Original Article

Optimising Laboratory Efficiency by Reducing Pre-Analytical Redo Testing: Impact of a Structured Staff Training Intervention in Urban and Rural Hospital Biochemistry Laboratories

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Abstract

Background: Pre-analytical errors are a major source of laboratory errors and can lead to specimen rejection, repeat testing, delayed diagnosis, increased healthcare expenditure, and compromised patient safety. Competency-based education may improve healthcare workers' practices and strengthen laboratory quality. However, evidence comparing its effectiveness in urban and rural healthcare settings remains limited. **Materials and Methods:** A retrospective quasi-experimental pre- and post-intervention comparative study was conducted in the biochemistry laboratories of one urban tertiary-care teaching hospital and one rural secondary-care hospital in West Bengal, India. The study included 49,524 laboratory specimens and 65 healthcare personnel involved in pre-analytical activities. A structured competency-based educational programme covering patient identification, specimen collection, labelling, transportation, specimen acceptance and rejection, prevention of haemolysis and clots, quality assurance, documentation, and incident reporting was implemented. Pre-analytical redo rates, staff competency scores, and repeat-testing expenditure were assessed before and after the intervention. Wilcoxon signed-rank test and linear regression were used for statistical analysis. **Results:** The urban laboratory redo rate decreased from 0.2693% to 0.0700%, representing a 74.0% reduction, while the rural laboratory rate decreased from 4.0087% to 1.6415%, representing a 59.1% reduction. A significant downward trend in monthly redo rates was observed in both the urban laboratory ($R^2 = 0.799$, $p = 0.0028$) and rural laboratory ($R^2 = 0.668$, $p = 0.0132$). Staff competency improved significantly in three of the four assessed groups. In the urban laboratory, competency increased among technologists from 8.13 ± 1.41 to 16.80 ± 1.45 ($p < 0.001$) and nursing personnel from 5.05 ± 1.61 to 14.95 ± 1.39 ($p < 0.001$). Rural nursing personnel improved from 4.60 ± 2.12 to 11.60 ± 2.80 ($p = 0.0019$). The urban laboratory achieved a net saving of ₹9,263, whereas the rural laboratory incurred an additional **₹135,963** in repeat-testing expenditure because of increased specimen workload. **Conclusion:** The structured competency-based educational programme was associated with improved staff competency and substantial reductions in pre-analytical laboratory redo rates in both urban and rural settings. The findings suggest that competency-based education can strengthen laboratory quality and patient safety; however, sustained improvement requires continuous quality monitoring, appropriate workload management, supervision, adequate infrastructure, adherence to standard operating procedures, and an effective laboratory quality management system.

Keywords: Pre-analytical errors; competency-based education; laboratory quality; specimen rejection; patient safety; quality improvement.

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Introduction

Lab reports play a crucial role in providing safe and effective patient care. Laboratories are a key element in the clinical practice of healthcare providers for diagnosing diseases, choosing the right treatment, determining whether it is effective and monitoring disease activity. A high standard of laboratory quality is essential to ensure high quality of medical care since a large percentage of clinical decisions are based on laboratory investigations. Despite the modernisation of laboratory instrumentation and analytical techniques that has significantly improved the precision of laboratory testing, errors that take place before the sample analysis occur most often.

Pre analytical phase encompasses all activities performed from the moment that a laboratory test is requested to when the sample is ready for analysis. These activities include proper identification of the patient, test request completion, specimen collection, labelling, transport, processing and storage. Any error in these steps can make specimens less reliable to test and cause changed quality of the specimen. Pre

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analytical issues are very common, such as specimen is haemolysed, insufficient sample volume, bad labelling, collection container used was inappropriate, clots in sample, specimen sample not collected, specimen is not collected properly. These deficiencies can cause specimen rejection, repeated sampling, delay in clinical diagnosis, avoidable healthcare expenditure, length of hospital stay and loss of patient trust in the laboratory.

