ARTICLE IN PRESS

Forensic Science International xxx (xxxx) xxx

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Quality Management in forensic science: A closer inspection

Wim Neuteboom [a], Alastair Ross [b,*], Lyndal Bugeja [c], Sheila Willis [d], Claude Roux [e], Kevin Lothridge [f]

[a] Netherlands Forensic Institute (Retired), Laan van Ypenburg 6, 2497 GB The Hague, Netherlands
[b] Academic Programs, Victorian Institute of Forensic Medicine, 65 Kavanagh Street, Southbank, Victoria 3006, Australia
[c] Department of Forensic Medicine, School of Public Health and Preventive Medicine, Monash University, 65 Kavanagh Street, Southbank, Victoria 3006, Australia
[d] Leverhulme Research Centre for Forensic Science, University of Dundee, Scotland DD1 4HN, United Kingdom
[e] Centre for Forensic Science, University of Technology, Sydney, Cnr Harris and Thomas Streets, Broadway, New South Wales 2007, Australia
[f] Global Forensic and Justice Centre, Florida International University, 8285 Bryan Dairy Road, Suite 125, Largo, FL 33777, United States

ARTICLE INFO

Keywords:
Quality management
Fit for purpose
Competences
Education & training

ABSTRACT

An international survey was conducted on the benefits and limitations of accreditation to ISO17025 in forensic science, and how quality management could be improved to reflect the complexities of the end-to-end process. The survey was in response to growing concern within the forensic science community that the standard ISO17025 (and ISO17020), which is the backbone of forensic science accreditation, does not have sufficient depth and reach to properly address the quality of both the inputs (crime scene traces) and outputs (e.g., opinions in a report) of forensic science. The survey was developed around three themes: (1) fitness for purpose, (2) competences and (3) education & training. It targeted directors and senior managers, including quality managers, of forensic science laboratories/facilities. The survey was developed by the research team and disseminated with the cooperation of the International Forensic Strategic Alliance (IFSA) and six regional Networks: the American Society of Crime Laboratory Directors (ASCLD), the European Network of Forensic Science institutes (ENFSI), the Australian and New Zealand Forensic Executive Committee (ANZFEC) (formerly SMANZFL), Acadamia Iberoamericana de Criminalistica Estudios Forenses (AICEF), Asian Forensic Sciences Network (AFSN) and Southern Africa Regional Forensic Science Network (SARFS). What emerged for each of the three themes of the survey are areas of concern where the forensic science community should reconsider its approach to quality management if it is to have continuing value and relevance into the future. The results are evaluated and discussed. Briefly, the results include evidence of a lack of fitness for purpose of ISO17025 as a standard for the forensic science continuum, a lack of agreement on what forensic science is and poor levels of recognition of crime scene investigation, many competences, particularly cognitive competences, are not identified, monitored or assessed and the incentive to gain accreditation and maintain continuous improvement is intrinsic rather than customer driven.

1. Introduction

The increased use of forensic science in investigations and criminal trials in the 1970s and early 1980s was tarnished by miscarriages of Justice *'in which forensic science evidence played a prominent part'* [1]. As a result, forensic science was the subject of significant criticism and a drive for a systematic approach to quality management was seen as a solution to avoid future problems [1]. A specific forensic science standard was not in place and the implementation of an existing, internationally accepted standard was sought. This apparent weakness was seen as a valuable opportunity to bring forensic science into the realm of other testing and calibration environments [2].

The outcome was the adoption of standard ISO17025 as it was deemed the most appropriate for this purpose. While ISO17025 had the presumptive advantage of being focused on laboratories, many aspects of the work undertaken by forensic laboratories and the competences of forensic scientists may challenge its fitness for purpose [3]. Concerns about fitness for purpose have been expressed by several authors [4–6].

Nevertheless, ISO17025 became the most-frequently used standard in forensic laboratories world-wide, most commonly as a step to

* Corresponding author.
E-mail address: ali.ross@forensicadvisoryinternational.com (A. Ross).

https://doi.org/10.1016/j.forsciint.2023.111779
Received 28 September 2022; Received in revised form 25 June 2023; Accepted 29 June 2023
Available online 4 July 2023

achieving a formal accreditation.

The forensic community has now worked to the standard ISO17025 and later also to the standard ISO17020, for some decades. Given the questions that continue to arise about quality management in forensic science, and the transformational changes that have taken place in forensic science since the adoption of ISO17025, re-evaluation of the appropriateness of the various elements of the standard is needed.

The aims of this study were to examine:

1. fitness for purpose of ISO17025 and ISO17020 as a quality management model for forensic science laboratories / facilities.

2. measures of practical and cognitive competence among the forensic science workforce.

3. education & training requirements of the forensic science workforce.

