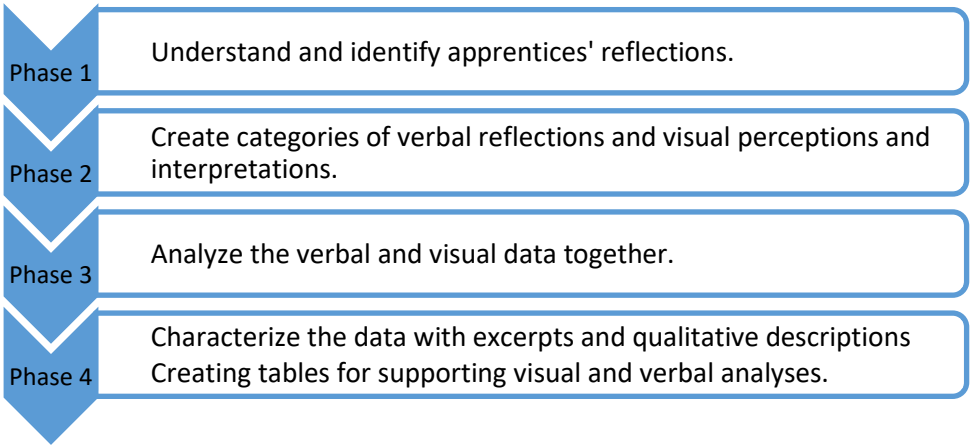


Figure 8. The analysis process in Study A.

The analysis proceeded in four phases (see Figure 8). My aim in the first phase was to

understand and identify the apprentices' reflections, perceptions, and interpretations, which involved reading and analyzing the verbal and visual data. The goal in the second phase was to identify the themes of the apprentices' reflections from the learning diaries. The verbal, written and visual data were categorized according to relevant text segments so as to assess the apprentices' professional development according to Goodwin's (1994) categories of professional vision, complemented with more inductively formed analytical categories. The interviews and self-assessments were semi-structured and covered issues such as self-development criteria, criticality, questioning, and knowledge building. Nine months after completing the training the apprentices were asked to reflect on their professional development and expertise in delayed self-assessments based on semi-structured questions. They were also asked to acquire feedback from experienced fingerprint examiners about their professional development and socialization into the fingerprint community.

In accordance with Goodwin's (1994) framework of professional vision, I analyzed how the apprentices carried out their visual analyses: they coded, highlighted, and produced material representations in the process of examining hundreds of latents in practical training modules. I selected seven samples of fingerprint cases from the Practical Training II data for detailed analysis, including several fingerprints and color codings. These materials facilitated the identification of coded minutiae, pattern types, AFIS finger searches and the relevant material, and AFIS orientation. Figure 9 shows one apprentice's example of a color-coding task.

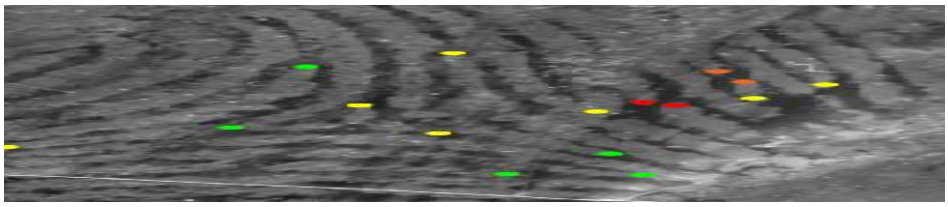


Figure 9. An example of color-coding done by an apprentice (green stands for good-quality minutiae, yellow for mediocre-quality minutiae, red for uncertain or poor-quality minutiae, and orange for minutiae marked during the comparison stage). In compliance with NBI safety policy, the image has been manipulated to preserve anonymity.

The learning diaries and the Practical Training I and II materials were analyzed side by side in the third phase to facilitate examination of the practical outcomes and the apprentices' reflections during the module. Analyses of the fingerprints and the AFIS search strategies from the written and visual materials were cross-compared among all

of the participants (apprentices and experienced examiners). The comparison focused on the development in terms of forming a professional vision (documented coding, highlighted perceptions, and annotated interpretations) of the individual apprentices compared with one another and with their instructors. Selected excerpts taken from verbal and visual data illustrated the analysis in the fourth phase.

In sum, the method used to analyze the data revealed deepening reflections, perceptions, and interpretations among the apprentices. More specifically, it showed how they reflected on their learning processes. The cross-comparisons between the apprentices and the experienced examiners further revealed similarities and differences, perceptions and coding interpretations, and showed evidence of development in the apprentices' professional visual capability and vision.

Study B. Methods of analyzing discrepant judgement and decision-making

The aim of Study B was to analyze the fingerprint examiners' investigative practices in the context of discrepant, challenging latents during fingerprint analysis and identification. I analyzed five discrepancy meetings involving six examiners, some of whom were involved in more than one discrepant case, thereby increasing the number of individual participants in the meetings to ten. The audio-recorded sessions were transcribed word by word and content-analyzed. The parts of the meetings that concerned professional development in general and did not relate to the analysis of fingerprint cases were not transcribed.

The analysis included three main phases (see Figure 10). The transcribed portions of text were read several times during the first phase to give the researchers an understanding of the fingerprint examiners' discussions and to define the categories according to the themes. Some initially considered categories were eliminated from the analysis because of ambiguous content or unsystematic occurrences.

All the researchers involved in the study read the data carefully and iteratively several times during the second phase to deepen understanding of the discussions, and tried out different kinds of pre-coding from the various perspectives. With the help of ATLAS.ti qualitative-data-analysis software we categorized a large number of text segments representing three "families" of more specifically coded fragments: interpreting fingerprint information, manipulating images, and making a decision. Several subcategories were also identified in each group, resulting in eight specific thematic categories. Excerpts and qualitative descriptions supporting the data were added in the third phase.

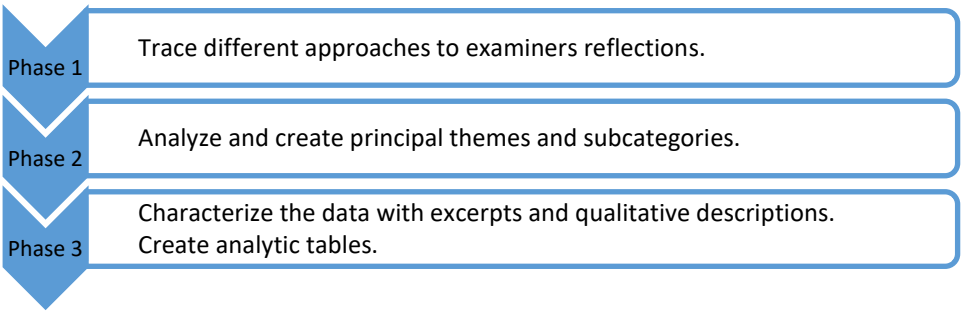
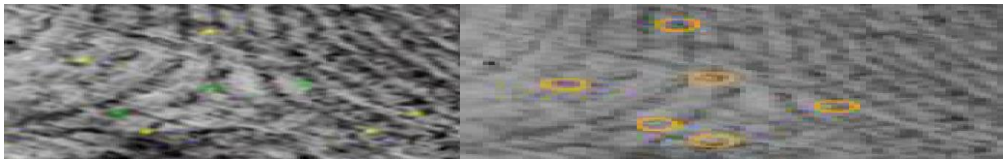


Figure 10. Phases of the analysis process in Study B.

Organizational quality reports and LIMS documentation (e.g., amounts of minutiae or quality definitions) were used to support the interpretations derived from the above-mentioned analysis. The quality reports comprised analyzed fingerprint images with color-coding and AFIS-screenshot documentation, as well as written descriptions of justifications of decisions regarding the identification process. Figure 11 refers to the different discrepancy-case examples included in Study B, and illustrates the work of two examiners who analyzed and documented the same latent, one with the help of Photoshop and other using AFIS markers.



a) b)

Figure 11. Case examples of discrepant latents. Images a and b show the different codings of two examiners. They were also differently manipulated (green stands for good-quality minutiae and yellow for mediocre-quality minutiae; the orange circles are AFIS minutiae markers added during the comparison stage). In compliance with NBI safety policy, the images have been manipulated to preserve anonymity.

