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Editorial

From Safety and Quality Assurance to Digital Transformation: Emerging Directions in Laboratory Science and Practice

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Abstract

The first six contributions considered in this Editorial provide a coherent view of the modern laboratory as an integrated system of safety governance, digital education, measurement confidence, diagnostic implementation, and clinical quality assurance. The papers considered here address occupational hygiene and health monitoring in university laboratories, the predictive modeling of chemical exposure risks among cleaning staff, the design of an immersive virtual reality laboratory for multidisciplinary student experiences, the evolving concept of measurement uncertainty in accredited laboratories, the field implementation of a near point-of-care HIV drug-resistance assay in Kenya, and the optimization of embryo culture conditions in IVF laboratories. Although these studies span different fields, they converge on a common message: laboratory excellence depends not only on instruments and protocols but also on human factors, training, exposure control, usability, uncertainty management, and translation into real-world decisions. This Editorial synthesizes these contributions and identifies future priorities for *Laboratories* as a forum for interdisciplinary laboratory science and practice.

Keywords: laboratories; occupational hygiene; health monitoring; machine learning; immersive virtual reality; measurement uncertainty; accreditation; point-of-care diagnostics; IVF laboratory; quality assurance

1. Introduction

The laboratory has always been a place where scientific knowledge is produced, verified, and translated. However, the six contributions considered in this Editorial show that the contemporary laboratory is no longer adequately described as a room equipped with instruments and methods. It is a complex operational ecosystem in which health and safety management, digital tools, quality assurance, metrology, user-centered design, and clinical decision-making must work together. The first six papers of *Laboratories* 2026, volume 3, therefore provide a valuable snapshot of a journal scope that is broad, applied, and strongly connected to the real conditions under which laboratories operate (Table 1).

Oosthuizen et al. [1] developed a risk-based occupational hygiene and health monitoring guide for university laboratories and facilities in the Australian context. Hedman [2] proposed an exploratory simulation tool using tree-based machine learning to model chemical exposure risks and asthma-like symptoms among professional cleaning staff in laboratory environments. Cuautle-Gutierrez and Cordero-Guridi [3] presented an immersive virtual reality laboratory designed for multidisciplinary student experiences in a private Mexican university. Pradella [4] reviewed the evolving definition of measurement

Check for updates

Received: 1 June 2026
Accepted: 2 June 2026
Published: 3 June 2026

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uncertainty and its implications for medical, testing, and accredited laboratories. Owiti et al. [5] evaluated the field usability and diagnostic performance of OLA-Simple, a near point-of-care HIV drug-resistance assay, in Kenya [5]. Finally, Mustapha and co-workers [6] reviewed optimization of embryo culture conditions in IVF laboratories, emphasizing quality assurance, key performance indicators, and emerging technologies.

Taken together, these papers demonstrate that laboratory practice is moving toward a more integrated model. Safety can no longer be reduced to incident response; it must include preventive exposure assessments and health monitoring. Education can no longer be limited to physical benches; it must be extended through immersive environments. Measurement reliability can no longer be restricted to numerical standard deviations; it must include uncertainty in qualitative and classificatory results. Diagnostic innovation can no longer be evaluated only in centralized expert laboratories; it must also be tested with intended users in realistic settings. Clinical laboratory performance can no longer be separated from environmental control, quality indicators, and emerging analytical technologies.

Table 1. Thematic overview of the first six contributions considered in this Editorial.

Reference	Laboratory Dimension	Main Contribution	Editorial Relevance
Oosthuizen et al. [1]	Occupational hygiene and health monitoring	A university-specific occupational hygiene and health monitoring (OHHM) guide was developed using industry guidance, university policies, and expert review, then implemented at Edith Cowan University.	Laboratory safety requires structured governance, exposure monitoring, and health surveillance.
Hedman [2]	Predictive occupational risk	A simulated cohort and tree-based models were used to explore links between exposure to cleaning chemicals and asthma-like symptoms.	Computational tools can support prevention when data are scarce but require cautious interpretation and future validation.
Cuautle-Gutierrez and Cordero-Guridi [3]	Digital and educational laboratories	A 45 m^2 immersive virtual reality laboratory was designed and assessed with students from multiple disciplines.	Laboratory education increasingly requires digital immersion, ergonomics, accessibility, and discipline-specific applications.
Pradella [4]	Metrology, uncertainty, and accreditation	The review discussed the definition of measurement uncertainty by the new Joint Committee for Guides in Metrology (JCGM) and its relevance for qualitative and classificatory results.	Accredited laboratories must manage uncertainty even when results are not simple scalar measurements.
Owiti et al. [5]	Decentralized diagnostics	Oligonucleotide ligation assay (OLA)-Simple was evaluated in Kenya for usability and performance as a near point-of-care HIV drug-resistance assay.	Analytical performance must be combined with training, usability, workflow, and implementation feasibility.
Mustapha et al. [6]	Clinical laboratory quality in in vitro fertilization (IVF)	The review synthesized embryo culture conditions, quality assurance (QA), key performance indicators (KPIs), dynamic culture systems, omics biomarkers, and AI in embryo selection.	Clinical laboratory success depends on environmental control, standardized performance indicators, and responsible adoption of emerging technologies.

