

Bridging Knowledge Gaps: A Requirement Elicitation Use case for Digitalizing Calibration Certificates

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Digitalization in metrology is not merely substituting manual processes with software but also incorporating the tactical knowledge of experts into digital systems. This use case explores the application of structured knowledge elicitation methods—such as unified modeling language (UML) diagrams, decision trees, and iterative feedback loops—to formally elicit the tacit knowledge of metrologists and integrate it into a digital system. For example, a calibration certificate typically records the measured value of an instrument, its associated uncertainty, and the date of calibration. These models, combined with cooperative sessions and iterative feedback loops, help translate tacit knowledge into well-defined workflows, ensuring that the resulting system maintains technical accuracy and expert insights. It also helps in ensuring accuracy, regulatory compliance, and stakeholder trust in the digital evolution of metrology.

I. INTRODUCTION

The growing digitalization of scientific and technological processes increasingly requires the collaboration of practitioners from different disciplines [1]. Within metrology this means an expanding requirement for software developers and metrologists to work hand-in-hand with each other to transform conventionally manual and expert-oriented procedures into organized, digital processes [2]. But these two groups have fundamentally distinct worldviews, terminologies, and working methods [3]. The absence of mutual understanding and a common conceptual framework frequently leads to communication barriers that make system design and implementation more difficult [4].

This cross-disciplinary challenge is especially apparent when computerizing intricate manual procedures, like the issuance of calibration certificates. Historically, calibration work is informed by formal procedures and tacit knowledge acquired over many years of practical experience [5]. The result of this process—a calibration certificate—needs to record not only measurement outcomes, but also contextual choices, adjustments, and

expert judgments. While systems are transitioning to create Digital Calibration Certificates (DCCs), the problem does not only involve digitizing measurement data, but also formalizing the decision-making mechanisms preceding certificate creation [6].

A key problem in such attempts is the elicitation and formalization of tacit knowledge. Much of metrologists' work relies on intuition, situational perception, and adaptable judgment but not on strict rules [7]. These types of competence cannot be easily conveyed in the formal logic necessary for software development. For instance, operations like drift correction rely on the subjective judgment of what an "unusual" reading is—a judgment not formally stated but in practice. Software developers, on the other hand, need well-defined conditions, flows, and data models to encode such decisions into executable code [3].

Solving these problems calls for a conscious bringing together of the views. Methods like Unified Modeling Language (UML) diagrams, process flowcharts, decision trees, and recursive feedback sessions can close the knowledge gap between metrology skills and technical design [8]. These methods facilitate co-modeling of processes so that metrologists can represent their tacit knowledge, and developers can optimize system requirements. With systematic cooperation and inclusive design, one can develop systems that embody both technical expertise and everyday know-how [9].

One valuable initiative addressing this cross-disciplinary knowledge divide is the strategic CABUREK Global Programme 2024-25 under the project Metrology for Digital Transformation in International Cooperation (M4DT-IC), coordinated by PTB [10].

At the heart of CABUREK lies its innovative methodology—**Capacity Building in Technical and Scientific Organizations Using Regional Experience and Knowledge**—which promotes the alignment of quality infrastructure (QI) services with user needs through regional collaboration, stakeholder involvement, and user-oriented innovation. Within this general framework, **Working Group 3 (WG3)** is tasked with the

specific issue of Digital Process Management in which 10 NMIs/DI/QI institutes are tasked with developing digital process flows that promote transparency, accessibility, and responsiveness in customer engagement. The WG3 platform has enabled participants—mostly from metrology institutes but not necessarily from IT backgrounds—to learn from each other’s diverse experiences and project environments stakeholders.

This has proven to be essential not only in understanding the functional requirements of digital calibration systems but also in identifying critical non-functional aspects like security, system performance, deployment choices and compliance with national and international policies. Interactive CABUREK Talks were also organized to promote these discussions, encouraging reflection on deployment trade-offs and stakeholder-specific constraints. These peer interactions supplement traditional requirement elicitation techniques by bringing to the surface domain-specific knowledge and cross-cutting issues early in the project life cycle [10].

This paper illustrates a DCC development use case as representative example of cross-domain digital change within metrology. It explains the communication and knowledge elicitation problems faced, methodological tactics employed to cope with them, and the technical lessons learned by the process. The conclusions state the need for ongoing interaction among domain specialists and developers and provide a set of lessons for future efforts [9].

