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Student Involvement Model in Laboratory Maintenance According to ISO 17025

Muhsin*, Mohammad Liwa Ilhamdi, Lalu Septiadi Wirandanu

Department of Biology Education, University of Mataram, Mataram, Indonesia
*e-mail: muhsinplp2020@gmail.com

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Abstract: Student engagement in laboratory quality systems is essential for strengthening maintenance compliance and technical competence, particularly when aligned with international standards such as ISO 17025:2017. This study aims to (1) design a student engagement model that complies with the requirements of clauses 6.2.2 and 7.6 of ISO 17025:2017 and (2) analyze the impact of its implementation on improving equipment maintenance compliance and student technical competence. The research design employs an explanatory sequential mixed-methods approach, with a dominant quantitative component and qualitative support. The research subjects included 22 key informants (laboratory coordinators, laboratory heads, technicians, and students) who were selected with purposive sampling. Data were collected through structured questionnaires, in-depth interviews, FGDs, and participant observation. Quantitative data were analyzed using multiple linear regression using SPSS 25, while qualitative data were analyzed thematically. The results showed that the model designed based on four pillars: training, documented participation SOPs, internal audit simulations, and portfolio systems effectively transformed students from passive learners into competent contributors to the laboratory quality assurance system. The implementation of the model was proven to significantly improve maintenance compliance (mean = +1.81) and technical competence (mean = +1.59). Regression analysis confirmed that the model explained 80.2% of the variance in compliance ($R^2 = 0.802$) and 78.1% of the variance in competence ($R^2 = 0.781$), with documentation quality ($\beta = 0.462$; $\beta = 0.423$) as the strongest predictor. Qualitative findings revealed a shift in mindset from obligation to ownership as a key mechanism. This study concludes that the developed model not only aligns with ISO 17025 but also provides a strategic approach to building sustainable quality cultures in educational laboratories.

Keywords: ISO 17025; Laboratory Maintenance; Student Involvement Model.

Introduction

ISO/IEC 17025:2017 establishes critical requirements for equipment maintenance (Clause 7.6) and personnel competence (Clause 6.2) as the foundation for the validity of laboratory test results. This global standard serves as the primary reference for ensuring data reliability, but its implementation in educational laboratories faces significant challenges. Data from the Ministry of Research, Technology, and Higher Education (2023) revealed that only 35% of laboratories in Indonesia fully comply with equipment maintenance requirements according to ISO 17025, with limited human resources and budget as the main constraints. A study examined 120 teaching laboratories in Southeast Asia, revealing that 60% of institutions struggled to meet personnel competency requirements due to a suboptimal ratio of PLP/Technician/Laboratory Assistant to students (1:183) [1]. This situation poses a threat to laboratory accreditation and research quality while also presenting opportunities to develop collaborative models that involve students as part of sustainable solutions.

Suboptimal laboratory equipment maintenance has a systemic impact on the validity of research results, cost efficiency, and work safety. Recent studies have shown that uncalibrated equipment can increase test result deviation by up to 40% [2, 3], while unscheduled maintenance can increase repair costs by up to three times [4, 5]. Furthermore, maintenance failure contributes to 30% of laboratory accidents involving exposure to hazardous materials [6]. These data underscore the urgency of a proactive and documented maintenance system, especially in the context of high-use educational laboratories.

Educational laboratories face complex challenges in meeting ISO 17025 standards due to limited resources and personnel. A field study at the University of Mataram revealed a student-to-teacher ratio of 1:50, which is significantly lower than the SNI 19-17025 standard of 1:20. The workload is increasingly heavy with 90+ practicum courses per year and 20-30 lecturer research projects per year, while 60% of the equipment is more than 10 years old and 15% is even older than 30 years (Internal Audit of the Biology Lab, 2023). This situation is exacerbated by a maintenance budget that only covers 12% of the ideal requirement [7], creating a gap between quality demands and operational capacity.

Student involvement in laboratory maintenance offers a strategic solution that aligns with the principles of experiential learning and the Tri Dharma of Higher Education. Recent studies have proven the effectiveness of this model: student participation in the Gadjah Mada University Biology Laboratory has successfully reduced downtime equipment by 25% through a maintenance rotation system [8]. Furthermore, Student participation in the maintenance rotation program reduced equipment repair response time from 7 days to 2 days [9]. Similarly, the "Student Lab Assistant" program at the Bandung

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Institute of Technology demonstrated a 30% increase in SOP compliance, while also strengthening students' technical competencies [10]. This approach not only addresses resource limitations but also serves as a direct learning medium that supports the dharma of education and research, while providing a tangible contribution to the dharma of community service through more reliable laboratory services.