The introduction of an updated version of ISO17025 in 2017 introduced greater flexibility related to quality manuals, quality policy and quality objectives. It also included a section on risk-based thinking. [7]. Further, work has been published by Wilson-Wilde in which she reviews the development of *international forensic science standards* (8) and similarly, Doyle (9) conducted a review of the forensic science quality standards framework. The review included risks and opportunities. In their article, Page et al. (10) make a comparison between quality management practices within DNA and fingerprints and the evolving digital evidence discipline. ISO has been active in developing standards specific to forensic science (11 and 12). Specifically these standards are ISO21043–1:2018, Forensic sciences – Part 1: Terms and definitions and ISO21403–2:2018, Forensic sciences - Part 2: Recognition, recording, collecting, transport and storage of items. However, concerns related to fitness for purpose for the forensic science continuum and the identification and maintenance of competencies remain.

It is worth noting that ILAC-G19:06/2022 [8] will be of assistance in the interpretation of ISO 17025: 2017 and ISO 17020:2012. Although the fact that an interpretation document is required may be an indicator related to fitness for purpose.

2. Material and method

2.1. Study design

This study comprised a cross-sectional survey of directors and senior managers (including quality managers) of forensic science laboratories or facilities. Approval to perform the study was granted from the Monash University Human Research Ethics Committee on 30 September 2021 (Project Number 30407).

2.2. Participants and recruitment

Participants eligible to complete the survey were directors and senior managers (including quality managers) of forensic science laboratories or facilities proficient in reading and writing in English. The recruitment method was via an email invitation sent to members of the International Forensic Strategic Alliance (IFSA) from the President. The IFSA Network comprises the: Asian Forensic Sciences Network (AFSN); the Australian and New Zealand Forensic Executive Committee (ANZFEC); European Network of Forensic Science Institutes (ENFSI); Acadamia Iberoamericana de Criminalistica Estudios Forenses (AICEF); American Society of Crime Laboratory Directors (ASCLD)); and Southern Africa Regional Forensic Science Network (SARFS). A summary of members and/or countries in IFSA Networks is shown in Table 1.

The email invitation stated the purpose, structure and link to the survey, that participation was voluntary and that participant names would not be requested. In addition to direct recruitment via email, the survey was also promoted on the websites of the respective forensic networks. Directors of the ENFSI member institutes were also individually invited to participate in the survey via email through the ENFSI Secretariat.

Table 1
Summary of IFSA Network members / institutes and countries.

Network Name	Members Institutes	Countries
Academia Iberoamericana de Criminalística y Estudios Forense (AICEF)	28	17
American Society for Crime Lab Directors (ASCLD)	300	11
Asian Forensic Science Network (AFSN)	61	17
European Network of Forensic Science Institutes (ENFSI)	72	39
National Institute of Forensic Science Australia and New Zealand (NIFS ANZ)	19	2
South Africa Regional Forensic Science Network (SARFS)	23	16
Total	503	102

2.3. Survey instrument development

The survey questions were developed by the research team which comprised international forensic science experts (Australia (AR, CR), Ireland (SW), the United States of America (KL) and the Netherlands (WN)) and a senior researcher (LB). The survey comprised a combination of coded (binary, multiple choice, matrix) and free text responses in four sections: (1) sociodemographic and occupational characteristics (six questions); (2) fit for purpose (seven questions); (3) competences (fifteen questions); and (4) education & training (seven questions).

The survey was developed in the survey software platform Qualtrics and was pilot tested for face validity and accessibility with nine international and experienced forensic science professionals during September 2021. Following minor revisions, the survey was distributed as described above on 9 November 2021 and closed 3 December 2021. One reminder was sent via email on 29 November 2021.

2.4. Data collection, hygiene and analysis

Once participants accessed the survey via the link and completed the acknowledgement that they read and understood the explanatory statement and consented to participate, access was provided to the survey questions.

After the survey period closed, the survey responses were downloaded into a Microsoft Excel spreadsheet. A review of each question was performed to identify missing data and the proportion of missing data for each respondent was calculated. Where the proportion of missing data was greater than or equal to 50 %, the response was excluded from the analysis.

A descriptive statistical analysis was performed using Microsoft Excel of included responses to report: participant response; participant socio-demographic and occupational characteristics; perceptions of fitness for purpose of ISO17025 and ISO17020 as a quality management model for forensic science laboratories / facilities; measures of practical and cognitive competence among the forensic science workforce; and education & training requirements of the forensic science workforce.

3. Results and discussion

3.1. Participant response and characteristics

There were 129 participants who responded to the survey of which 32 (24.8%) were excluded because over 50 % of the survey questions were not responded to. The distribution of survey responses included and excluded from the analysis by region is shown in Table 2. The highest number of responses was from Europe (77.6 %, n = 67) which may reflect the more direct approach adopted within the ENFSI network. North America provided the second highest level of returns amongst the networks.