II. USE CASE: DIGITAL CALIBRATION CERTIFICATES AT NPL INDIA

The DCC initiative at CSIR-NPL exemplifies the interdisciplinary challenges involved in mapping metrological competence into ordered digital frameworks. Although DCCs seek to substitute human-readable, paper-based certificates with ordered, machine-readable documents, producing such systems involves both extracting structured data and the experts' implicit reasoning.

A. Key Challenges in Knowledge Elicitation

A.1. Tacit Expertise and Implicit Decisions

Metrologists tend to use tacit knowledge—intuition, experience, and situational judgment—whereas system developers need formal, rule-based logic.

For example, as indicated in Figure 1, properties like `measure_uncertainty` and `uncertainty` are related to calibration choices that do not necessarily have defined thresholds. The vagueness of terms such as "unusual reading" makes them difficult to represent in structured systems.

A.2. Schema Complexity and Interoperability

The DCC ecosystem has complex stakeholder relationships. Figure 2, the stakeholder diagram, exhibits several interconnected parties that range from calibration fees and services through to BIPM/NPL services and CMCs. There is a need for shared schema that reflects both mandatory requirements as well as laboratory-specific differences to achieve interoperability between NMIs.

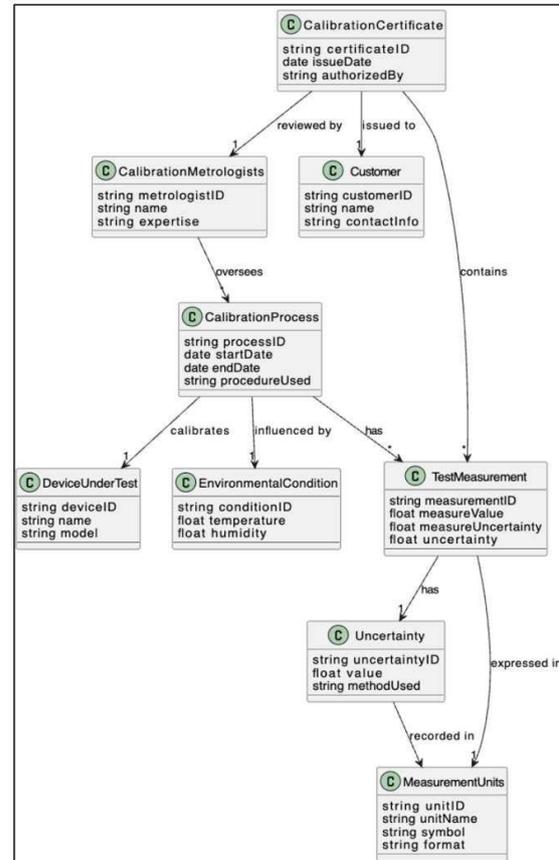


Figure 1 Class Diagram depicting the entities involved in the calibration certificate

A.3. Resistance to Automation

Metrologists are concerned with losing control over decision-making in automatic systems. Since calibration entails high-level judgments (e.g., choosing correction techniques, assessing drift), reliance on system transparency and expert override provisions becomes critical.

A.4. Workflow Complexity

Figure 2 describes a multi-stakeholder calibration process that includes equipment, responsible individuals, customers, services, and environmental information. Representation of these interactions in a modular software

architecture demands precise modeling of relationships, roles, and procedures.

Figure 1 also assists by demonstrating how test measurements, uncertainty, and calibration procedures are logically organized.

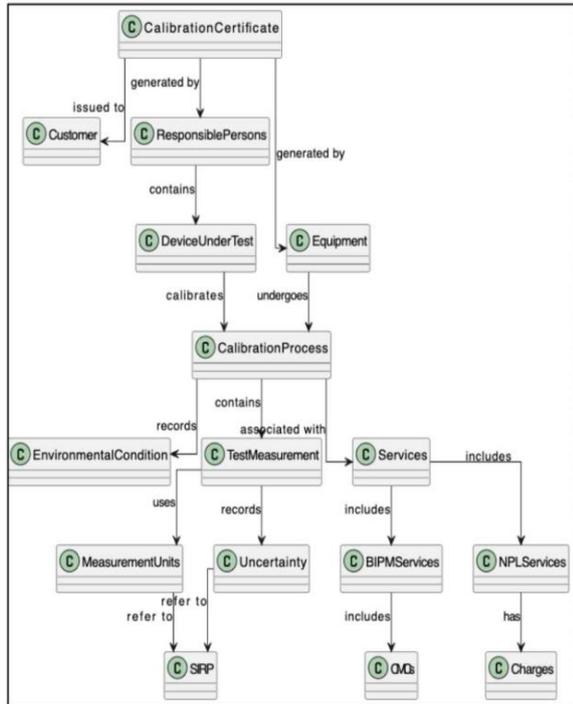


Figure 2 Stakeholder Diagram showing how entities interact in the ecosystem of a digital calibration certificate