According to the research results above, several fundamental weaknesses in the model were identified. existing student involvement in laboratory equipment maintenance. Student participation programs have not been integrated with the specific requirements of ISO 17025, particularly regarding maintenance documentation (Clause 7.6) and competency validation (Clause 6.2) [11]. Existing models lack a continuous evaluation mechanism to ensure compliance with quality standards [12]. This condition opens up opportunities for innovation in our research to develop a structured framework that: (1) links student activities to specific clauses of ISO 17025, (2) implements an evidence-based assessment system, and (3) integrates outcome learning with laboratory accreditation requirements. This research introduces a novel value that distinguishes it from previous studies. This model explicitly integrates student activities with the ISO 17025 quality management system, specifically in fulfilling clauses 6.2.2 (personnel competence) and 7.6 (equipment maintenance) through a structured documentation mechanism. This element ensures that we are technically complete and institutionally sustainable.

Based on the gap identification and originality of the model, this study answers two key questions: (1) How to design a student engagement model that complies with the requirements of clauses 6.2.2 and 7.6 of ISO 17025? and (2) How big is the impact of model implementation on improving equipment maintenance compliance and student technical competence in educational laboratories? These questions are designed to test the effectiveness framework both qualitatively (model design) and quantitatively (impact of implementation), while filling the previously identified gaps in the literature. This research has two main contributions: First, in the academic realm, this study develops a work-integrated learning approach. The first to comprehensively integrate student activities with the ISO 17025 quality management system, particularly in clauses 6.2 (personnel competence) and 7.6 (equipment maintenance). Second, practically, this research produces an evidence-based implementation guide that includes: (1) a technical training module, (2) an integrated documentation system, and (3) a periodic evaluation mechanism - a ready-to-use solution package for educational laboratories with limited resources. This dual contribution bridges the gap between higher education theory and internationally standardized laboratory management practices.

This research is limited to the implementation of essential equipment (microscope, autoclave, oven, incubator, analytical balance, spectrophotometer, and PCR) in an educational biology laboratory during a 6-month trial period. This limitation was chosen because: (1) the characteristics of biological instruments require specific maintenance protocols (e.g., biological decontamination), and (2) a duration of 6 months is sufficient to evaluate 1 full cycle of instrument calibration according to ISO 17025. This study does not include a comprehensive financial impact analysis due to limited access to laboratory operational budget data.

Research Methods

This study employs a descriptive design with an explanatory sequential mixed-methods approach, with a dominant quantitative component and qualitative support [13]. The research subjects consisted of 22 key informants selected through purposive sampling, including a laboratory coordinator (1 person), a laboratory head (1 person), technicians (3 people), and students (17 people). Data were collected through triangulation methods, namely participant observation, in-depth interviews, FGDs, and structured questionnaires designed to evaluate indicators based on clauses 6.2 (Human Resources) and 7.6 (Method Validation) of ISO 17025.

Quantitative data were analyzed using multiple linear regression with SPSS 25 to measure the influence of independent variables (training frequency, audit involvement, documentation quality, and portfolio system) on dependent variables (students' technical competence and compliance in equipment maintenance). This analysis aimed to test causal relationships and determine the extent to which model implementation influenced improvements in compliance and competency. Meanwhile, qualitative data from interviews, FGDs, and observations were analyzed thematically to identify contextual variables, operational constraints, and field needs in designing the participation model.

Findings from both approaches were integrated through convergent triangulation to validate and deepen the interpretation of the results. This integration resulted in evidence-based policy recommendations, such as optimizing training frequency, to develop a student engagement model that aligns with ISO 17025.

Results and Discussion

Descriptive Overview of the Implementation Context

Respondent Demographic and Operational Profile

Prior to implementing the student engagement model, a comprehensive baseline assessment was conducted to profile the research subjects and understand the operational context of the Biology Laboratory at the Faculty of Teacher Training and Education, University of Mataram. Overview of the initial conditions (baseline). It is crucial to understand the pre-intervention situation and, subsequently, to accurately measure the model's impact. This study involved 22 key informants selected through purposive sampling to ensure representation of all stakeholder groups integral to laboratory operations. Demographic details are presented in Table 1.

As illustrated in Table 1, students constitute the largest stakeholder group (77.3%), confirming their central role as both users and implementers of the proposed model. The technician group, although small, has significant average experience (8.3 ± 2.1 years), representing a core of institutional knowledge. The gender distribution is fairly balanced across the groups.