The methods allowed a detailed analysis of the fingerprint-examination process, which revealed new aspects in the making of judgements and decisions. For example, examiners supplemented information by adding, picturing or modelling missing details of the latent in line with their own inferences.

Study C. Methods of studying organizational development and rule construction

The purpose of Study C was to find out how the challenges related to the digitalization of fingerprint investigation in Finland were addressed in the developmental seminars held in the NBIFL. My colleagues and I analyzed the data collected from a series of 10 developmental seminars in a fingerprint laboratory during which fingerprint examiners jointly discussed and developed their work processes, analytical methods, decision-making criteria and rules of documentation. A total of 12 examiners specialized in working with fingerprints participated in these seminars, including ten print (registering) and latent fingerprint examiners.

All ten developmental seminars were audio recorded. The sessions that were closely connected with the topic of the research were transcribed word for word, and those that were more remotely related to the analytical themes were transcribed selectively, focusing only on the sections that concerned the analytical themes under study. General discussions on professional development, organizational issues and the treatment of specific documentation (e.g., OSAC guidelines and ENFSI best-practice manuals) were excluded.

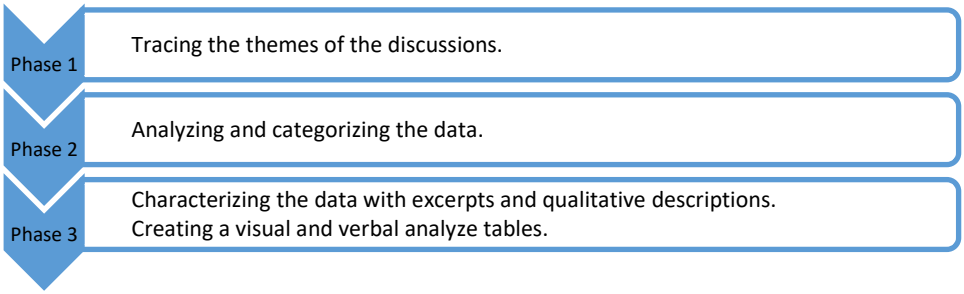
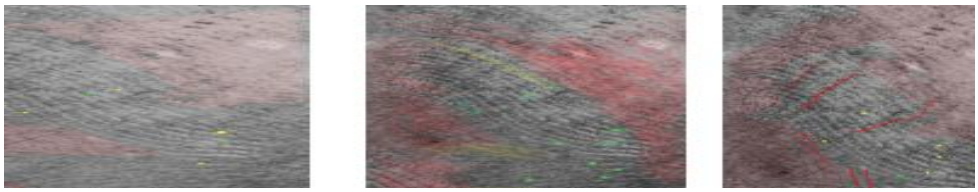


Figure 12. Phases of the analysis process in Study C.

The transcribed data were content-analyzed, supported with ATLAS.ti software, and the main discussion themes were traced (see Figure 12). The detailed reading and coding of the seminar transcripts facilitated the systematic categorization of the data in two closely related analytical "code families": 1) rules and criteria and 2) technical tools and the division of labor among the examiners. Complementary bodies of data (other transcribed discussions, PowerPoint slides, preliminary tasks, LIMS and AFIS documentation, self-assessments) were used to support the analysis. During the workshops, the examiners were engaged in parallel but independent coding of challenging latents (see Figure 13

for an example). Images a, b and c represent diverging highlighting of the same latent by three examiners. The examiners also produced written justifications for their coding.



a) **b)** **c)**

Figure 13. A preliminary task for the examiners to analyze and assess as being of value or of no value. Three examiners produced divergent highlighting of the same latent. (Green stands for good-quality minutiae, yellow for mediocre-quality minutiae, and red for uncertain, poor quality). In compliance with NBI safety policy, the images have been manipulated to preserve anonymity.

The images in Figure 14 represent six examiners' divergent ways of coding the same latent given as a preliminary analytical task during the set of developmental seminars.

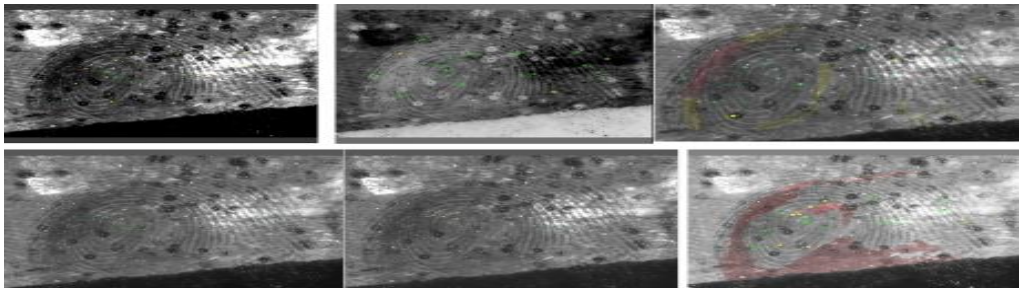


Figure 14. The professionals were given a preliminary task in the developmental seminars and were asked to color-code one (the same latent) with all the information analyzed (green stands for good quality, yellow for mediocre quality, red for uncertain, poor quality). The images represent six examiners' divergent ways of coding the same latent. In compliance with NBI safety policy, the images have been manipulated to preserve anonymity.

The workshop focused on the criteria for coding latents and documenting examinations. The following themes were selected for detailed analysis: criteria for no-value fingerprints, color-coding of latents, practices of using AFIS and LIMS systems, documenting the associated fingerprint-examination process, and the division of labor

between examiners during this process. To ensure the reliability and validity of the analysis, the authors read through all the data several times, determined the main themes, and identified important issues to be addressed in the seminar discussions. All the authors were involved in all aspects of the data analysis.

In sum, the data from the developmental seminars helped to make the justifications and decisions of the fingerprint examiners more transparent, better documented visually, and more clearly verbalized. The examiners collectively constructed the criteria both for no-value fingerprint decisions and for documenting their justifications and decisions. The data reveals that that the examiners' ways of using digital tools become more harmonized during the period under investigation.

5.3 Research method

Multiple methods were used in analyzing the processes and practices of fingerprint investigation and associated personal and collective learning discussed in this dissertation. I relied especially on multiple-case-study and action-research methodologies. Case studies are suitable for empirically investigating complex phenomena in real-life contexts (Yin, 2009). The multiple-case studies undertaken focused on the professional-development trajectories of two apprentices (Study A), and pairs of fingerprint examiners taking part in discrepancy meetings (Study B). Analyzing the content-rich cases appeared to provide in-depth understanding of the participants' professional learning and practices on the personal as well as the social level. Action research was involved in all the studies comprising this dissertation in terms of implementing interventions related to apprenticeship training (Study A), discussing cases of discrepant latents (Study B), and developing organizational rules and regulations (Study C). The action-research approach facilitated analysis of the practical problems of fingerprint investigation, and promoted collective development, assessment and reflection with regard to work practices.

The data in each study were collaboratively subjected to qualitative content analysis (Saldaña, 2012; Krippendorf, 2013), supported with ATLAS.ti 7.0 software designed to foster qualitative data analysis. Qualitative content analysis is well suited to the study of contextual processual learning and activity, facilitating the systematic analysis of heterogeneous bodies of complex, content-rich and meaningful data. The data used in the present dissertation consisted of a) written texts, b) transcribed interaction episodes and c) visual coding, highlighting, and written annotations made during fingerprint

investigations. The chosen method was deemed adequate for the purpose because it is well suited to analyzing relevant units of language-based or visual data from texts, images, voices and other observables from different analytical perspectives. The unit of analysis could be episodes, encounters, roles, groups, or social organizations, for instance (Saldaña, 2012). The analyst is well advised to reduce the sampling to a manageable and conceptually representative set of units. Text can be read and analyzed on several levels, including words, sentences, and paragraphs, or as concepts, frameworks, issues or genders, and so on. Qualitative research demands deep reflection on the emergent patterns and meanings of human experience and conduct (Saldaña, 2012), and analyses should focus on similarities, differences, frequencies, sequences and correspondences in the coded data (Saldaña, 2012). This kind of analytical approach is necessary to create a durable and analyzable record of otherwise transient phenomena. If the results are to be comprehensible to other scholars it is necessary to explain the interpretative steps taken during the analysis so as to formulate answers to the research questions (Saldaña, 2012).