B. Addressing the Challenges: Modeling and Implementation

B.1. Structured Modeling of Expert Processes

In order to make decision-making explicit, Unified Modeling Language (UML) diagrams and decision trees are utilized. Figure 1, the class diagram, gives us a template to lay out relationships like CalibrationProcess → TestMeasurement → Uncertainty. Whereas Figure 2 represents the larger stakeholder interactions. Recursive co-modeling sessions enable metrologists to check and tailor representations to align with real-world practices.

B.2. Schema Standardization Using ISO-Compliant Formats

Based on the object model in Figure 1, A unified XML/JSON schema is created which aligns with ISO 17025 requirements. CertificateID, processID, and uncertaintyID attributes were mapped for traceability and platform interoperability.

B.3. Hybrid Reasoning and User-Centric Adoption

To maintain the autonomy of experts, a hybrid reasoning system is used. Rule-based elements performed deterministic logic (e.g., certificate formatting), while AI elements supported anomaly detection (e.g., drift outside normal limits), always needing user consent before execution. Training sessions and phased adoption plans also aid in minimizing resistance by engaging metrologists in hands-on feedback loops.

B.4. Modular Architecture Based on Model-View-Controller Approach (MVC)

With reference to Figure 2, the DCC system is implemented using the **Model-View-Controller (MVC)** architecture—an architectural pattern that separates concerns into three interconnected components: the *Model* (e.g., DeviceUnderTest, EnvironmentalCondition) for handling data and logic, the *View* for user interfaces, and the *Controller* for decision logic and certificate generation. This modular implementation enhances flexibility, simplifies maintenance, and facilitates scalability as the system evolves [11].

B.5. Cross-Disciplinary Knowledge Elicitation through CABUREK

The CABUREK M4DT-IC WG3 offers a collaborative environment where participants, predominantly from metrology institutes, share knowledge and learn from various project experiences. The project enables participants to comprehend not just the functional elements of digital calibration systems but also important non-functional elements, including security, performance, deployment options, and standards compliance.

Through CABUREK M4DT-IC, discussion sessions were arranged to address these issues, facilitating consideration of deployment trade-offs and stakeholder-specific constraints. Peer discussion reinforces standard requirement elicitation methods to guarantee that domain-specific knowledge and cross-cutting concerns are resolved early in the project life cycle.

B.6. Steps Ahead

Numerous initiatives are planned to ensure the continuous development and resilience of the DCC system. Schema compatibility can be confirmed using interoperability testing, and it will facilitate smooth platform-to-platform certificate exchange. Data contextualization can be improved through the integration of semantic web technologies and standardized ontologies. This will allow for better semantic interoperability and intelligent querying. To guarantee the coherence of rule-based and AI-assisted reasoning components, formal verification techniques like model checking can be explored. To reduce the audit burden, compliance automation tools can be created to expedite adherence to ISO/IEC 17025 standards. In conclusion, CABUREK-led partnerships can be extended through workshops, shared repositories, and co-development environments [13]. This can promote inter-institutional knowledge exchange and assist the long-term viability of digital metrology systems.

III. IMPACTS AND LESSONS LEARNED

The development of the DCC system at CSIR-NPL is a step towards a technological revolution and a challenge to knowledge management. As revealed in Figures 1 and 2, the shift required reimagining calibration not only as a technical process but also as a structured, interoperable data ecosystem. The main impacts and synthesized lessons learnt from this use case are highlighted below.

A. Practical Impacts

Structured knowledge representation and traceability by employing object-oriented models facilitated tracing relationships among calibration actors and objects like devices, environmental conditions, uncertainties, and measurement units [4]. Organized representation made traceability of calibration choices more effective, which is crucial for internal audits as well as for international comparisons [6].

Interoperability between metrology systems to develop a schema compatible with ISO/IEC 17025 and compliant with international initiatives like PTB's DCC framework provided semantic interoperability [13]. This provides avenues for cross-border acceptability and automated validation of certificates [5].