The pre-intervention operational profile, collected through in-depth interviews and a baseline questionnaire, revealed significant gaps between current practices and the requirements of ISO/IEC 17025:2017. The findings are summarized in Table 2.

Table 1. Demographic Profile of Research Participants (N=22)

Stakeholder Groups	n	%	Gender (M/F)	Average Age (SD)	Average Lab Experience (Years)
Laboratory Coordinator	1	4.5%	1 / 0	48.0	2.0
Head of Laboratory	1	4.5%	0 / 1	55.0	10.0
Laboratory Technician	3	13.6%	1 / 2	38.7 (5.5)	8.3 (2.1)
Student	17	77.3%	6 / 11	21.4 (1.2)	1.8 (0.9)
Total	22	100%	8 / 14		

Description: SD = Standard Deviation

Table 2. Pre-Implementation Operational Profile of the Model in the Laboratory

No	Aspects (ISO 17025 Clauses)	Pre-Implementation Status	Evidence from Qualitative Data
1	Training & Competence (6.2.2)	Of a nature ad hoc and informal. The average training frequency for students is 0.5 times/semester, primarily focused on basic equipment operation rather than maintenance.	"Training usually happens right before they need to use a particular instrument for their thesis. It's just a short demonstration, not a structured program." (Technician, ID-T01)
2	Participation in Audit	There are none for students. Auditing is seen as a task solely the responsibility of laboratory management and technicians.	"Audit? That's for the lab head and admin staff. It's the students who are audited, not the audit participants." (Lab Coordinator, ID-LC01)
3	Documentation Control	Documentation exists, but it is not easily accessible to students. SOPs are kept in the coordinator's office.	"I know there's an SOP somewhere, but I never actually read it. I just ask the technicians how to do things." (Student, ID-S05)
4	Maintenance Activities (7.6)	Reactive (*reactive*) is not preventive. The technician is solely responsible. Students are explicitly prohibited from touching the equipment for maintenance.	"If something breaks, we just mark it 'Broken' and report it to the technician. We're not allowed to calibrate or even clean the sensitive parts." (Student, ID-S08)
5	Reward & Recognition System	There is no formal system that recognizes students' contributions to quality assurance.	"What reward? Cleaning the lab is part of our job. There's no added value for doing it well." (Student, ID-S12)

Data baseline describes a traditional top-down laboratory management system, where students predominantly act as passive users of the facility, rather than active stakeholders in its quality ecosystem. The lack of structured training, non-involvement in the audit process, and poor integration with the documentation system clearly demonstrate a misalignment with the competency and participation requirements embedded in clauses 6.2.2 and 7.6 of ISO 17025 [14-15]. This operational context underscores the absolute need (clear necessity) for the developed model and provides a benchmark that is definitive for measuring the effectiveness of interventions with rigor.

Initial Challenges and Readiness: Pre-Implementation Thematic Analysis

A thematic analysis of qualitative data from in-depth interviews and focus groups conducted prior to the model's implementation revealed several profound structural and cultural challenges. These challenges not only hinder student engagement but also constitute a significant barrier to establishing a quality culture aligned with the principles of ISO 17025 in educational laboratory environments [16]. These findings confirm the significant (readiness gap) significant difference between ideal and real conditions. Results from the pre-implementation thematic analysis revealed three structural and cultural challenges, which are significant barriers to student engagement and the establishment of an ISO 17025-based quality culture. First, the dominance mindset instrumentalwhich views laboratory equipment maintenance as a purely technical burden, rather than an investment in learning. This perception positions students merely as "users" rather than "partners," thereby delegitimizing their potential role in the quality assurance ecosystem. Second, the challenges of the supporting infrastructure. Stored quality documents (SOPs, logbooks) that use highly technical language, along with a lack of training, create practical barriers to participation. This widens the gap between students and formal procedures, fueling a culture of "asking directly" that neglects documentation. Third, the absence of recognition mechanism (recognition). Formal learning becomes a barrier to motivation. Student contributions are not linked to academic (credits, certificates) or non-academic rewards, so they are perceived as extra work with no value. Without incentives, voluntary participation becomes unsustainable and relies on sporadic personal initiative.

Based on the thematic findings above, it can be concluded that the pre-implementation conditions of the laboratory are not yet ready to adopt a student engagement model that complies with ISO 17025. The challenges faced are multi-dimensional, including cultural aspects (mindset), systemic (documentation & training), and motivational (incentives) [17]. These three challenges reinforce each other, creating a cycle of dependency on technicians and passivity among students. Therefore, the designed model must not only answer "how to engage" but must also be able to overhaul the mindset, simplify the system, and create clear added value for students. Identification of this comprehensive challenge is a critical foundation for designing targeted and realistic interventions.