2. Safety Governance as the Foundation of Laboratory Excellence

The article by Oosthuizen et al. [1] is a timely reminder that laboratory quality begins with the health and safety of the people who work, teach, learn, and conduct research in laboratory settings. University laboratories are distinctive environments. Teaching laboratories are often structured and supervised, whereas research laboratories may involve greater autonomy, changing experimental designs, smaller work groups, and more hazardous or less characterized substances. The authors addressed this complexity by developing a comprehensive occupational hygiene and health monitoring guide tailored to a university context.

A key strength of the guide is its risk-based logic: occupational hygiene monitoring informs the need for health monitoring, rather than treating health surveillance as an isolated administrative requirement. The process also demonstrates how universities can learn from mature industrial safety systems without copying them uncritically. In this case, policies and guidance from the Western Australian mining sector and several Australian universities were examined, reviewed by an industry advisory group of university health and safety managers, and then refined for implementation at Edith Cowan University [1].

This contribution has broad relevance beyond one institution or one national context. Many universities contain laboratories that use volatile organic compounds, particulate-generating technologies, biological materials, reagents, gases, and emerging processes such as additive manufacturing. Yet the governance of exposure assessments and health monitoring is often uneven. The guide presented by Oosthuizen et al. [1] provides a model for creating centralized coordination, defining responsibilities, engaging external expertise when needed, and adapting monitoring strategies to local regulations and institutional structures.

The second safety-related paper, by Hedman [2], complements this governance perspective by showing how predictive analytics might support earlier recognition of occupational risk. The study focused on professional cleaning staff, a group that is essential for maintaining safe and hygienic laboratories but may be underrepresented in laboratory health research. Using a simulated cohort based on occupational exposure patterns, the author compared Decision Trees, Random Forest, Gradient Boosting, and XGBoost to predict asthma-like symptoms associated with exposure to cleaning chemicals. High exposure to hydrochloric acid and ammonia, together with workplace type, emerged as important factors [2].

The editorial significance of this work lies in its preventive imagination. The model is exploratory and simulated, not a replacement for real exposure surveillance. Nevertheless, it illustrates how laboratories may eventually combine exposure inventories, task-based information, health outcomes, and interpretable machine learning to identify higher-risk situations. When linked to robust occupational hygiene programs such as the one proposed by Oosthuizen et al., [1] predictive tools could help laboratories move from reactive compliance to proactive risk management [1,2].

3. Digital Laboratories and the Educational Mission

The laboratory is also a learning space. Cuautle-Gutierrez and Cordero-Guridi [3] addressed this dimension by developing an immersive virtual reality laboratory for undergraduate students in engineering, medicine, architecture, and basic sciences. Their work is relevant because higher education increasingly needs laboratory environments that can expose students to complex systems, spatial reasoning, specialized software, and simulated professional scenarios without always requiring full-scale physical infrastructure or high-risk experimentation.

The proposed facility was not presented as a purely technological novelty. The authors considered physical space, safety, cost, hardware, software, ergonomics, and disciplinary relevance. A 45 m^2 space in a university library maker area was configured with four immersive virtual reality stations. The selected design used suspended screens and stationary

stations, achieving ISO/IEC TR 23842-1 compliance at a lower estimated cost than a more reconfigurable alternative [3]. This is an important practical message: digital laboratory innovation must still obey the same constraints that shape physical laboratories, including safety, accessibility, maintenance, usability, and budget.

The student assessment also offers useful insight. Participants from multiple disciplines identified the experience itself and the ability to view and interact with virtual environments as attractive elements. At the same time, responses revealed interface difficulties, visual adjustment issues, spatial concerns, and occasional discomfort such as dizziness or visual problems [3]. These findings are valuable because they avoid simplistic enthusiasm for immersive technologies. Virtual reality can motivate learning, support spatial understanding, and extend practical experiences, but its adoption must be guided by ergonomics, session design, technical calibration, accessibility, and evidence-based pedagogical evaluation.