Interpretations emerged in the present dissertation through successive steps of reading the data and categorizing its specific contents, supported by my forensic expertise as well as concepts and theories adopted from research literature. The analyses relied on a close reading of the texts and other data. The transcribed audio-recorded discussions were read several times, simultaneously with the coding of the main themes and the defining of recurring issues that would enhance understanding and facilitate explanation of the fingerprint examiners' activities. There is also a risk of biased interpretation because the analyst's own experience and understanding may affect the findings (Krippendorf, 2013). To avoid structural redundancy and prevent "noise" and the favoring of one outcome over another, the qualitative analyses were carried out collectively among the co-authors and supervisors in numerous iterative cycles. My long experience in forensics and our joint insights into the theoretical literature and the data analyses were thus integrated so that we could answer the questions posed in this dissertation. In the following chapter I explain in more detail the setting of each study, and the data collection and analysis.

6 The main findings of the research

In the following sections I summarize the main findings reported in the three published articles. The original articles provide a more detailed account of the research results.

6.1 Study A: Tracing two apprentices' trajectories toward adaptive professional expertise in fingerprint examination

The purpose of Study A was to develop a new training program for fingerprint investigation and to examine two trainees' trajectories in developing their adaptive expertise. Renewal of the examination system required a transformation of the traditional procedure based on sustained practical workplace learning. As part of the NBIFL developmental action, I modernized the training program for fingerprint experts in 2009, introducing features such as apprenticeship-type learning, intensive reflection in as well as on action, and the social development of expertise (see Mustonen & Himberg, 2011). The program was designed to provide theoretical knowledge and ample opportunities for collectively shared learning so as to minimize subjective influences and locally generated practices that characterized the previous mentor-novice type of training. Although cultivated individual skills are critical, they are not enough, and need to be embedded in well-articulated shared frameworks and practices complying with national and international quality standards. The main findings of Study A were as follows:

First, the analysis revealed that the apprentices developed strong visual, practical and conceptual capabilities of fingerprint examination. In the case of good-quality latents, the coherence of their coding improved and there was less variation between apprentices and experienced examiners in coding minutiae. They also developed adequate skills in color coding and AFIS search strategies. The coding of poor-quality latents varied between all examiners, from apprentices to the fully experienced. The author of this thesis continuously and carefully analyzed and compared all aspects of the apprentices' documentation.

Second, the strategy was to engage apprentices in the collective efforts of the fingerprint group and to socialize them to take in valuable tacit knowledge and avoid adopting maladaptive personal practices as much as possible. Continuous evaluation and feedback were given as an important part of social-reflective dialogical participation in the community. They adopted the new social role of competent examiner and became competent members of the fingerprint community by gradually assuming responsibility

for maintaining more demanding quality standards and engaging in developmental actions. The feedback from the experienced examiners confirmed the successful socialization of the new trainees. However, the data also revealed that one of the apprentices was also learning "bad habits" from experienced examiners, being reluctant to document investigations after reaching a conclusion.

Third, the apprentices showed evidence of critical and constructive reflection and active assessment related to their performance and skills. However, they differed in how they reflected on their professional performance. One of them reflected very openly on her professional development, whereas the other was more withdrawn in this regard. The latter was, at the same time, a very skilled examiner. There was not a straightforward relation between their self-reflections and the levels of performance reached at the end of the training: their long-term trajectories of professional development cannot yet be known.

Fourth, the training also fostered the building of an extended professional network. The program consisted of study modules with different NBIFL investigators, field training in crime-scene units, participation in developmental seminars and the collection of data from the network of forensic laboratories in Europe.

Fifth, the apprentices' competences were assessed in independent ENFSI fingerprint tests, and CTS confirmed their advancement. The term 'professional vision' appeared straightforwardly to fit with and characterize the visual competences relevant to fingerprint examination, including coding, highlighting, producing, and articulating associated material representations (e.g., documentation). The apprentices learned to use professional tools for representing, searching for, and comparing fingerprints, and also for producing associated material artefacts.

In sum, the apprentices' progress toward becoming personal, adaptive and competent fingerprint examiners was monitored with the help of a variety of data including self-reflection, exercises, continuous assessment and feedback. Overall, the results characterized them as interested, motivated, and capable of learning and becoming more deeply involved in the expansive activities of the fingerprint community. This appeared to allow the newcomers to adapt and also to critically view the knowledge and practices shared with them. At the same time, experienced examiners and apprentices were able to share their knowledge with one another. Such collective training practices appeared to make questioning and reflection easier in challenging professional situations.

6.2 Study B: Discrepancies in expert decision-making in forensic fingerprint examination

The purpose of Study B was to analyze fingerprint examiners' investigative practices in the context of conflicting decisions. The aim was to see how a pair of examiners who analyzed the same latent and ended up with diverging interpretations had originally identified the fingerprint details, categorized the latent, and made the judgements and decisions during the fingerprint-identification process. The examiners were asked to provide written and annotated documentation supporting the analysis of their decisions. The discrepancy meetings focused on each examiner's articulation of what was to be seen in the latent and what features each of them had considered relevant to the analysis. The data made it possible to observe, understand and study how examiners constructed their decisions in discrepant cases of fingerprint examination.

In the past, decisions in discrepancy situations (diverging decisions reached by two different examiners regarding identification, or no identification) complied with the official organizational guidelines made according to conclusion of no identification. Such an approach encouraged examiners to rely on their subjective and personal approaches when dealing with difficult cases. There was no documentation on interpretations and no reflection on the reasons for the disagreements: the basis of the decision-making remained opaque.

Study B focused on discrepant decisions about problematic latents selected from a larger number of analyzed fingerprints. The examiners processed the fingerprint images in various ways to enhance them and make the minutiae easier to identify. They used partial and limited information, making judgements while they coded the images using the GYRO (see Langenburg & Champod, 2011) procedure so as to distinguish between the poor and good areas of the latent, and to highlight selected minutiae and details. Their different ways of manipulating the images appeared to affect their later interpretations and decisions to some degree, and this process was neither transparent nor documented. Although processing facilitated the analysis of the latent, the fingerprint examiners faced various practical obstacles in their daily work related to digital image processing, and tended to be reluctant to document their decisions.

The examiners used professional tools and practices to interpret fingerprint information, manipulate images, and guide their decision-making. They differed in how they technically manipulated images according to their personal criteria and ways of using symbolic communication tools such as color coding. They also focused on different aspects of the latents, and consequently ended up with different and incongruent

interpretations. The results thus reveal the examiners' varying ways of analyzing and categorizing the data, shaping outlines, identifying traces and noise, as well as supplementing information. Such practices represented their constructive work of "modelling" fingerprints and making personal inferences. It appears from the data that they mentally imagined the significant details and filled in missing parts of the latent images that were typically blurred, distorted or messy. This imagining turned out to have minor value in the final decision-making, but it raised serious concerns about bias in the examiners' work. One consequence of the results of Study B was the decision to revise the NBIFL's standard operating procedures and further develop practices of documenting decisions.

6.3 Study C: Organizational learning in forensic fingerprint investigation - constructing community rules to overcome critical challenges

The main purpose of Study C was to examine various aspects of organizational learning involved in constructing collective rules of fingerprint examination aimed at enhancing the quality of investigations in the NBIFL. As a part of the developmental actions, I organized a series of seminars aimed at engaging the whole fingerprint community in reflecting on the development of joint principles of investigation practice.

The digitalization of the fingerprint-examination process under the new Laboratory Information Management System (LIMS) facilitated more effective and rigorous quality work. To that end, the processes, documentation, and application of rules and criteria within the fingerprint community were refined. The digitalized process made it possible for examiners to go beyond the former, often vague, methodological criteria and further develop rules of practice.

Study C focused on the above-mentioned developmental seminars, which took place in a situation in which the digitalization of forensic investigation had induced a major transformation in the tools and instruments used. The seminars provided a context and framework for facilitating expansive and organizational learning in fingerprint investigation. Intervention data provided empirical evidence of the formation of such reflective ways of working.

During the seminars, the fingerprint examiners jointly discussed and developed their analytical methods, decision-making criteria, rules of documentation, and work processes. The results revealed the complex ways in which they shared their practical professional knowledge and collectively developed decision-making criteria and rules

of practice. New rules and practices were needed to adapt to and comply with the changing quality requirements and evolving international standards.