Student Engagement Model: Integration of Clauses 6.2.2 and 7.6 of ISO 17025:2017

Based on an in-depth analysis of the initial challenges, a student engagement model was designed that aims not only to improve equipment maintenance compliance but also to instill a quality culture and build standardized technical competencies. This model was specifically designed to meet the key requirements of ISO 17025:2017, particularly Clause 6.2.2 (Human Resources and Competencies) and Clause 7.6 (Assuring the Validity of Results, which in this context encompasses equipment maintenance and calibration).

Structural Framework of the Model

The proposed model is designed as a cyclical system (*cyclic system*) which is integrative and consists of four main components: input, process, output, and feedback. The framework of this model is visualized in Figure 1.

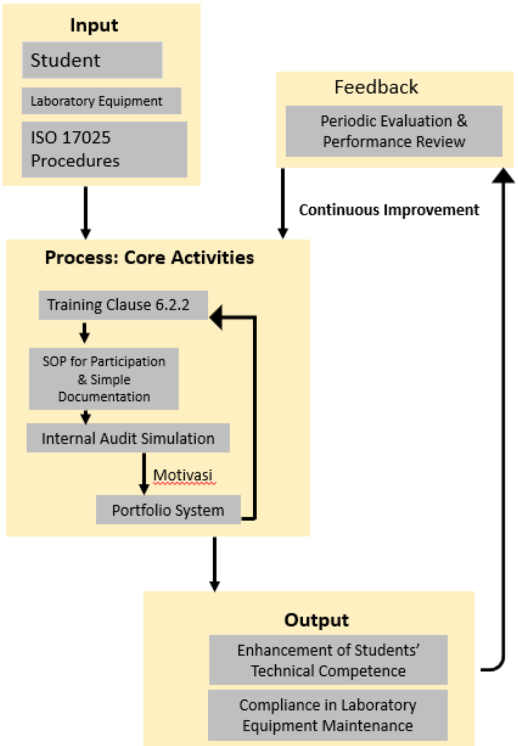

Figure 1. Student Involvement Model in ISO 17025-Based Laboratory Equipment Maintenance

This model converts key input resources—motivated students, laboratory equipment, and ISO 17025 procedures—toward quality assurance goals. Students are positioned as active agents, not mere users, while international standards serve as the definitive framework for all laboratory asset maintenance and calibration activities [18]. The core of the model is a structured series of activities that transform inputs. Through competency training (Clause 6.2.2), participation in documented maintenance using adapted SOPs (Clause 7.6), and internal audit simulations, students experience hands-on experiential learning. This process not only builds technical skills but also instills a deep understanding of the quality philosophy behind each procedure. Direct outputs include documented improvements in student technical competency and verified equipment compliance. To ensure sustainability, a feedback loop in the form of quarterly performance evaluations is implemented. This mechanism, which includes surveys and data reviews, closes the system loop by continuously refining the process (continuous improvement).

Conformity with ISO 17025:2017 Requirements

Based on in-depth analysis, a student engagement model was designed to strategically meet the specific requirements of ISO 17025:2017. This model directly addresses Clause 6.2.2 (Competence) through the implementation of training, thus ensuring that every student performing maintenance tasks has proven competence and that this status can be demonstrated to the auditor, in this case, the laboratory manager. Furthermore, this model aligns with Clause 7.6 (Ensuring Validity of Results) by integrating students into routine monitoring and maintenance activities, such as temperature recording or simple calibration. Each activity is documented in an equipment logbook that provides objective evidence and traceability, audited, proactively ensures the validity of test results and instills a culture of quality within the laboratory.

Furthermore, the model's design was validated by in-depth interviews with laboratory managers, which revealed an urgent need for a new paradigm. Qualitative data from interviews with laboratory coordinators and heads identified three key themes that directly validated the need for the model. First, the imperative to transform students' roles from mere users to strategic partners with a sense of ownership *of* laboratory assets and quality, thus breaking the cycle of indifference. Second, this model is viewed as a long-term investment in capacity building, which equips graduates with competencies, skills, and high-value practices, such as a documentation discipline and an understanding of quality standards. Third, this model is designed to create a sustainable system, reducing dependence on specific individuals by institutionalizing good practices into a cycle that is continuously updated by new students, thus ensuring the sustainability of a culture of quality.