For *Laboratories*, this contribution supports a broad view of laboratory education. A modern laboratory journal should welcome studies that examine how laboratory learning is designed, experienced, and improved. The educational laboratory is not only a place for replicating known experiments; it is a space for preparing students to interact with complex professional environments, digital twins, simulation platforms, and multidisciplinary workflows. As immersive and hybrid laboratories expand, future studies should incorporate validated learning outcomes, comparison with conventional practice, long-term skill retention, and the inclusion of students with diverse needs.

4. Measurement Confidence and Accreditation in a Changing Laboratory Landscape

Pradella's [4] review addresses a foundational issue for all laboratories: how confidence in results should be understood and communicated. The paper discusses the renewed Joint Committee for Guides in Metrology (JCGM)'s view of measurement uncertainty, emphasizing that uncertainty should not be restricted to a numerical parameter associated with scalar measurement. In many medical, biological, forensic, molecular, and testing contexts, laboratories produce results that are qualitative, ordinal, nominal, classificatory, or dependent on thresholds and decision rules. For these outputs, traditional expressions of dispersion may be incomplete or unsuitable.

This is not only a theoretical metrology issue. Accreditation standards, such as ISO 15189 and ISO 17025, require laboratories to evaluate and manage measurement uncertainty, but the practical meaning of that requirement becomes complex when the result is a classification, identification, sequence, mutation call, or clinical category [4]. Pradella [4] argues that laboratories should not respond to this complexity by declaring uncertainty irrelevant. Instead, they should use the available ISO guidance, professional expertise, manufacturer information, validation data, and performance characteristics to make uncertainty meaningful for the intended use.

The link between this review and the other papers is strong. The OLA-Simple study, for example, reports sensitivity, specificity, percent agreement, uninterpretable results, mutation-specific limitations, and a modified Sanger sequencing reference [5]. These features are all part of confidence in a diagnostic result. Similarly, predictive risk models must communicate probability, uncertainty, and limitations when used for safety decisions [2]. IVF laboratories must interpret embryo development and selection under controlled but biologically variable conditions [6]. The contribution by Pradella therefore provides a conceptual bridge across the issue: laboratory results are useful only when their uncertainty is understood in relation to decisions.

5. From Centralized Expertise to Field-Ready Diagnostics

The implementation study by Owiti et al. [5] is a strong example of laboratory translation. HIV drug-resistance testing is clinically important, but in many low- and middle-income countries it remains constrained by cost, centralized infrastructure, technical complexity, cold chains, and long turnaround times. OLA-Simple was developed as a near point-of-care assay intended to detect clinically relevant HIV drug-resistance mutations through a simplified workflow that includes lyophilized reagents, lateral-flow detection, and software-guided execution [5].

The study design appropriately combined usability and diagnostic performance. Thirteen laboratory technicians were recruited, including participants with and without prior polymerase chain reaction (PCR) experience. Twelve completed training and attained competency, and most were able to execute the test within six hours. Technician feedback highlighted user-friendly features, including straightforward reagent reconstitution, concise software prompts, and a shorter sample-to-result process than conventional genotyping [5]. This is an essential lesson for diagnostic laboratories: a test that performs well in expert hands may still fail in practice if it is not usable by the people expected to implement it.

The analytical findings were also encouraging. Among 147 archived plasma samples, 132 produced interpretable OLA-Simple results. Compared with Sanger sequencing, the assay achieved high sensitivity, specificity, and percent agreement across selected major HIV drug-resistance mutations [5]. At the same time, the authors were careful to discuss the remaining challenges, including uninterpretable results and mutation-specific performance issues. This balance is valuable because translational laboratory research must identify both readiness and barriers.

The broader implication is that decentralized laboratory systems need technologies that are not only accurate but also teachable, maintainable, quality-controlled, and compatible with regional workflows. In this respect, OLA-Simple fits the same conceptual pattern as the OHHM guide and the IVR laboratory: the laboratory innovation is assessed in relation to users, settings, and implementation constraints [1,3,5].

6. Clinical Quality Assurance: The IVF Laboratory as a Highly Controlled System

Mustapha et al. [6] bring the editorial discussion to the clinical embryology laboratory, where environmental control and quality assurance directly influence patient outcomes [6]. In IVF and ICSI, embryo culture conditions are critical because early embryos are sensitive to oxygen tension, pH, temperature, air quality, culture media, handling practices, and laboratory workflows. The review emphasizes that even small deviations in these conditions may affect embryo development, viability, implantation potential, and, ultimately, clinical success.