In sum, the developmental seminars facilitated the elaboration of shared strategies and norms of working with the evolving set of digital instruments. Challenges arising from the encountered tensions related to the digitalized investigative practices were jointly resolved. As a result of the seminars, the fingerprint examiners constructed tentative criteria for no-value fingerprints, but were not open to new possible decision-making scales. They also constructed criteria for the levels of color-coding to be used during the examination process, and to be documented when reporting examinations. They worked out operational procedures for using color-coding to indicate the clarity and quality of the fingerprint. In cases of poor- and mediocre-quality fingerprints it was decided to document the minutiae with the help of Photoshop. In the case of high-quality fingerprints, it was decided that AFIS screenshots would facilitate the documentation. Visual documentation was not necessary in cases of no-value latents, which only required justification of the decision. The criteria and procedures for the discrepancy meetings were collectively constructed during the seminars, and the resulting feedback and ideas were utilized. The preliminary tasks given to different groups of examiners were used in the process of working out digitalized examination practices and procedures. The examiners identified best practices of working with AFIS, in search strategies, for instance, developed practices for using LIMS, elaborated documentation practices, and articulated further aims of developmental quality work. One of the main aims achieved through the seminars was to continue developing the LIMS process.

As a result of the developmental seminars the fingerprint examiners collectively succeeded in their efforts to verbalize and construct their perceptions and interpretations toward defined, joint understandings of the criteria of no-value fingerprints, criteria for color-coding, and procedures for dealing with discrepant judgments and decisions. The NBIFL also found the discussions useful: it decided to include some of the new rules in its operational guidelines and quality requirements, and devised new instructions governing professional activities in the laboratory.

The results show how experienced, senior examiners actively reflected on and verbalized their activities and their justification with the apprentices at the seminars. This supported the developmental orientation of the community and the verbalization of various aspects of fingerprint investigation. The findings also revealed the complex ways in which fingerprint examiners share their practical professional knowledge, and collectively draw up decision-making criteria and rules of practice. New rules and practices were suggested to ease their adaptation to changing quality requirements, evolving international standards, and the challenges of digitalization and documentation.

6.4 A summary of the findings

This dissertation focuses on a variety of issues: aspects of adaptive expertise, challenges related to decision-making, organizational learning in various investigative processes, shared rule construction, as well as individual and collective knowledge creation and decision-making in the NBIFL. The main findings are summarized below.

First, there is evidence of a radical transformation in the instrumental practices and social organization of fingerprint investigation, which the forensic community went through during the course of the study. The challenges related to personal competences and collaborative working practices were too complex to be resolved immediately, therefore I had to carry out a series of studies, collect multi-faceted data, and engage the whole examination community in finding ways of enhancing processes and operational methods. Conducting action research in a forensic context requires social creativity, collective reflection, and joint deliberation so as to generate novel ideas for improving professional practices.

Second, a professional vision emerged as a very important analytical concept that structured and made visible the interpretations and justifications of the fingerprint-examination process. Although the studies were qualitative and interpretative in nature, all of them relied on the in-depth analysis of numerous fingerprints either individually or jointly. I traced the examiners' coding practices, highlighting and annotating the latents being analyzed and using the resulting information to constrain interpretation.

Third, the articles included in the dissertation revealed hidden problems and limitations of prevailing examination practices, such as opaque local practices that became increasingly transparent through digitally mediated activity. Durable digital representations and processes made many tacit aspects of forensic investigation visible and subject to collective reflection and transformation. Fingerprints are content-rich entities. Variation between examiners in operational procedures is not likely to lead to erroneous conclusions in the case of high-quality latents. With regard to the more difficult latents, however, the reluctance of experienced examiners to document their examination processes reduced the likelihood of identifying weaknesses and learning from other examiners' experiences.

Fourth, the results confirm the importance of renewing the training of fingerprint investigators, and especially of cultivating adaptive experts capable of reflecting on their activity and with a sophisticated professional vision. I reported the results of developing such a training program in Study A, and described the trajectories of two apprentices. The training program appeared to be successful in terms of engaging apprentices in

intensive reflection in and on activity, actively seeking learning opportunities, and building extended professional networks. A large number of training tasks as well as standardized fingerprint-examination tests revealed that the apprentices acquired a sophisticated professional vision. It was critical to involve experienced examiners in the training of the apprentices so as to support the sharing of their knowledge with newcomers. Many of them had not trained apprentices before so they had to challenge themselves. The knowledge-sharing process was also a learning curve for the experienced professionals. Professionals have to share their historical and social knowledge, and frameworks and perspectives that sustained their engagement in the activity in a meaningful way. The newcomers not only learned new skills, however, but also appeared to adopt some maladaptive habits, such as the reluctance to document judgments and decisions. Another challenge was that experienced examiners, who acquired their professional skills when engaged in their daily practices several years after their apprentice-mentor training, demonstrated the variation in professional vision. In spite of these limitations, however, the novel training program with its structured and transparent, collective way of working enabled the effective socialization of newcomers into the community. In fact, NBIFL has hired one new apprentice and this training program has been updated. The basic structure remains the same, but some developmental revisions between and within the modules have been carried out. This update was implemented by the apprentices who were trained in the program reported in this study.

Fifth, the results revealed how the digital work process collectivized the fingerprint-investigation procedure in terms of distributing analyses among several independent examiners. The analysis of the discrepancy meetings conducted in Study B revealed the reasons behind the fingerprint examiners' divergent interpretations and decisions, and how they justified them. It seems from the findings that they often relied on partial or incomplete information – in accordance with Goodwin's professional-vision framework - when making judgements about difficult and distorted latents. Sometimes they even mentally "repaired" low-quality, poor latents by supplementing the missing information. Although their constructive inferences did not appear significantly to distort the final decisions, one should be aware of the subjective-bias risks involved. One implication arising from this dissertation study is that overly vague or limited organizational and international guidelines, as well as a lack of knowledge about different kinds of bias effects, may lead to personal characterizations and interpretations of poor-quality latent decisions and conclusions. It is therefore necessary to develop operational procedures though which to work out transparent, repeatable and accurate ways of analyzing challenging fingerprint cases, justifying decisions, and documenting examination

processes. It is essential not only to improve pre-service training but also to provide more effective professional-development opportunities. International studies such as Dror (2017), and the suggestions of ENFSI provide a variety of tools for resolving these kinds of challenges (see enfsi.eu). Further studies on the interpretative work of examiners are warranted.

Sixth, Study C reported action research that involved engaging the fingerprint community in collectively addressing the challenges through joint discussions and reflections on professional practices and quality improvements. I organized communal activities for forensic investigators to enhance their understanding of the new challenges and to find productive ways of improving quality when using new technology-mediated tools and instruments. The results revealed how the community elaborated shared criteria and rules of fingerprint examination, and agreed about joint practices in their work with digital instruments and environments. Discussions among fingerprint examiners produced rich data that facilitated deeper investigation into the basis of the decision-making and the overtones, and identified the challenges inherent in the processes, methodologies, rules and overall guidelines of fingerprint analysis. The seminar discussions resulted in the renewal of workflow processes and operational practices involving the use of technical instruments and tools.

It is quite rare in a normative culture for traditional top-down managerial methods to foster reflective and transformative processes. A major motive for promoting reflectivity in an organizational context is to create a supportive setting in which people share experiences, build capacity and agentic involvement, and jointly overcome challenges and contradictions (Schulz, Kajamaa & Kerosuo, 2015). The NBIFL decided to use the results of the present study in the further development of examination practices, and to include some of the rules devised during the seminar in its new operational guidelines. The results emphasize the importance of common training and the need to devise unified analytical practices that comply with transparency and reliability requirements, and to exploit decision-making opportunities. Digitalization offers no new solutions in forensics without high-quality multi-dimensional research. The developmental seminars revealed the need for shared strategies and norms when working with digital instruments.