As can be seen from the data, the percentage of responses from the various Network members was quite varied. It is acknowledged that

Table 2
Frequency and proportion of participant responses included and excluded by IFSA Network region.

Region	Included		Excluded		Total
	n	%	n	%	n
Asia	3	42.9	4	57.1	**7**
Australia / New Zealand	12	66.7	6	33.3	**18**
Europe	52	77.6	15	22.4	**67**
Latin America	2	100.0	-	-	**2**
North America	26	81.3	6	18.8	**32**
Southern Africa	-	-	1	100.0	**1**
Other, specify	2	100.0	-	-	**2**
Total	**97**	**75.2**	**32**	**24.8**	**129**

from an international perspective this could lead to a skewing of the results.

An analysis of the participants age group showed that almost 50 % (n = 46, 47.4 %) were aged between 50 and 64 years. A further 40.2 % (n = 39) reported their age as between 35 and 49 years. An analysis of the participants years of experience employed as a director or senior manager (including quality manager) by region showed that approximately 50 % (n = 50, 51.5 %) had > 10 years' experience (Table 3). Therefore, the seniority of the respondents is inline with the intended target group.

It may be that management experience is not specific to forensic science but gained elsewhere in a government system or private enterprise.

The results regarding the three key elements of the survey (Fitness for purpose, Competence and Education & Training) are consecutively presented and discussed.

3.2. *Fitness for purpose*

It is relevant to recall that the ISO17025 standard was not developed for the forensic science domain. It was used in part because of the lack of a specific forensic science standard and in part the need to illustrate that forensic science laboratories were performing to accepted norms from outside the area. Increased sophistication of technology made the laboratories providing such services the perceived heart of modern forensic science. Therefore, the ISO17025 standard for testing laboratories was seen as being most promising for forensic science. However, a disadvantage was the concept of the processes: in a forensic laboratory, the processes are deviant compared to most non-forensic laboratories. It could be argued that the analysis phase of forensic science can be standardised but the 'inputs and outputs' cannot. It should be noted that the Organisation of Scientific Area Committees for Forensic Science (OSAC) in the USA are considering this issue.

Fitness for purpose is challenged because the central element of forensic science (input), the trace, is anything but uniform and the forensic science findings (output) are revisable approximations about the past event. Fitness for purpose is further challenged by forensic science's expanding role in areas such as forensic intelligence and rapidly evolving areas such as digital forensic science. Overall, current QM models increasingly struggle with the complexity of the whole forensic science process.

Table 4
Frequency and proportion of tasks considered forensic science by respondents.

What tasks best define what a forensic scientist does?	Yes		No		Total
	n	%	n	%	n
Crime scene investigation	48	49.5	49	50.5	97
Laboratory analysis	97	100.0	-	-	97
Interpretation of analyses, including statistics	87	89.7	10	10.3	97
Reporting of results	89	91.8	8	8.2	97
Testimony	79	81.4	18	18.6	97
Management of other scientists	37	38.1	60	61.9	97
Research	52	54.7	43	45.3	95
Other, specify	10	10.3	87	89.7	97

These issues are relevant even before we consider the issues of how the scene is examined or decisions made as to what should be examined.

3.2.1. *What is forensic science?*

To properly consider fitness for purpose, we should have a good understanding about forensic science. However, in answer to the question 'what is forensic science', there was a lack of agreement prompted by the many roles and functions carried out and likely also prompted by the lack of a recognised definition of forensic science and established forensic science principles. These factors highlight the challenge as to how quality management in general and accreditation in particular can best support forensic science and whether ISO17025, for example, is fit for purpose.

Of concern, 50.5 % (n = 49) of respondents did not consider crime scene investigation (CSI) part of what a forensic scientist does (Table 4). While this is probably reflective of the structure of forensic science service providers where CSI is generally the remit of police facilities, CSI is a fundamental part of forensic science.

3.2.2. *Research*

Science should be based on research but there was a pre-survey perception amongst the authors, based on observation and the number and source of forensic science articles being published and their specific content, that the present laboratory systems did not facilitate research. [9].

The results were different from expected with 71.1 % (n = 69) of respondents claiming to carry out research and a similar number reporting that they are encouraged to publish 72.2 % (n = 70). The discrepancy may be related to the definition of research and a high percentage of case-based research, potentially unpublished, may be a clue to this.

Experience amongst the authors is that the outcome of much of the case-based research stays in the case file and is not made available to the forensic science community. Obviously, this is a missed opportunity and the lack of circulation of internal research/development outcomes must result in duplication of effort in an already overstretched arena.