Several aspects of the review are particularly relevant to the broader laboratory community. First, the authors highlight the importance of physiological oxygen tension, noting the widespread use of reduced oxygen culture conditions to limit oxidative stress [6]. Second, they emphasize pH regulation and temperature stability as essential for maintaining cellular homeostasis and protecting oocytes and embryos during manipulation. Third, the review discusses laboratory air quality, including volatile organic compounds and other contaminants, linking embryo culture success to environmental monitoring and air filtration strategies [6].

The review also underscores the need for quality assurance and key performance indicators. Fertilization rates, blastocyst formation rates, implantation rates, equipment calibration, culture media validation, and environmental monitoring are not merely administrative data. They are tools for continuous improvement and the early detection of laboratory drift [6]. This view aligns with the broader 2026 issue: whether the topic is

occupational hygiene, diagnostic performance, measurement uncertainty, or IVF culture, laboratory quality depends on sustained monitoring, documentation, and feedback.

Emerging technologies add another layer of opportunity and responsibility. Dynamic culture systems, microfluidics, metabolomics, proteomics, time-lapse imaging, and artificial intelligence may improve embryo selection and personalize laboratory practice [6]. Yet their adoption must be accompanied by validation, transparency, quality control, and clinical accountability. In this sense, the IVF laboratory exemplifies the wider challenge facing all laboratories: innovation should increase reliability and equity, not merely technological complexity.

7. Cross-Cutting Lessons for Laboratories

The first cross-cutting lesson is that laboratory science must be user-centered. The users in these papers include students in immersive learning environments, cleaning staff exposed to irritant chemicals, technicians implementing HIV drug-resistance testing, laboratory professionals managing uncertainty, IVF teams monitoring embryo culture, and institutional safety managers coordinating exposure surveillance [1–6]. Their experiences are not peripheral. They determine whether laboratory systems are safe, trusted, teachable, and effective.

The second lesson is that safety, quality, and performance are inseparable. Occupational hygiene programs protect people and improve institutional accountability [1]. Predictive modeling can support prevention if linked to real monitoring and validation [2]. Digital laboratories must be safe, accessible, and pedagogically meaningful [3]. Measurement uncertainty is part of the quality of every reported result, including qualitative classifications [4]. Near point-of-care diagnostics require both analytical accuracy and operational usability [5]. IVF outcomes depend on controlled culture environments and rigorous KPIs [6].

The third lesson is that digitalization is now embedded in laboratory practice. Machine learning, immersive virtual reality, software-guided assays, probabilistic reasoning, time-lapse imaging, and artificial intelligence all appear across the papers considered here [2–6]. These tools can extend laboratory capability, but they also demand interpretability, validation, data governance, training, and responsible implementation. Digital transformation does not reduce the need for human expertise; it changes the form in which that expertise is applied.

Finally, the six contributions support an editorial view of *Laboratories* as a journal with a deliberately broad scope. Laboratory research should not only include analytical methods, but also safety governance, quality systems, laboratory education, accreditation practice, clinical workflows, user experience, and implementation. Such breadth is not a weakness. It reflects the reality that laboratories are multidisciplinary systems whose performance depends on the integration of science, technology, standards, and people.

8. Future Perspectives

Future submissions to *Laboratories* can build on these directions in several ways. Occupational hygiene studies should move toward prospective exposure datasets, standardized monitoring protocols, and the evaluation of health-monitoring outcomes after implementation. Predictive safety tools should be validated using real-world measurements and designed to complement, not replace, professional judgment. Digital laboratory education should report learning outcomes, usability, accessibility, and cost-effectiveness. Studies on uncertainty should provide practical case examples for molecular, qualitative, and digital workflows. Diagnostic implementation research should integrate analytical performance with training time, workflows, quality control, cost, supply chains, and clinical decision impacts. Clinical laboratory reviews should continue to connect environmental control, KPIs, emerging technologies, and patient outcomes.

https://doi.org/10.3390/laboratories3020007

In conclusion, the first six contributions of *Laboratories* 2026 portray laboratories in transition. They show that laboratory excellence requires safe environments, validated models, immersive and inclusive education, meaningful uncertainty management, field-ready diagnostics, and rigorous clinical quality systems. These priorities should remain central to the journal's editorial identity. The laboratory of the future will not be defined only by its instruments; it will be defined by how reliably, safely, transparently, and effectively it serves science and society.

Conflicts of Interest: The author declares no conflicts of interest.

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