7 General discussion

The purpose of this investigation was to provide an in-depth understanding of the personal and collaborative expertise of professionals specialized in fingerprint examination, and to facilitate interventions with them that would support the organizational transformation of practices of learning and working in forensics. Fingerprint examination is a domain that has been radically transformed through digitalization and the introduction of international standards and quality requirements. The present dissertation addresses the various ways in which this transformation affected the practices of individuals in the field of fingerprint examination in Finland. Its main scientific contributions are as follows: 1) Working out methods suitable for the training of adaptive and collaborative experts in fingerprint investigation; 2) Developing and testing an organizational approach to dealing with serious problems in practice, specifically with regard to conflicting interpretations of fingerprints and arriving at justifiable decisions based on mutual negotiation; and 3) Developing and testing an approach to organizational learning designed for the fingerprint-investigation community and based on a series of developmental seminars. The intervention efforts reflected multiple aspects of the vision presented in European Forensic Science 2020, as well as recommendations of NAS (2009) such as developing novel training and educational models, enhancing examination and evaluation processes, improving methodological procedures, and justifying decisions. The discussion in this final chapter covers the theoretical, methodological, and practical implications of the research.

7.1 Theoretical implications

The present dissertation examines expertise in the institutional practice of fingerprint investigation from a sociocultural perspective and as a socially distributed process mediated by shared tools and practices among expert communities and networks.

The notion of a *professional vision* (Goodwin, 1992) offers a quality perspective enabling experts to explain how they interpret significant events from their investigative material, and provides a communicative vehicle in a court of law. As a concept, it has emerged as a major explanatory factor that is perfectly suited to the context of fingerprint

investigation and allows the expert to explain his or her interpretations and visionary practices. Fingerprint investigators need to have sophisticated visual capabilities developed through sustained training (Billett, 2006). Referring to a professional vision helps them to conceptualize socially mediated ways of coding, highlighting, and annotating fingerprints. In a very concrete sense, visual analysis was not a passive flow of information from external images to the minds of examiners: the data revealed the examiners' constructive efforts in supplementing (repairing, modelling missing details) and manipulating images. The present dissertation confirms the value of Goodwin's (1994) conception of a professional vision in enhancing understanding of and explaining expertise in visualization-rich domains such as fingerprint investigation. Having a professional vision requires personally cultivated visual competences that are mediated by shared instruments and practices, revealing the interdependence between individual and social aspects of expertise (Billett, 2006). As far as I know, the important role of a professional vision in understanding expertise in fingerprint investigation has not been acknowledged in earlier studies: it appears to be suited to several areas of forensic investigation, including tool marks, shoe prints, and handwriting, for example.

Fingerprint investigation is a complex problem-solving activity, a competence that, to a great extent, is based on sustained personal training and experience. Fingerprints are information-rich, and contextual factors affect many aspects of their analysis. Because the analytic practices rely on visual competences, many aspects of associated expertise are not well articulated or expressed in words and guidelines. Although forensic science is considered trustworthy, many of the enacted practices are based on *implicit, tacit, and local knowledge* accumulated through extensive experience and are, therefore, somewhat "encrypted" in nature. These practices may resist insights into component processing. Many studies have addressed the vulnerability and subjectivity of fingerprint examiners' work in terms of expert judgement, decision-making, cognitive bias, and methods of fingerprint comparison. The limitations of experience-based approaches became evident in the transformation to digitally mediated investigation practices that make divergent interpretations and heterogeneous justifications more transparent and explicit. Both research and experience indicate that an individual examiner's personal skills and competences play a crucial role in the reaching of reliable and valid conclusions. Keeping up and improving professional competence requires strong community support, however, so as to make transparent, reflect on, and improve investigative practices.

The present dissertation also demonstrates the importance of collective practices that foster *adaptive expertise* in both novices and experienced professionals. My own orientation toward adaptive expertise changed during the dissertation process. At first, I saw it as an individual problem-solving capacity, and later began to understand the importance of shared practices of reflecting and conceptualizing professional activity, identifying and overcoming challenges, and directing efforts to improving and transforming joint practices. It involves second-order activity (Engeström, 1987), eliciting proactive adaptation to the transformative requirements of fingerprint work. Adaptive expertise, therefore, is not only a matter of personal professional competence but also, and to a significant degree, represents collectively shared practices and methods among expert cultures and networks (Bereiter & Scardamalia 1993; Hakkarainen et al. 2004). In an effort to elicit adaptive expertise I engaged the apprentices in the textual practices of building and comparing their learning diaries and discussing critical issues of fingerprint examination with senior examiners and the supervisor (Mustonen & Hakkarainen, 2015). Beyond the fast cycles of pattern recognition and case interpretation, the apprentices were invited to participate in deliberated analyses of their professional activity to foster the building of professional knowledge (Eraut, 2010). It is assumed that such social practices are helpful in adaptively explicating and re-mediating evolving professional competences. It appears to me that the apprentices in question did indeed appropriate practices of adaptive expertise in terms of cultivating their epistemic agency (Billett 2011), in other words their interest in, motivation for, and capability of learning and deepening participation in the expansive activities of the fingerprint community. Earlier theories of expertise tend to be individualistic in nature, but recent scientific discourse has emphasized its *socially distributed nature* (Hakkarainen et al., 2004; Engeström, 1992; Edwards, 2010). At the same time, however, individually mastered competences also matter because professionals cannot productively participate in expert communities and networks without having sophisticated actionable knowledge, contextual understanding, and operational competences of their own (Edwards, 2010). Expertise develops in stages, from following given rules and instructions as a novice with limited knowledge to becoming increasingly flexible, situationally sensitive, goal-directed and skilled in strategic planning. Professional development also involves negotiation between collective norms and practices, and personal, evolving subjectivities and identities (Billett, 2011). As a result of these efforts, adaptive expertise came to be seen as a socio-epistemic practice that shaped the apprentices' learning and practices in

mutual engagement with senior examiners.

This dissertation has also brought to light the importance of rules governing the repeated-examination activities involved in fingerprint investigation. The developmental processes that were facilitated involved moving from implicit and local regulations toward more explicit and collectively elaborated, organizational rules. These rules cannot be straightforwardly or mechanically applied, however, because of the ethno-methodological nature of the forensic material (the complexity of fingerprints, clarity challenges, and variation in latent print development methods, for example), and the context has to be considered. Collective reflection and common guidelines are necessary, too, because any rule can be followed in multiple ways in practice (Wittgenstein, 1953). I have reported on the combined efforts of the current fingerprint-examination community to work out joint operational rules related to using instruments, assessing fingerprint quality, and making decisions. Moving from traditional subjective and non-reflective examination procedures to more transparent, socially constructed practices (guided by more explicit and jointly agreed rules) requires major collective efforts.

The present study was also inspired by *Engeström's expansive learning approach* (2001, 2009), which facilitates the analysis and conceptualization of organizational-transformation processes and means of action. I did not systematically apply this framework in my study, but certain aspects of it are reflected in my intervention efforts. I used activity theory to promote reflection on the old and the new processes of forensic investigation, and followed the ongoing changes in tools, rules, subjects, communities and the division of labor, and the mediating objects of professional work. The process involved many mini-cycles of organizational development that were reminiscent of activity theory but also shared some characteristics of action research. I organized a series of intervention-based developmental seminars in which tensions and challenges related to past, current and future work were reflected on. The activity-theoretical focus on tension, ruptures and breakdown motivated me to organize discrepancy (or initially "contradiction" meetings) among experienced professionals. Examiners modelled, tested, and concretized their perceptions and processes in accordance with verbalized new rules and criteria, and implemented new models in their activities. Overall, the results confirm the relevance of an activity-theoretical focus in studies focusing on the role of tools, practices, and tension in organizational transformation.

I have also shown how the methods of fingerprint investigation were profoundly transformed through digitalization, which made the processes transparent and durable,

and thereby subject to collective reflection and deliberate improvement. The transformation was related to intensify international efforts to standardize expert work, increase accountability and improve quality. Novel *epistemic professional cultures* are needed to adapt to such challenges, as Nerland (2012) points out (see Knorr Cetina & Reichmann, 2015; Edwards, 2012; Mørk, Aanestad, Haseth, & Grisot, 2008). This dissertation reports my efforts to implement associated interventions at NBIFL through developing a new training system and engaging the workplace community in developmental seminars. The new training program engaged newcomers in intensive reflection, as well as in active participation in developing novel investigative methods in interaction with national and international expert networks. The developmental seminar encouraged the fingerprint-investigation community deliberately to reflect on, make visible and transform its professional practices in line with internationally shared instruments, guidelines, and standards. In sum, the present dissertation attests to the importance of investigating socio-epistemic practices of professional communities, and gives an empirical account of an epistemic professional community in action in the field of fingerprint investigation.