3.2.3. *Accreditation*

With respect to achieved accreditation to ISO17025, the area with

Table 3
Frequency and proportion of years of experience as a director of senior manager by IFSA Network region.

Years' Experience (Senior)	< 12 months		1–5 years		6–10 years		> 10 years		Total
	n	%	n	%	n	%	n	%	n
Asia	-	-	-	-	2	66.7	1	33.3	3
Australia / New Zealand	1	8.3	1	8.3	1	8.3	9	75.0	12
Europe	4	7.7	11	21.2	11	21.2	26	50.0	52
Latin America	-	-	-	-	2	100.0	-	-	2
North America	2	7.7	7	26.9	3	11.5	14	58.8	26
Other specify	1	50.0	1	50.0	-	-	-	-	2
Total	8	8.2	20	20.6	19	19.6	50	51.5	97

lowest proportion of accredited laboratories/facilities where the service was offered was CSI (32.1 %, n = 18/56) and digital/multi-media services (57.1 %, n = 32/56 for ISO 17025. By comparison, for the other three areas (physics/pattern interpretation, chemistry/instrumental analysis; and biology/DNA) the proportion of accredited laboratories/facilities where the service was offered was at least 85 % (Supplementary Table 1). Of interest, between 6 % and up to 22 % of survey respondents either did not answer this question or the responses were unusable which may be an indication of respondent's uncertainty around this point.

There are several possible reasons for the relatively low proportion of ISO17025 accredited laboratories/facilities for CSI and digital/multimedia (digital forensic science). Firstly, CSI is routinely offered by police facilities where accreditation is not usually considered a priority, secondly, digital/multimedia (digital forensic science) is a relatively 'new kid on the block' and use of the standards is less obvious at this stage and thirdly, validation of methods which are evolving so rapidly is problematic.

It is worth, briefly, taking a closer look at digital forensic science given its rapid and continuing evolution and its role in the digital transformation of forensic science. For some time, there has been international debate as to whether ISO17025 is fit for purpose for this discipline [10–12]. The debate correctly revolves in part, around continuous change and the resultant difficulties in meeting ISO17025 requirements for verification/validation of new tools and methodologies. However, proper digital forensic science investigation sits within the context of the overall forensic science continuum and the discipline should be subject to the same competency criteria as specified in the relevant clauses of ISO17025.

It should also be noted that 12.5 % (n = 7/56) of CSI laboratories/facilities were accredited to ISO17020. This is not a surprising finding because ISO17020 is an inspection standard rather than measurement and calibration standard which is the basis of ISO17025.

Self-improvement and the need to have good quality results for the criminal justice system were the key reasons given for accreditation (73.2 %, n = 71; 72.2 %, n = 70 respectively). Legislation and gaining membership of an international forensic network were also frequently reported reasons for accreditation (56.7 %, n = 55; 43.3 %, n = 42 respectively). Approximately 15 % (14.4 %, n = 14) of respondents gave other reasons for accreditation.

Of interest, the European Network of Forensic Science Institutes (ENFSI) mandates accreditation for membership but this is not the case for other international Networks. Also, in some jurisdictions accreditation is a requirement for facilities to engage in uploading data to and searching national databases (e.g., DNA).

The results indicate that the forensic science community is the key driver in the quality management/accreditation initiative and that 'customers' have had very little influence. The latter point is reinforced by the fact that customer surveys did not rate highly in aspects leading to continuous improvement (4.1 % rated as *bringing the most improvement*) when compared to audits (49.5 %), proficiency testing (47.4 %), corrective actions (42.3 %) and management reviews (23.7%).

It is noteworthy that quality management and accreditation are viewed as valuable by the forensic science community itself, where accreditation is in place. However, following the ISO philosophy, the quality management standard was designed with a customer focus in mind and for forensic science this model falls short where the so-called customers (police, court) with their totally different scientific background (natural sciences versus legal sciences) have shown little or no interest in engaging with accreditation. Example: the customer in the forensic domain cannot have an opinion on the appropriateness of a laboratory method or the required competences of a laboratory examiner. But, because the survey was aimed at laboratories rather than customers of forensic science, it is not known, from the survey, whether accreditation affects customers' level of confidence in the quality of forensic science.

To continue with this theme, the survey results indicated that the benefits of accreditation were largely seen as internal to the organisation rather that external (e.g., for customers). Benefits which featured most strongly were increased reliability and validity of test results (85.6 %, n = 83); improved/systematic management system (85.6 %, n = 83); self-improvement (83.5 %, n = 81) and confidence/pride in the organisation (77.3 %, n = 75). It is arguable that indirectly, the benefits do relate to the customer and where the benefits were better categorised from a customer perspective, the standard could be tweaked such that it became more fit for purpose.

The authors acknowledge the work being conducted through ISO/Technical Committee 272 on specific forensic science standards which is a promising development.