Holistically, this model not only provides technical solutions compliant with ISO 17025:2017 but also offers a strategic framework for building a sustainable quality culture [19]. By combining compliance with international standards and validation of management needs, this model effectively transforms students into competent partners in ensuring the validity of results and the sustainability of laboratory management systems.

Data Analysis

To empirically answer the second research question, descriptive and inferential statistical analyses were conducted on the data collected before and after the model implementation. This analysis aimed to measure the magnitude of the model's impact on two key dependent variables: equipment maintenance compliance level and student technical competence level.

Pre and Post Implementation Comparative Analysis

As a basis for the analysis, descriptive statistical comparisons were conducted for the two dependent variables. Data were collected using a validated structured questionnaire with a 1-5 Likert scale. The results of this comparison are presented in Table 3.

The results presented in Table 4 demonstrate a highly significant increase in both dependent variables following the implementation of the model.

1. The Maintenance Compliance Level experienced a mean increase of 1.81 points (from 2.42 to 4.23). The post-implementation mean score of 4.23 (on a scale of 5) indicates that, on average, the compliance level has been in the "high" category. The decrease in standard deviation from 0.62 to 0.58 indicates that the consistency of compliance behavior among students also became more even after the intervention.
2. The students' technical competence level also showed a mean increase of 1.59 points (from 2.65 to 4.24). This increase reflects the model's effectiveness in transferring specific technical knowledge and skills. As with the compliance variable, the standard. The decreasing number indicates a more homogeneous distribution of competencies among the participants.

From Table 4, it is clear that the sharp increase in both variables provides a strong initial indication that the implemented engagement model has had a substantial positive impact. The greater mean change in the compliance variable compared to competence can be interpreted to mean that the model has not only succeeded in improving individual capabilities but also succeeded in fostering discipline in the consistent application of procedures, a critical aspect of a quality management system. Further analysis using inferential statistics is necessary to test the significance and strength of this relationship, as well as to control for other variables.

Table 3. Comparison of Descriptive Statistics of Dependent Variables Pretest and Posttest Model Implementation (N=17)

Dependent Variable	Period	Mean	Standard Deviation	Minimum Value	Maximum Value	Mean Difference
Maintenance Compliance	Pre-Implementation	2.42	0.62	1.00	3.00	+1.81
	Post-Implementation	4.23	0.58	3.00	5.00	
Technical Competence	Pre-Implementation	2.65	0.71	1.00	4.00	+1.59
	Post-Implementation	4.24	0.55	3.00	5.00	

Results of Multiple Linear Regression Analysis

To test the specific influence of each independent variable on improving competency and compliance, a multiple linear regression analysis was conducted. This analysis allows identification of which variables most significantly contribute to the changes that occur after model implementation.

The results of the regression analysis (Table 4) provide a clear and strong picture of the determinants of model success. The results of the regression analysis confirm the predictive power of the proposed model. The model for technical competence is significant ($F = 20.115$, $p < 0.001$), with $R^2 = 0.781$, while the model for maintenance compliance is even stronger ($F = 22.874$, $p < 0.001$; $R^2 = 0.802$). These findings suggest that the four independent variables collectively serve as highly effective predictors, particularly for evidence-based compliance.

Table 4. Results of Multiple Linear Regression Analysis for Dependent Variables of Technical Competence and Maintenance Compliance

Independent Variables	Technical Competence			Maintenance Compliance		
	B (b)	t	p	B (b)	t	p
(Constant)	0.451	1.210	0.243	0.385	1.117	0.280
Training Frequency (X_1)	0.318 (0.347)	3.112	0.006	0.285 (0.312)	2.891	0.010
Participation in Audit (X_2)	0.229 (0.251)	2.445	0.026	0.261 (0.288)	2.785	0.013
Documentation Quality (X_3)	0.398 (0.423)	3.874	0.001	0.431 (0.462)	4.322	<0.001
System Portfolio (X_4)	0.192 (0.209)	2.101	0.049	0.173 (0.190)	1.989	0.063
R^2		0.781			0.802	
Adjusted R^2		0.742			0.765	
F-value		20.115			22.874	
p (Model)		<0.001			<0.001	
Df		(4.17)			(4.17)	

For technical competence, documentation quality emerged as the strongest predictor ($\beta = 0.423$, $p = 0.001$), followed significantly by training frequency ($\beta = 0.347$, $p = 0.006$), audit participation ($\beta = 0.251$, $p = 0.026$), and portfolio system ($\beta = 0.209$, $p = 0.049$). A similar pattern was observed for Maintenance Compliance, where

Documentation Quality was again the dominant predictor (β = 0.462, $p < 0.001$). Audit Participation (β = 0.288, p = 0.013) and Training Frequency (β = 0.312, p = 0.010) were also significant, but the Portfolio System was not statistically significant (β = 0.190, p = 0.063) for this outcome.