7.2 Methodological reflections

The purpose of the present dissertation was to analyze the personal, collective, and organizational aspects of expertise and learning related to fingerprint investigation in the context of digital transformation. The dissertation comprises three studies: Study A follows two apprentices in the process of becoming professionals (within-person development); Study B concerns discrepancies between examiners who make conflicting decisions (inter-personal level); and Study C focuses on the developmental seminars (community-level).

The three studies complement one another and in combination give a comprehensive view of the transforming processes and practices of fingerprint investigation in the context of digitalization. Learning, which is a socially negotiated process embedded in inter-related personal and social practices and structures (Billet, 2006), should be examined on the individual and the collective level in the context of organizational change.

Organizational learning is a complex subject of study. It is history-dependent and mediated by transforming socio-technical instruments and practices. A multi-level

approach that integrates theoretical and practical knowledge is needed to promote socio-technical organizational change. It is necessary to study the organizational and situational conditions to identify potential boundaries in terms of learning. Negative boundaries are encountered when collaboration and learning through experimentation are blocked because errors cannot be openly discussed. An effective learning organization encourages and facilitates learning by structuring its policy and processes of strategy formation, evaluation, implementation and improvement. Such processes allow professionals to realize their potential to create a better future through more effective, dynamic and expansive learning (Argyris & Schön, 1996; Senge, 1990; Daft & Weick, 1984).

An organization that is willing to look horizontally beyond its own boundaries by means of scanning (data collection), interpreting (data and international guidelines), and learning (actions taken) is more likely to build open relationships and to foster learning across individual, collective, and organizational levels (Daft & Weick, 1984). Collaboration and open interaction are essential for achieving such aims, and also support the development of a professional learning culture. A collaborative community produces more valid information than non-cooperating individuals: it supports the making of informed choices and the assumption of collective responsibility for monitoring success in their implementation. Personnel with valid information are effective: they actively and flexibly pursue challenges and organizational change, which is possible in an open culture (Argyris, 1990).

This dissertation is based on *multi-level data* concerning individual knowledge and competence, peer interaction, and collective reflection. Multiple studies relied on complementary methods for triangulating the complex processes of fingerprint investigation. A crucial aspect of the data interpretation was the analysis of tens of fingerprints individually, in pairs, or as a community: this validated many of the assessments and conclusions presented in this dissertation. For confidentiality reasons, this core aspect of the analyses could not be fully reported in the published articles. Most of the data was qualitative, in accordance with the complex nature of the examination processes under investigation. It includes apprentices' written reflections, interviews, novices' and experts' annotations of fingerprints, protocols of discrepancy meetings, and documentation on relevant parts of the developmental seminars.

Intervention methods were used extensively in this investigation, namely in implementing a new training program and assessing its effectiveness, engaging experienced professionals in the new practice of having discrepancy meetings, and involving the whole community of fingerprint examiners in collectively reflecting on and improving their practices. The present dissertation is exploratory, in accordance with the complex, multi-level, and systemic nature of fingerprint investigation. The study could be characterized as action research in terms of reflecting on prevailing practices, designing improvements, and making changes accordingly (Lewin, 1946). The development of fingerprint examination is nevertheless a long-standing and continuous process, of which the present research covers only a small part. One limitation is the lack of data on some of the effects of the interventions, such as how the new rules and operational procedures were put into in practice later on.

The *reliability* of this dissertation study lies in the use of multiple, complementary sources of data that reduced the impact of the limitations. These sources included interview talk, discourse interaction, documentation of learning and investigative processes, as well as the actual fingerprints that were being analyzed. The large amount of data required for each study was screened carefully and selected for further analysis according to its relevance: in many cases it would have been practically impossible to analyze everything.

The analysis and interpretation of the data involved an extended research community, comprising me and three supervisors, representing heterogeneous areas of expertise. Decisions regarding what to include and what to exclude were reached in collaboration with the supervisory team. Everyone involved read the data several times and decided on the analytical categories during several iterative cycles of reflection, category construction, and iterative refinement. Disagreements and divergent interpretations were sorted out through joint discussion and close examination of how the categories and the actual data were related. In the data analysis we followed the-categorization as closely possible, and provided extensive quotations from the participants' statements to allow their diverse voices to be heard. The possibility of alternative interpretations is also acknowledged. We critically evaluated the process, and the articles included in this dissertation have been reviewed in international publications.

The *validity* of the present dissertation relies, to a great extent, on the following process involving the re-analysis of fingerprints that a) the apprentices and the experienced investigators examined during training (Study A); b) the investigators

analyzed in a discrepancy meeting (Study B), and c) members of the fingerprint-examination community independently scrutinized during the developmental seminars. In most cases, several independent examiners analyzed the fingerprints and compared their possibly diverging minutiae, areas of color coding, and documentation. Moreover, hard fingerprinting skills were assessed on standardized international fingerprint-examination tests taken by both newcomers and veterans. My decades of practitioner experience as a fingerprint examiner was a critical factor in enhancing validity in that I could relate the discourses and reflections to the investigative practices in question.

Whereas the *author's role* was crucial in analyzing the fingerprint-examination cases, the qualitative textual, the interview and the interaction data were analyzed collaboratively in numerous reflective sessions. Moreover, although the research was carried out as rigorously as possible, my involvement evidently affected the results and their interpretation, as well as the nature of the qualitative studies. I worked with a team of supervisors in distributing analytical tasks among team members to ensure the consistency of the analytical procedures and standards. This qualitative procedure involving recontextualizing, reinterpreting and redefining the research questions continued until a satisfactory interpretation was reached. The open-ended and tentative nature of text interpretation in part of the qualitative research gave me the opportunity to process and reflect on the data consistently and against uniform standards.

As explained in the section on methods, I assumed responsibility for carrying out the interventions. I functioned as the quality manager of the fingerprint community and initiated the current series of studies after becoming aware of the limitations and challenges of the fingerprint-investigation process. My participation in European and international collaboration with other fingerprint-examination communities significantly affected the direction of my efforts. I was also involved in selecting novel investigation instruments, such as AFIS, and was in consultation with the developers. Auditing other forensic-examination communities helped me to become aware of the limitations of our own methods. Having worked as a fingerprint examiner for two decades, I was very familiar with the traditional practices. Account should therefore be taken of my central role in shaping the investigations, analyzing the data and interpreting the results. I was constantly interacting with the professional examiners, and used my experience in directing future efforts. I was, for instance, personally responsible for guiding the training of the two apprentices. Study C, in turn, was carried out in close interaction with the fingerprint-examination community, and we collectively verified many inferences

and conclusions. Nevertheless, I assume full responsibility for all claims made in this dissertation.

It should be borne in mind when the present research findings are interpreted that the data were collected from the Finnish National Bureau of Investigation (NBI), which affects the degree to which the results are *transferable* to other contexts and settings. The research is anchored in socio-historically developed practices and processes developed at a Finnish forensic organization in general, and in their fingerprint analysis in particular. Consequently, the results cannot straightforwardly be *generalized* to other contexts or foreign organizations. Simultaneously, however, forensic research takes place in the context of intensive international interaction, which has also shaped the activities of the NBI. Many of the methods, instruments and practices are shared with international and European colleagues, hence many of the issues addressed in this dissertation are likely to resonate with international colleagues. Our own developmental efforts were inspired by the efforts of other communities, and many of the findings are likely to spark the interest of foreign investigators. Hence, despite the focus in this dissertation on the content-rich examination of forensic-investigation practices that are characteristic of the Finnish NBI, I believe that many of the findings could easily apply elsewhere, because the challenges addressed are common across international forensic communities.

In sum, qualitative content analysis with many case studies and action research based on context-sensitive methods appeared adequately to capture the many complex aspects of the fingerprint-examination process. A qualitative approach was adopted to make the analyses not only reliable and valid but also interesting to read, understandable, and easy to follow. Hence, it may be useful in the future to carry out further experimental and controlled studies on fingerprinting expertise.