Finally, with respect to accreditation, respondents were asked to identify the negative aspects of accreditation and not surprisingly, cost was highly ranked (70.1 %, n = 68). In a presentation to a meeting of the International Association of Forensic Sciences (IAFS) in Oxford, UK in 1984 [13], Margaret Periera who was then the Controller of the Forensic Science Service (FSS) posed the question related to quality management in forensic science "Can we afford it?" Ms Periera then said, "I think the more appropriate question is 'Can we afford to be without it?'" Some 40 years on, Pereira's questions are still relevant but the answer to the second question should be a resounding no, so long as the system we employ is fit for purpose.

A further high ranking negative related to accreditation, was that it encourages overly complicated documentation (62.9 %, n = 61). Again, the question needs to be asked who is this driven by? In the view of the authors it is not the stakeholders or the accreditation bodies (AB's). Rather, it is the continual self-inclusion of additional requirements following corrective actions with poor root cause analysis and without proper periodic review and management. It is exacerbated by poor skills in the initial structuring of an efficient and effective documentation system.

Respondents were generally of the view that accreditation does not stifle scientific curiosity (76.3 %, n = 74). However, in the author's experience, this does not sit well with the fact reported earlier that there is little publication related to research from the forensic science community. Indeed, there is anecdotal information that scientists stick rigidly to SOPs when they are in place rather than sense check.

3.3. Competence

ISO17025 has several clauses dealing with competence*, including requirements for education, qualification, training, technical knowledge, skills and experience* and the requirement that *personnel have the competence to perform laboratory activities* and records maintained. Forensic scientists need both practical and cognitive competences. Therefore, a fit for purpose standard needs to identify such competences and facilitate their assessment. In reality, there appears to be a lack of agreement in relation to the core competences required, and against which the standard is assessed. This may be related to the lack of agreement as to what constitutes forensic science and to the variation in practice in different jurisdictions.

3.3.1. Core practical and cognitive competences

The practical competences (Fig. 1) with a large proportion ranked as *essential* were specialist technical knowledge (81.4 %, n = 79); science training (80.4 %, n = 78); analytical skills (70.1 %, n = 68); and oral and written communication skills (56.7 %, n = 55; 55.7 %, n = 54 respectively). Interestingly in today's environment where there is pressure to consider probabilities in reporting for feature comparison disciplines, for example, mathematical/statistical ability (17.5 %, n = 17) were ranked relatively low. However, there is a possibility that this is considered as an implicit part of science training.

With respect to the cognitive competences (Fig. 2) the following had a large proportion ranked as *essential*: critical thinking (72.2 %, n = 70);

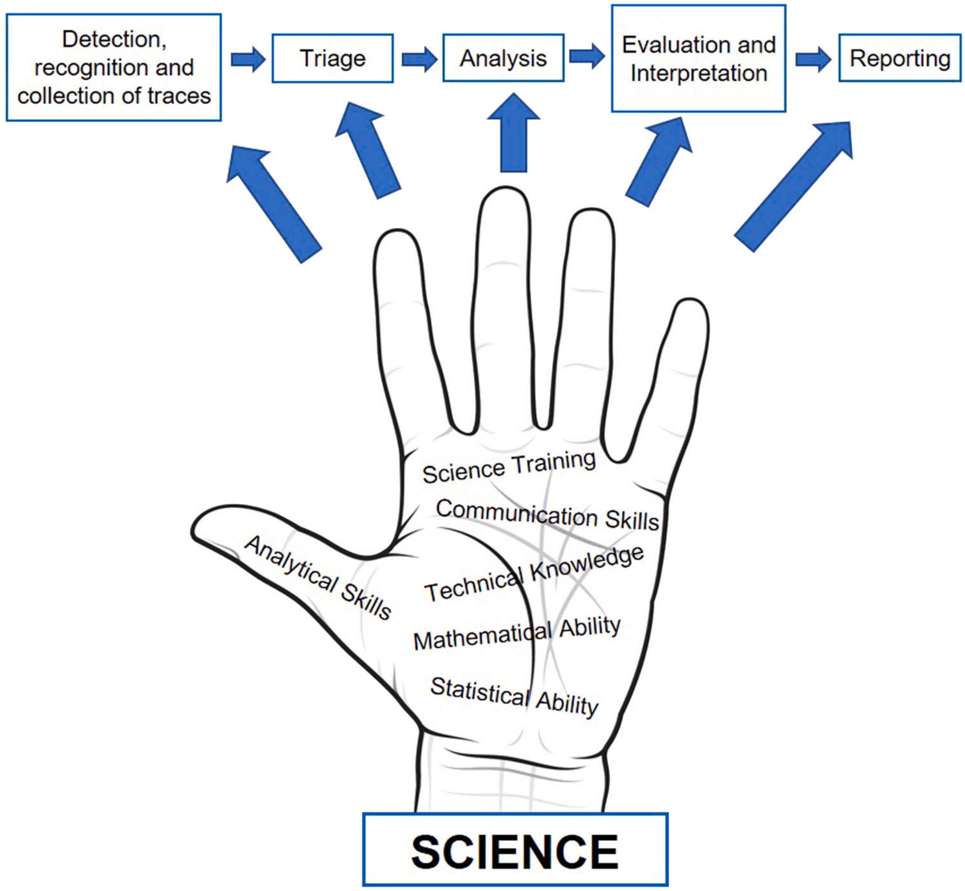

Fig. 1. Practical competences.