The predominance of documentation quality in both models confirms the hypothesis that structured and accessible procedures are the foundation for competent and compliant performance. The significance of audit participation indicates that a deep conceptual understanding of the 'why' of a procedure is a stronger driver of behavior than training alone. The insignificance of the Portfolio System for Compliance (p = 0.063) indicates that continued compliance is driven more by the internalisation of quality values and integration into the system than by extrinsic incentives, which may only be effective in triggering initial participation. Based on the data analysis results above, it is evident that the regression results not only demonstrate the model's influence but also successfully uncover the mechanisms behind this influence. Documentation quality and audit participation emerged as two of the most critical leverage points for sustainability interventions and the replication of future models.

Quantitative findings not only demonstrate the model's effectiveness but also reveal complex driving mechanisms aligned with quality management theory. Regression analysis confirms that outcome improvement is influenced by dynamic interactions between variables, with competency and compliance playing distinct roles.

Documentation quality emerged as the strongest predictor (β = 0.423 for competence; β = 0.462 for compliance), reinforcing the fundamental proposition that documentation is the backbone of consistency in a quality system. This finding aligns with Smith (2021), who asserted that clear, concise, and accessible procedures are a critical foundation. In the context of high-rotation students, well-managed documentation serves as an "ever-present coach," ensuring reproducibility and reducing instructional variation, thus becoming a most strategic leverage point.

The significance of audit participation (β=0.288 for compliance) reveals an important insight: understanding the 'why' behind procedures is a more powerful driver of behavior than simply knowing the 'how.' This is consistent with quality culture theory (Wilkinson, 2019), which states that true compliance stems from the internalization of quality values. Audit experience transforms maintenance from an administrative task into a meaningful contribution, fostering ownership and voluntary compliance through deep conceptual understanding.

Although the portfolio system did not have a direct, significant impact on compliance (p = 0.063), this finding aligns with Self-Determination Theory (Deci & Ryan, 2000). Portfolios effectively motivate initial student participation, but ongoing compliance with equipment maintenance is driven by intrinsic factors arising from the process itself. Activities such as calibration, documentation, and peer audits—which are recorded in the portfolio—more powerfully fulfill students' intrinsic needs. The need for competence is met by mastering the ISO 17025 standard, autonomy is achieved by being trusted to manage equipment, and connectedness is fostered by contributing to a quality laboratory community. Portfolios are thus not merely extrinsic incentives but rather a means of demonstrating and reflecting their intrinsic engagement [20].

These findings lead to the conclusion that while all model components are important, the optimal strategy for building a sustainable quality culture in educational laboratories is to invest in developing a superior documentation system and creating mechanisms that enable students to understand the holistic context of their work through audits, rather than relying solely on a portfolio system.

Qualitative data analysis reveals the underlying mechanisms driving transformative changes in student engagement models, the impact of which goes beyond significant quantitative improvements in compliance and competency. Thematic analysis identifies a fundamental psychological shift from perceiving maintenance as an external obligation to a sense of ownership (*ownership*) that is internalized. This transition is primarily driven by two key components of the model: formal competency certification, which provides legitimacy and confidence to students, and participation in audit simulations, which provides crucial contextual understanding of the 'why' (the rationale behind every procedure). This fostered ownership is the key driver of the long-term sustainability of this model.

Furthermore, qualitative findings reveal contextual enablers and barriers that quantitative data alone cannot capture. While statistical models confirm the significance of training frequency, observations suggest that a supportive mentoring approach, rather than mere instruction, is the true catalyst for effective learning. The study also uncovered significant operational barriers, such as conflicts with academic deadlines, that hindered consistent participation. Furthermore, peer influence and positive group dynamics emerged as powerful social enablers, reinforcing normative behaviors and fostering collective commitment to quality practices.

Ultimately, the most profound impact of this model is its role as a vehicle for instilling core quality values, which align with Schein's organizational culture model. Students progress beyond simply using quality artefacts (e.g., logbooks) to internalizing shared values such as integrity and accountability. Through participatory and social learning, these values begin to shape core assumptions, evident in the phenomena of self-correction and peer supervision. This triangulation of quantitative and qualitative evidence confirms that the model successfully transforms the laboratory into a cultural learning environment, one that invests in the formation of future scientists with an ingrained quality ethos.