7.3 Implications regarding the methods and practices of fingerprint examination

During its history of over one hundred years the field of forensics has witnessed the development of new investigative methods and the introduction of digital tools and instruments. However, there have been no major breakthroughs in the forensic sciences as a whole, and service providers have failed to reach a consensus on matters such as methods, investigation processes, decision-making guidelines, reporting decisions,

documentation, and training programs. Given these uncertainties, and criticism from inside and outside the forensic community, service providers are actively trying to resolve the complex challenges related to fingerprint investigation. To that end, novel digitally mediated and collaborative processes are being developed and tested. Thus far, however, many of the pressing problems addressed in the present dissertation remain unresolved. In the following I recommend certain key actions to be taken if progress is to be made in the field of fingerprint examination.

A vision and a strategy for advancing forensic investigation

Advancement in the methods and practices of fingerprint examination requires the initiation of active collaboration among multidisciplinary networks of international scientists. The Vision for European Forensic Science 2020 (Council of the European Union, 2011) advocates the fostering of cooperation among authorities to make collaborative progress, and the report, *Forensic Science in Criminal Courts: Ensuring Scientific Validity of Feature-Comparison Methods* describes the steps taken following the publication of the NAS report (2009) in the USA. In addition, organized scientific and non-scientific forensic networked groups such as the National Institute of Justice (NIJ), the National Institute of Standards and Technology (NIST) in the USA, and the European Network of Forensic Science Institutes (ENFSI) have been fostering developmental activity in forensics. After the publication of the NAS report (2009) by the US Department of Justice, forensic laboratories became aware of the need for a global breakthrough in the cultivation of transparent and collaborative professional practices mediated and enhanced through innovative ways of using digital tools and instruments. Current digital tools and instruments, including new virtual-knowledge resources, facilitate the systematic tracing of analytical and decision-making processes. There is an urgent need to enhance the validity and reliability of scientifically established and objective forensic methods.

In Europe, the ENFSI has invited member states to implement its vision of developing the forensic-science infrastructure, and together with various working groups and organizations has published best-practice manuals and guidelines for European Forensic Laboratories. However, currently these best practices do not provide adaptive, coherent tools that will enable organizations to solve problems related to identification, operational methods, the bias effect, and decision-making, nor do they cover developmental aspects such as using novel digital technologies and virtual-knowledge

databases. It is essential that experts representing multiple disciplines collect, understand and analyze the comprehensive digital data that characterizes forensic investigation. The aim in the present study was to tackle these challenges by shedding light on the work of forensic experts, providing tools for finding novel solutions, and enhancing the validity and reliability of fingerprint investigation and other forensic work. However, divergence in national organizations and forensic disciplines (in terms of administration, economic situation, levels of education, and digital tools, for example) has led to the present complex situation. An international vision and a strategy statement about fostering high-quality forensic services do not guarantee real action on the national level. National commitment to the drawing up of a strategy and action plan, and implementing it by mutual agreement are prerequisites if the challenges identified in this dissertation are to be met.

Fostering a culture of organizational learning

Organizational learning as a strategy should be introduced and developed on the individual, the collective and the institutional level. An effective learning-oriented organization encourages and facilitates professional development in its policy and strategy formation, and in its evaluation, implementation, and improvement processes. Effective collaboration and open interaction are essential in achieving such aims. Developing the organizational capacity to do so requires capitalizing on advances in multidisciplinary scientific knowledge, as well as promoting individual, social and organizational transformation. Open interaction in collective knowledge-creation processes supports the building of novel development-oriented cultures, which the forensic industry urgently needs. The following is one example. The documentation produced by the examiners during the fingerprint-investigation process varies in quality. Documenting these examinations is a demanding task, but it is necessary for improving the quality of the investigation on every level. Storing data in LIMS, verbalizing and color-coding could be used as tools for building a culture that is open to socially shared, transparent fingerprint-investigation practices, and hence enhances organizational learning. Documenting fingerprint examinations in detail also makes it easier for other examiners openly and consistently to assess the accuracy and validity of the work. Long-term professional change and quality-enhancement actions are needed to foster open and reflective as well as reliable and valid collective examination practices.

Emerging challenges related to digitalization

Digital instruments facilitate the flexible scanning and analysis of data on different levels, making processes more transparent and allowing the introduction of novel services. Digital processes are currently developed in accordance with evidence-based material (ten prints and case/latents). However, the integration of these processes does not accord with the reality of the practices. Experts have to work with diverse digital tools in different environments and following various processes, often without adequate interconnection and integration between digital systems. There are no common methods or straightforward guidelines for assessing the digital quality of the evidence material. Digital information systems (e.g., AFIS, LIMS) are used in socially constructed, ad hoc, and inefficient ways because of the structure of the software and the contextually varying processes. Developing collaboratively constructed ways of using the digital tools and instruments, and developing roles, practices and processes related to adaptive expertise would benefit providers of forensic services.

Digital tools provide quite a flexible basis on which to modify and shape operational procedures: they make it possible, for example, to capture latents at the scene of the crime and automatically transfer them to AFIS-mediated analytic processes. These new tools and services will benefit the whole criminal-investigation community in speeding up the crime-solving process and helping to prevent national and international organized crime. The future-oriented transformation to the digitally mediated analysis of fingerprints and other pieces of evidence from the scene of the crime will require systematic efforts in terms of developing organizational practices. It will be vital to reflect on and systematically develop customer-driven and user-friendly services based on highly integrated digital systems, and anchored in quality requirements and shared examination frameworks.

Challenges related to the quality, validity, and reliability of evidence that affect the whole process, from the scene of the crime to the activities of the NBIFL, should be addressed, and improvements should be made. As a starting point, providers of forensic services could develop their processes to cope with sophisticated routines and the adaptive aspects of expertise. Current technology would allow the automation of some forensic-investigation processes. This would presuppose the more effective use of personnel, and would require training for productively merging human activities with technological systems. However, Finland's examiners have open-mindedly confronted

existing challenges and constructed a novel digital tool (LIMS) to manage work flows, as well as to document interpretations of decision-making. LIMS is excellent in terms of identifying and confronting challenges, but there is still much to do. For example, the problem of digital-image "noise" in different decision-making phases should be resolved.

It is inevitable that digitalization will bring major challenges (e.g., 4D technology, the use of artificial intelligence in pattern and speech recognition, the field of computer vision, the virtual personal assistant, touch screens, and smartphones) to practices of forensic investigation, and will lead to the decentralization of routine processes at every stage. These challenges are forcing service providers to find new ways of organizing the work flow within forensic laboratories, as well as on the international level. The extensive exchange of DNA and fingerprint information between European countries, and on the global level has brought new unprecedented challenges and risks to countries that have signed contracts to exchange biometrics and information, and this will only intensify. Large-scale national and international exchange of other forensic information, even in the cyber and intelligence division, is commonplace. Such collaboration relies on shared instruments based on modern digital platforms tailored to the requirements of each case. It is also the reality that digitalization makes it easier to work and buy services across borders: for instance, fingerprints or even X-ray images can be analyzed and statements can be written anywhere. Expert work is no longer dependent on the place or even the country. Networking with external service providers and using collective tools would already be possible if it were not for national legal restrictions and data-protection regulations, but some kind of future-orientated forensics must be prepared for.

New decision-making frameworks

Forensic examiners repeatedly face challenges in terms of understanding the variety of decision-making options requiring extensive knowledge. Scientific researchers and international scientific groups have come up with various suggestions for solving these decision-related problems.

Researchers have also devised models reflecting the bias effects that may cognitively contaminate forensic experts' interpretations and conclusions (Dror, 2016; 2017). There is a wide variety of decision models, including statistical, Bayesian probability and likelihood-ratio approaches, verbal scales and descriptions of decision phases, and also

a variety of documentation guidelines. ENFSI has recently recommended the use of likelihood ratio for measuring the value of forensic results. This is not an imperative, but it gives a strong incentive to unify decision and report models. Optional recommendations such as this allow forensic laboratories to decide in their own, sometimes incoherent, way about how they report their conclusions.