reasoning (69.1 %, n = 67); logic (64.9 %, n = 63); problem solving (62.9 %, n = 61); informed judgement (56.7 %, n = 55) and hypothesis formulation and testing (53.6 %, n = 52). Reconstruction had the lowest proportion of competences ranked as *essential* (32.0 %, n = 31). Forensic crime scene reconstruction is described as the process of determining the sequence of events about what occurred during and after a crime and may include blood spatter interpretation, trajectory and shooting reconstruction and accident reconstruction [14]. However, Morgan [15] takes a much more holistic and conceptual approach to forensic reconstruction which *'enables the discipline to be a true scientific endeavour rather than solely a series of mechanical and standard technical operations.'*.

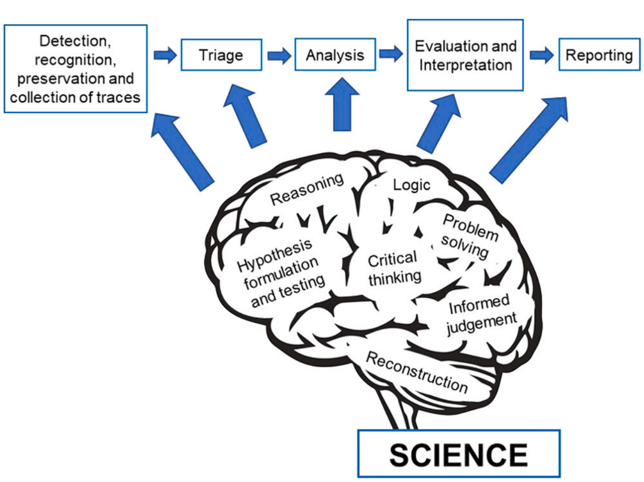

Fig. 2. Cognitive competences.

It is interesting to contemplate whether the lack of focus on reconstruction is related to the previously discussed lack of focus on crime scene investigation, or it may be that there is not a general understanding of the concept of reconstruction and this is reflected in the response to cognitive competences. Ristenbatt et al. [16] argue that the lack of practised science at the crime scene is contributing to this situation. It is also possible to argue that because of the testing focus of ISO17025 the purpose of reconstruction is forgotten.

3.3.2. Competence requirements and assessment

There was a clear sliding scale in the survey results regarding the assessment of competences. The average reported assessment across forensic science disciplines for practical competences ranged from 73.9 % (n = 52/68 responses) for science training to 31.5 % (n = 22/67 responses) for mathematical ability. The average reported assessment across forensic science disciplines for cognitive competence ranged from 47.0 % (n = 32/67 responses) for informed judgement to 29.7 % (n = 19/66 responses) for reconstruction (supplementary Table 2).

A similar picture emerged in relation to competence requirements. Approximately 70 % (n = 68) of respondents reported to have fixed entry level requirements for practical competences, of which over 90 % (n = 62) are defined in job descriptions. For cognitive competences approximately 50 % (n = 48) reported to have fixed entry level competence requirements of which over 85 % (n = 42) are defined in job descriptions. The authors agreed that these figures are not impressive when considering what the ISO17025 requirements are for competence (not fully quoted). For example:

> *6.2.2 The laboratory shall document the competence requirements for each function influencing the results of laboratory activities.*

6.2.3 The laboratory shall ensure that the personnel have the competence to perform laboratory activities.

6.2.5 The laboratory shall have procedure(s) and retain records for: f) monitoring competence of personnel.

3.3.3. Acquisition and maintenance of competences

The survey revealed that the initial recruitment interview was the main tool used to test the acquisition of competences (71.1 %, n = 69) followed by internal (46.4 %, n = 45) and external training (38.1%, n = 37) and authorisation boards (33.0%, n = 32). The main tools used to check for competency maintenance were proficiency tests (82.5 %, n = 80), case record peer review (79.4%, n = 77) and audits (71.1 %, n = 69). None of these tools particularly relate to assessing the maintenance of cognitive competences and this is a critical gap in forensic science quality management which requires urgent attention/research.