Transparency and reproducibility of calibration choices by making formal expert decisions, decision trees and logical models, the system enhanced more transparency regarding uncertainty and measurement corrections derivation. This is particularly vital in fields where reproducibility underpins scientific and legal metrology [8].

Modular and maintainable design to keep the concerns separate through MVC-based design made the logic, interface, and data layers cleanly separated. This modularity makes future modifications—like updating the calibration process or adding new types of services—much more viable.

Empowerment through digital skill-building, piloting the system with active metrologist involvement builds trust and empowered domain experts to participate in system design. It turns the digital transformation into a co-created experience rather than a top-down imposition [10].

B. Generalized Lessons for Digital Transformation in Metrology

Iterative knowledge elicitation is critical, and tacit knowledge cannot be drawn out in one workshop [5]. Rather, iterative cycles with UML models and decision trees—checked by metrologists—guarantee that domain understanding will not be lost in translation. This is in line with knowledge engineering best practice [7].

As observed in Figure 2, calibration data engages with varied services (e.g., BIPM, SIRP, NPL charges). The DCC schema, therefore, needs to be modular and extensible [2]. Utilizing linked data principles and metadata tagging guarantees durability and reusability of digital records [9].

Digitalization must never replace human judgment, particularly in edge cases or uncertain situations. Permitting expert validation at decision points—like uncertainty estimation or environmental anomaly detection—is important for trust [3].

Conformity of the DCC architecture to globally accepted standards such as ISO 17025, brought inbuilt adaptability to the system across NMIs and regional quality infrastructures [2].

Even a technically effective system may break if users do not adopt it. Pilot deployment, incremental training, and incorporation of user feedback at every phase broke resistance and promoted acceleration of adoption—a lesson with wide applicability to digital public infrastructure initiatives [12].

The CABUREK project was instrumental in bridging the knowledge gap between software developers and metrologists. Through interactions among the professionals from different metrology institutes, CABUREK allowed the participants to gain a better understanding of functional and non-functional requirements at the beginning of the project. In this collaborative setting, issues such as security, performance, and compliance with national and international standards were found to be valuable.

Also, CABUREK Talks created a formal forum where these challenges could be addressed, allowing participants to consider in-depth real-world deployment trade-offs. These discussions not only enriched the requirements elicitation but also verified that the resulting system would fulfill the specific needs of each metrology institute while satisfying overarching digital transformation objectives [10].

IV. CONCLUSION

The digital revolution of metrology, with its potential to enhance precision, traceability, and interoperability, brings challenges and cross-disciplinary issues. This research addressed those challenges in the context of the DCC project at CSIR-NPL, in order to make software developers work together with experts in metrology to develop a structured, standard, and forward-looking system.

At the heart of the transformation was the need to bridge the communication divide across two disciplines with inherently different knowledge paradigms—one based on experiential, tacit knowledge and the other on explicit, rule-based representation. Through systematic knowledge elicitation methods like UML diagrams, decision trees, and continuous verification, we can re-express subtle metrological processes as formal models executable in a digital system. This approach enabled common ground and co-creation, reducing requirements ambiguity and enhancing the fidelity of digital models.

The use case illustrates how object-oriented modeling and modular architecture (e.g., MVC) facilitate the system to capture calibration workflow complexity, ranging from uncertainty estimation and environmental conditions to user interaction and secure certificate generation. Most importantly, by using joint modeling and validation

process, metrologists had more confidence in the system, whereas developers obtained domain knowledge that guided improved design decisions.

Application of internationally harmonized standards (e.g., ISO/IEC 17025, JSON/XML schema) guarantee that the resulting DCC system would be compatible with worldwide metrology projects and regulatory schemes [13].

Overall, this research illustrates that successful digital transformation of metrology is more than a technological undertaking but a socio-technical process encompassing repeated knowledge elicitation, co-modeling, and establishment of trust. The integration of digital technologies into metrology requires a systematic approach that balances technical innovation with the preservation of expert knowledge [14].

Through the capture of expert knowledge in an organized and interoperable way, the DCC project paves the way for more intelligent, more transparent, and harmonized metrological services. The methodology and results outlined here are part of the expanding body of global effort toward digital calibration, and provide a guide to follow for subsequent projects that wish to traverse the tangled intersection of measurement science and digital engineering.

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