Verbal scales have been used as a communicative decision-making model for years in many forensic disciplines. A verbal scale is understandable and logical, and serves well in reporting and communicating forensic results in court, for instance. Given the lack of high-quality hard, "big" data in Finland, verbal scales would facilitate the communication of probative values among experts. They could also be of help to laboratories seeking to improve their evaluation practices and develop their entire reporting format. At the same time, the NBIFL should train experts to assess probabilities in casework. There are interpretation risks involved in using unified verbal scales, but the important thing is to be aware of them, and to build a common understanding so as to improve communication between scientists and non-scientific communities (Marquis et al., 2016). Verbal scales with likelihood estimation is a technique of statistical analysis that adds elements of certainty to propositions. The use of unified verbal scales is also worth considering, as is their use in service requests or low-quality evidence. Finland has been developing its forensic services for years, and the adoption of verbal scales with novel digital tools would be another step forward.

Cultivating adaptive forensic expertise

Improving the quality of forensic investigation requires higher levels of expertise, including the mastery of scientific knowledge and methods. Experts have to be skilled in advanced knowledge processing, critical thinking and non-routine problem solving, as well as in using, applying and accumulating scientific knowledge to justify their decisions to society. New demands for quality, training, and transparency create the need for a novel type of multidisciplinary, adaptive forensic expertise. The traditionally rigid requirements related to the qualifications and basic education of forensic experts, as well as the absence of national training programs have led to international confusion regarding forensic competence. The need for scientists with a high level of expert knowledge and the ability to find new solutions to novel problems is growing because forensic disciplines are facing major transformation in the form of "robotization",

digitalization and scientification, and with it new quality and transparency requirements. Although routine fingerprint-examination processes will be digitalized, forensic investigators with a high level of adaptive expertise and multi-professional competence will still be needed to analyze poor-quality, distorted latents, make justifiable decisions, and engage in the further development of methods and practices. An adaptive expert is active in networking, oriented toward knowledge advancement, and continuously learning in pursuit of organizational and technological improvements.

Forensic expertise entails a high level of responsibility for protecting human rights and observing national laws and decrees. Thus far, international forensic institutions do not agree with regard to training requirements for fingerprint examiners. Most of the training is carried out in-house with no or only a few quality-assessment tools and future-oriented pedagogic structures. There are some international fingerprint-identification tests (e.g., CTS, ENSFI) for fingerprint examiners, but they test only some aspects of reliability in the examination of individuals. In Finland, however, elements of certification have been built into the training program (see Mustonen & Hakkarainen, 2015; Mustonen & Himberg, 2011). According to Mustonen and her colleagues, it is critical to engage apprentices in the systematic cultivation of adaptive expertise in terms of integrating professional and scientific knowledge, engaging in transparent examination practices, and deliberately reflecting on professional practices that will enable them to sort out conflicting decisions (Mustonen et al., 2015).

As noted earlier, Finland has had its own fingerprint-expert training program since 2010. This novel program can be adapted to suit the laboratories' strategy, and implemented across all comparable forensic disciplines. It may be easily adaptable and suited to other practice-based areas of forensic investigation, such as tool marks, documents, and handwriting. Its application in other workplace training activities is also encouraged. In addition, international agreement in terms of structure, roles, and competence requirements in the acquisition of routine and adaptive expertise, as well as nationally implemented modules and international courses, would ensure progress in the right direction.

To ensure quality, training should be implemented within a national, official education system offering the advantages of high-quality educational planning and implementation. In addition, national and international universities offering study programs in mathematics, adult education, philosophy and psychology, for example, should incorporate forensic studies into their educational programs, in mutual

cooperation between universities and forensic institutes.
In sum, reforming the education and training should be the major aim to ensure the reliability and validity of forensic investigation in the future. Cooperation across all levels has to be promoted. The training program also offers suggestions for revising the modules according to emerging needs and the organization's operating environment. Current modules should include elements of statistical concepts, the different approaches of scientific studies, and taxonomies of various sources of bias contamination. Law-enforcement educators should construct novel curricula that address the challenges of integrating professional and academic knowledge. The Police University College in Finland, for instance, as well as other educational institutes, should open up channels through which professionals with an academic and multidisciplinary education qualify as a police officer or investigator. Technology-supported and practice-oriented learning should also be encouraged via e-learning, gamification, blended learning and other modern educative tools and pedagogies. These actions should be implemented as soon as possible to ensure the availability of proactive operators in digital environments.

Building adaptive communities

Rapid transformation in the tools and technologies of forensic investigation, and in associated patterns of organizational activity, highlights the need for more flexible adaptive experts, and for adaptive leadership in multi-professional expert communities. Organizations are actively seeking new solutions to overcome emerging technological, social, and organizational challenges, and have to face, diagnose and resolve situations of which they have little or no experience or know-how. Sophisticated communication and negotiation competences are needed to support the articulation and explication of professional know-how with regard to forensic investigation. It will not be possible for forensic experts to solve complex problems without a solid grounding in formal, procedural and self-regulative knowledge acquisition. Leading experts in rapidly changing professional environments require reflective dialogue and transformative capabilities to develop effective personal and social learning strategies. The ability to work across boundaries and a problem-solving orientation support the building of communal knowledge and the development of shared innovative solutions. Adaptive leadership and management play a crucial role in meeting the challenges of forensic investigation. At this point, I should point out the relevance of a multidisciplinary and

reflective understanding of human learning, personal and social motivation, and professional epistemic cultures to forensic investigation.

In this respect, the cultivation of a learning-oriented organizational culture is more of a necessity than formerly assumed. Forensic investigation takes place in inter-organizational boundary zones in which knowledge has to be exchanged: there are challenges when two or more expert communities represent multiple areas of professional knowing. Such networks represent diverse conceptions, interests, priorities, professional languages, epistemic conceptions, and assumptions. This in combination with different levels of status and power have resulted in communication difficulties, and even in conflicting understandings of the supply of and demand for forensic services. There needs to be a solid scientific basis of activity together with an awareness of international developments in the field. Within this framework, networking interaction plays an important role in terms of improving the quality of forensic investigation. Finland has taken advantage of the internationalization of the field, and actively participates in the international scientific working groups focused on forensics. The country has a great deal of experience and accumulated knowledge to be shared with international colleagues. The new, collective, forensic practices, developed to overcome the challenges of digitalization, should also conform to emerging quality requirements.

The present dissertation focused on locally situated forensic activities at NBIFL. I have reported on systemic efforts to develop a more collective approach to forensic investigation, and to engage examiners in developing their associated professional practices. My central role in initiating and monitoring the present organizational improvement has been very rewarding. It has been especially inspiring to be involved in transforming research into practice in the course of the present series of studies. I hope this dissertation sheds light on the challenge between research and practice, while at the same time encouraging other forensic investigators to apply and implement the methods and findings in their own organizations. My vision is to work in a transparent, open, and growth-oriented atmosphere that nourishes the motivation in experts to learn, to develop their collectively shared expertise, and to assume a significant role in meeting the emerging challenges to improve the quality of forensic investigation.

Future challenges

The global fourth industrial revolution is transforming professional work across various fields, including forensic investigation. Digitalization is forcing us to modernize,

digitalize and automatize many aspects of professional work. New strategies are needed because relationships are becoming totally reshaped across various levels: the roles of expertise, working processes and tools, relationships with customers and citizens, and the organizational structures of the forensic industry. At the same time, digitalization is in novel forms of industrial innovation such as machine learning, robotics, and artificial intelligence, and in novel hybrid digital evidence and huge data resources. Digitalization is challenging the public sector on every level. The risks concern the difficulties human experts have fully to understand the digital instruments and systems with which they are working and on which they increasingly rely. There are also emerging risks such as digital terrorism that threatens the security of public infrastructure, identity theft, and the influence of biometric or novel elements on digital economic crime.

Information and digital storage have been moving to the "cloud", and this trend is expanding rapidly. Novel innovations in work processes are controlled by various organizations and different kinds of software with elements of artificial intelligence. This kind of digitalization is changing the roles of and the relationships between experts, technical instruments and processes, as well as the places in which the examinations are carried out. It brings the global aspect into real-life processes and practices. A major challenge is to build novel transformative bridges from old socio-technical systems to new ones by ensuring both high levels of security and the development of transformative professional expertise. Forensic service providers should be aware of the whole field of forensics and its complexity, and should be familiar with novel forms of collaboration between different forensic industries and associated areas of expertise. Forensics as a service industry is expected to orchestrate its own future.

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