In relation to the survey question about whether external assessors (e.g., at accreditation inspections) check competence acquisition 79.4 % (n = 77) reported that checks were conducted and 17.5 % (n = 17) reported that they were not (note that n = 3 did not respond). The main tools used for checking were reviews of proficiency tests (92.8 %, n = 90), training records (87.6 %, n = 85), case file reviews (80.4 %, n = 78) and senior staff interviews (58.8 %, n = 57).

The fact that 17.5 % (n = 17) reported that competence acquisition and maintenance were not externally assessed is of significant concern. Again, none of the main tools previously mentioned particularly relate to assessing the maintenance of cognitive competences and it calls for very clear documentation of competences if external assessment is to be successful. There is a role for accreditation bodies (ABs) here in ensuring that there is compliance with ISO17025 Clause 6.2 and it seems clear that this role is not being fulfilled. However, to be fair, this is difficult where the forensic science community has not adequately identified the competences. Therefore, it appears that this issue is with the implementation of the standard rather than with its content.

3.4. Education and training

Globally, education & training for forensic scientists is not uniform or homogenous [17]. Most programs have developed organically from specialised technical competences available within each institution instead of being based on universal or at least well accepted forensic science principles and theories. Forensic science education & training comes in many different forms ranging from unstructured in-house training to formal tertiary qualifications and outcomes are inconsistent. In addition, many forensic scientists are recruited from courses other than those badged as forensic science, for instance a pharmacist who is in-house trained to become a forensic drugs expert.

In terms of continuing education and professional development, the most common method mentioned was attendance at conferences and seminars (92.8 %, n = 90). Others mentioned were quality management (84.5 %, n = 82), in-house programs (73.2 %, n = 71) and presentation of expert evidence (57.7 % n = 56). Higher degrees and certification which are arguably as effective as forms of professional development were both listed at just over 30 % (34 %, n = 33 % and 35.0 %, n = 34 respectively).

The level to which professional development, whether mandatory or discretionary, is funded by the organisation is reported at approximately 55 % and while professional development is generally monitored it is not universally counted towards promotion.

4. Conclusions

4.1. Fitness for purpose

There is a lack of clarity about what constitutes forensic science, probably exacerbated by the different disciplines which constitute forensic science and the mix of services provided by individual organisations. What is required is an umbrella view incorporating a definition and principles which align with forensic science and its practice. For this, readers should familiarise themselves with the Sydney Declaration [18] which is designed to address this issue.

What emerged from the survey is that ISO17025 in particular (and to a lesser extent ISO17020) is used more in laboratory-based activities rather than other aspects of forensic science (e.g. CSI and digital forensic science). The authors are of the view that ISO17025 is more suited to the analysis side of forensic science and less suited to the accreditation of the 'inputs' and 'outputs' processes.

It is of real concern that crime scene investigation is not generally seen as an integral part of forensic science with full engagement in quality management practice given it is fundamental to the delivery of valid forensic science outcomes.

Similarly, and as discussed previously, digital forensic science is expanding exponentially and the current standards may struggle to keep pace with its impact and the rapidity of its growth [19,20].

It is vital for the forensic science community to come to terms with these issues and to ensure that any quality management system is globally fit for purpose.

We say that the forensic science community should come to terms with these issues quite deliberately because the quality management initiative is internally driven. It is quite clear from the survey that the incentive to gain accreditation and maintain continuous improvement is intrinsic rather than customer driven.

4.2. Competence

There is broad agreement on the practical and cognitive skills required for forensic science practitioners. However, methods for assessing cognitive competence are not in place and therefore not documented adequately to fulfil ISO17025 requirements.

Competence based requirements are clearly stated in ISO17025 Clause 6.2 and as these are not being met, particularly with respect to cognitive competences, the question needs to be asked as to why accreditation is being granted. While the onus for competence identification, acquisition and maintenance essentially sits with the employing organisation, there is no doubt that accreditation bodies (AB's) have a role to play in ensuring these criteria are being met. This does not appear to be the case.

One of the confounding issues here is whether there are existing methods for assessing cognitive competences, especially those essential for valid forensic science service delivery. The authors are not aware of any but are exploring possibilities for research into and resolution of this issue.

4.3. Education and training

The survey revealed that methods for continuing professional development (CPD) are in place but not universally considered with respect to promotion. The survey also revealed that only 60 % of CPD costs are met by the employing organisations.

This equates to a double whammy with respect to practitioner's CPD. On the one hand they must personally cover a reasonable proportion of the costs and on the other hand what they achieve gains little recognition in terms of promotional opportunities.

Continuous improvement for organisations and CPD for practitioners is essential for maintaining the validity and integrity of forensic science service provision and this should be universally recognised and adopted.