Theoretical and Practical Implications

Theoretically, this study makes a significant contribution to the literature on quality management in higher education by expanding the scope of ISO 17025 implementation. The findings indicate that the elements of non-permanent staff (students) can not only play a role as passive participants, but can also be integrated as active partners and an integral part of the quality assurance system through a structured model. This is achieved by transforming students into competent agents of quality culture, thereby overcoming the traditional paradigm that limits quality responsibility to permanent staff.

A deeper theoretical implication is the strengthening of the concept of participatory quality culture in the context of educational laboratories. This research proves that the internalization of quality values such as integrity, consistency, and responsibility can be built through the mechanism of experiential learning (training, audit simulations) and competency recognition. Thus, this model not only fulfils standard clauses procedurally but also successfully instils basic underlying assumptions, where working according to standards has become a norm that is lived and maintained together by the entire laboratory community [21].

Practically, the findings of this study yield specific and immediately implementable policy recommendations for educational laboratories. First, a top priority should be the development of student-friendly quality documentation. SOPs and logbooks need to be redesigned with clear language, intuitive visuals, and easy digital access. Investments in documentation quality have been shown to have a leverage effect that is greater than simply increasing the frequency of training. Second, the reward system should shift to ongoing, non-material recognition. Providing tiered competency certificates that can be added to academic transcripts or student portfolios is far more effective and less burdensome on the laboratory's operational budget in the long run.

Furthermore, integrating quality assurance activities into the curriculum is a strategic step. Internal audit simulations should be included in the practicum module, so that students not only learn quality theory but also experience its application firsthand. Furthermore, technical training for students should be designed with a mentoring approach, where laboratory technicians are equipped with the skills to be supportive mentors, not just supervisors. Finally, to address fluctuating participation due to academic load, it is necessary to develop an automated reminder system that schedules maintenance activities in consideration of the academic calendar, ensuring system continuity even during busy periods.

Conclusion

Based on comprehensive data analysis, it was concluded that a student engagement model in accordance with ISO 17025:2017 was successfully designed through structural integration between clauses 6.2.2 (Competence) and 7.6 (Assurance of Validity of Results). This model was realized through four main pillars: (1) training, (2) SOP participation in routine maintenance documented in a logbook as objective evidence, (3) internal audit simulation to build a holistic understanding, and (4) a portfolio system. This design directly addresses the literature gap by transforming students from passive users to stakeholders active in the quality assurance system. The implementation of the model proved a significant and substantive impact. Quantitative analysis revealed a significant increase in maintenance compliance (mean = +1.81) and technical competence (mean = +1.59). Linear regression confirmed that the model explained 78.1% (R^2 = 0.781) of the variance in competence improvement and 80.2% (R^2 = 0.802) of the variance in compliance, with documentation quality (β = 0.423; β = 0.462) as the strongest predictor. Qualitative data enrich the findings by revealing the mechanism of change, namely the shift in mindset from obligation to ownership and internalization of quality culture. Thus, this model is not only operationally effective but also strategic in building quality cultures sustainable in educational laboratories.

Author's Contribution

Muhsin: conceptualized the study, developed the research framework, and drafted the manuscript. M. L. Ilhamdi: contributed to the interpretation of the results. L. S. Wirandanu: assisted in manuscript revision.

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References

[1] F. Y. Inbanathan *et al.*, "Assessment of public health laboratory preparedness and response in WHO South-East Asia region during the COVID-19 pandemic: Lessons learned and future directions," *Lancet Reg. Health Southeast Asia*, vol. 31, 2024, Art. no. 100496, doi: 10.1016/j.lansea.2024.100496.

[2] A. Kumar, P. S. Liang, and T. Ma, "Verified uncertainty calibration," in *Adv. Neural Inf. Process. Syst.*, vol. 32, 2019.

[3] B. Fakić, S. Lemeš, B. Muminović, O. Beganović, M. Hadžalić, and K. Varda, "Calibration of test and measuring equipment in pandemic conditions," in *Proc. Int. Conf. New Technol., Dev. Appl.*, Cham, Switzerland: Springer, 2023, pp. 283–290, doi: 10.1007/978-3-031-31066-9_30.

[4] T. J. Weidner, "Planned maintenance vs unplanned maintenance and facility costs," *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 1176, no. 1, p. 012037, 2023, doi: 10.1088/1755-1315/1176/1/012037.

[5] C. Drent, S. Kapodistria, and J. A. C. Resing, "Condition-based maintenance policies under imperfect maintenance at scheduled and unscheduled opportunities," *Queueing Syst.*, vol. 93, no. 3, pp. 269–308, 2019, doi: 10.1007/s11134-019-09627-w.