CRediT authorship contribution statement

Wim Neuteboom, Alastair Ross, Lyndal Bugeja, **Sheila Willis, Claude Roux and Kevin Lothridge:** Conceptualisation and Methodology. **Lyndal Bugeja:** Software and Analysis **Wim Neuteboom and Alastair Ross** Original Draft Preparation, **Sheila Willis, Claude Roux and Kevin Lothridge** Reviewing and Editing.

Declaration of Competing Interest

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.forsciint.2023.111779.

References

[1] Gov.Uk, Independent report. Report of the Royal Commission on Criminal Justice (1993), ISBN 0101226322, Cm. 2263.
[2] A. Ross, W. Neuteboom, Implementation of quality management from a historical perspective: the forensic science odyssey, Aust. J. Forensic Sci. (2019), https://doi.org/10.1080/00450618.2019.1704058.
[3] A. Ross, W. Neuteboom, ISO-accreditation - is that all there is for forensic science? Aust. J. Forensic Sci. (2021) https://doi.org/10.1080/00450618.2020.1819414.
[4] F. Crispino, C. Roux, Forensic-led regulation strategies: are they fit for security problem-solving purposes? in: Q. Rossy, D. Decary-Hetu, O. Delemont, M. Mulone (Eds.), The Routledge International Handbook of Forensic Intelligence and Criminology, 2017, pp. 65–76.
[5] D. Hazard, E. Stauffer, P. Margot, Forensic science and the paradigm of quality, in: G. Bruinsma, D. Weisburd (Eds.), Encyclopedia of Criminology and Criminal Justice, Springer, New York, 2014.
[6] Willis SM. Power, process, people—A presentation on quality and competence in forensic science, delivered at EAFS2009. Sci Justice. 2010;50(1):23–25. doi: 10.1016/j.scijus.2009.11.079. [Crossref], [PubMed], [Web of Science ®], [Google Scholar].
[7] StandardsStores - 17025Store, Transitioning from ISO 17025:2005 to ISO/IEC 17025:2017, https://17025store.com/iso-17025-standards/what-is-iso-17025/transition-17025–2005-to-17025–2017/.
[8] UKAS, ILAC-G19:06/2022 Modules in a Forensic Science Process, https://www.ukas.com/resources/technical-bulletins/ilac-g1906–2022/.
[9] C. Roux, C. Weyermann, From research integrity to research relevance to advance forensic science, Forensic sciences research 6 (4) (2021) 292–294.
[10] Forensic Notes, ISO 17025 – Right for Digital Forensics?, https://www.forensicnotes.com/iso-17025-right-for-digital-forensics/.
[11] G. Tully, N. Cohen, D. Compton, G. Davies, R. Isbell, T. Watson, Quality standards for digital forensics: learning from experience in England & Wales, Forensic Sci. Int.: Forensic Investig. 32 (2020), 200905.
[12] P. Sommer, Accrediting digital forensics: what are the choices? Digit. Investig. 3 (4) (2006).
[13] M. Periera, Quality assurance in forensic science, Forensic Sci. Int. 28 (1) (1985) 1–6, https://doi.org/10.1016/0379-0738(85)90159-8.
[14] Connecticut State: Department of emergency services and public protection, crime scene reconstruction, https://portal.ct.gov/DESPP/Division-of-Scientific-Services/_content/Crime-Scene-Reconstruction.
[15] R.M. Morgan, Conceptualising forensic science and forensic reconstruction. Part I: a conceptual model, Sci. Justice 57 (6) (2017) 455–459, https://doi.org/10.1016/j.scijus.2017.06.002.
[16] R.R. Ristenbatt III, J. Hietpas, P.R. De Forest, P.A. Margot, Criminalistics traceology, criminalistics, and forensic science, J. Forensic Sci. 67 (2022) 28–32, https://doi.org/10.1111/1556-4029.14860.
[17] S. Willis, Forensic science, ethics and criminal justice, in: J. Fraser, R. Williams (Eds.), Handbook of Forensic Science, Taylor & Francis Group, 2009 (ProQuest Ebook Central).
[18] C. Roux, R. Bucht, F. Crispino, P. De Forest, C. Lennard, P. Margot, M.D. Miranda, N. NicDaeid, O. Ribaux, A. Ross, S. Willis, Sydney declaration – revisiting the essence of forensic science through its fundamental principles, Forensic Sci. Int. (2022), https://doi.org/10.1016/j.forsciint.2022.111182.
[19] E. Casey, O. Ribaux, C. Roux, Digital transformations and the viability of forensic science laboratories: crisis-opportunity through decentralisation, Forensic Sci. Int. 289 (2018), https://doi.org/10.1016/j.forsciint.2018.04.055.
[20] Roux C., Editorial: Challenges and opportunities of society's digital transformation, Precedent AULA 1; (2020).