[6] F. Fatemi, A. Dehdashti, and M. Jannati, "Implementation of chemical health, safety, and environmental risk assessment in laboratories: A case-series study," *Front. Public Health*, vol. 10, Art. no. 898826, 2022, doi: 10.3389/fpubh.2022.898826.

[7] I. N. Handayani, "Pelatihan gerakan sadar inspeksi dan pemeliharaan pencegahan peralatan di UPT Laboratorium Kesehatan Daerah Kota Tangerang," *Int. J. Community Serv. Learn.*, vol.

6, no. 1, pp. 51–60, 2022, doi: 10.23887/ijcsl.v6i1.39213.

[8] J. Fachiroh *et al.*, “Development of a biobank from a legacy collection in Universitas Gadjah Mada, Indonesia: Proposed approach for centralized biobank development in low-resource institutions,” *Biopreserv. Biobanking*, vol. 17, no. 5, pp. 387–394, 2019, doi: 10.1089/bio.2018.0125.

[9] M. A. Maher, A. M. Wofford, J. Roksa, and D. F. Feldon, “Doctoral student experiences in biological sciences laboratory rotations,” *Stud. Grad. Postdoctor. Educ.*, vol. 10, no. 1, pp. 69–82, 2019, doi: 10.1108/SGPE-02-2019-050.

[10] G. Nauryzbayeva and G. Revalde, “Development of technical competence of undergraduate students,” *J. Educ. Sci.*, vol. 61, no. 4, pp. 47–53, 2019, doi: 10.26577/JES.2019.v61.i4.05.

[11] J. A. Nirmalasari, “Teknik pemeriksaan ektoparasit pada komoditas lobster air laut di Balai Besar Karantina Hewan, Ikan dan Tumbuhan (BBKHIT) Bali,” Ph.D. dissertation, Universitas Airlangga, Surabaya, Indonesia, 2024.

[12] F. R. Golra, F. Dagnat, R. Bendraou, and A. Beugnard, “Continuous process compliance using model driven engineering,” in *Proc. Int. Conf. Model Data Eng.*, Cham, Switzerland: Springer, 2017, pp. 42–56, doi: 10.1007/978-3-319-66854-3_4.

[13] W. Wipulanusat, K. Panuwatwanich, R. A. Stewart, and J. Sunkpho, “Applying mixed methods sequential explanatory design to innovation management,” in *Proc. 10th Int. Conf. Eng., Project, Prod. Manag.*, Singapore: Springer, 2020, pp. 485–495, doi: 10.1007/978-981-15-1910-9_40.

[14] E. Dreković, M. Radosavljević, and M. Bejtović, “Analysis of limitations of ISO standards implementation from the external stakeholders’ point of view,” *Facta Univ., Ser.: Econ. Org.*, pp. 117–134, 2021, doi: 10.22190/FUEO210402010D.

[15] A. Rodima *et al.*, “ISO 17025 quality system in a university environment,” *Accredit. Qual. Assur.*, vol. 10, no. 7, pp. 369–372, 2005, doi: 10.1007/s00769-005-0011-x.

[16] D. Zapata-García, M. Llauradó, and G. Rauret, “Experience of implementing ISO 17025 for the accreditation of a university testing laboratory,” *Accredit. Qual. Assur.*, vol. 12, no. 6, pp. 317–322, 2007, doi: 10.1007/s00769-007-0274-5.

[17] B. Javed and A. Akhlaq, “A systematic review of exploring the multiple dimensions of data-driven culture,” *Int. J. Trends Innov. Bus. Soc. Sci.*, vol. 2, no. 4, pp. 522–536, 2024, doi: 10.48112/tibss.v2i4.953.

[18] World Health Organization, *Laboratory Quality Management System: Handbook*. Geneva, Switzerland: WHO, 2011.

[19] S. Pillai, J. Calvert, and E. Fox, “Practical considerations for laboratories: Implementing a holistic quality management system,” *Front. Bioeng. Biotechnol.*, vol. 10, Art. no. 1040103, 2022, doi: 10.3389/fbioe.2022.1040103.

[20] C. Clark, T. K. Chow-Hoy, R. J. Herter, and P. A. Moss, “Portfolios as sites of learning: Reconceptualizing the connections to motivation and engagement,” *J. Literacy Res.*, vol. 33, no. 2, pp. 211–241, 2001, doi: 10.1080/10862960109548110.

[21] E. H. Schein, *Organizational Culture and Leadership*, vol. 2. Hoboken, NJ, USA: Wiley, 2010.