It has been determined that reducing pre analytical errors is most effectively achieved by improving the competency of staff. Structured education, compliance with standard operating procedures, competency assessment and regular monitoring of lab quality indicators are some of the quality improvement programmes that have been performed in the past to improve lab performance. Continuous staff education and systematic quality control are also recommended by international requirements and/or professional know-how, in order to ensure consistency and safety of the patient. The effectiveness of these interventions may vary on the organisational level (for example, resources availabilities, supervise, infrastructure, workload and staffing).

In the Indian healthcare delivery system, few studies have looked at whether learning programs based on competency can achieve equivalent outcomes in laboratories with varying organizational environments. It is usually found that urban tertiary care laboratories are better equipped, have trained staff and well established quality systems while rural secondary care laboratories may experience manpower constraints, infrastructure issues, and resource constraints. Evaluating educational interventions in these contrasting environments is therefore important for identifying practical and sustainable strategies to improve laboratory quality across diverse healthcare settings.

With this perspective, the present study was designed to determine the effectiveness of a structured competency-based educational intervention in improving pre-analytical laboratory quality indicators in the biochemistry laboratories of an urban tertiary-care teaching hospital and a rural secondary-care hospital in West Bengal, India. The study assessed changes in laboratory redo rates, competency levels of healthcare personnel, expenditure associated with repeat testing, and overall laboratory performance before and after implementation of the educational programme.

Materials and Methods

Study Design: The present investigation adopted a retrospective quasi-experimental pre-intervention and post-intervention comparative design to determine the effectiveness of a structured competency-based educational programme on pre-analytical laboratory quality indicators. Laboratory performance was evaluated before and after the intervention in an urban tertiary-care teaching hospital and a rural secondary-care hospital, allowing assessment of the programme's effectiveness under different organisational and healthcare environments.

Study Setting: The research was carried out in the Departments of Biochemistry of two healthcare institutions in West Bengal, India: an urban tertiary-care teaching hospital located in Kolkata and a rural secondary-care hospital situated in Midnapore. The study was conducted over an eight-month period, from January to August 2025. Both laboratories routinely perform clinical biochemistry investigations; however, they differ in terms of patient load, workforce availability, operational workload, and laboratory infrastructure. These contrasting characteristics provided an appropriate setting to assess the effectiveness of the competency-based educational intervention under different healthcare delivery conditions.

Study Participants: The study involved healthcare personnel who were directly responsible for activities performed during the pre-analytical phase of laboratory testing. These responsibilities included patient identification, venous blood specimen collection, specimen labelling, transportation, processing, and acceptance of samples for laboratory analysis.

A total of 65 healthcare professionals participated in the study. Of these, the urban tertiary-care hospital included 30 laboratory technologists and 20 nursing personnel, while the rural secondary-care hospital contributed 5 laboratory technologists and 10 nursing personnel. All eligible staff members who remained in service throughout both the pre-intervention and post-intervention periods were included in the study.

Inclusion Criteria

- Laboratory technologists and nursing personnel actively engaged in specimen collection and other pre-analytical laboratory activities.
- Healthcare personnel who were employed continuously during both the pre-intervention and post-intervention phases of the study.
- Staff members who willingly participated in the competency-based educational programme.

Exclusion Criteria

- Healthcare personnel appointed after commencement of the intervention.
- Staff members who were not directly involved in specimen collection or pre-analytical specimen handling.
- Personnel who were absent during the competency evaluation process.

Educational Intervention: Using the institutional standard operating procedures, the structured competency based educational programme was designed based on the internationally recognised laboratory quality management guidelines. The programme included active learning methods, hands-on skill development sessions, demonstrations, supervised skill development sessions, competency assessment and feedback.

The educational content covered correct patient identification, venous blood collection procedures, labelling of specimens, safe transportation of specimens, acceptance and rejection criteria, avoidance of haemolysis and clots, quality assurance procedures, specimen safety in the laboratory, infection prevention, documentation procedures, and incident reporting. Only slight adjustments were made in both hospitals to incorporate local workflow procedure needs, when implementing standardised teaching materials and competency assessment checklists.

Data Collection: To assess pre-analytical redo rates after and before the introduction of the educational programme, laboratory quality records were analysed on a monthly basis in a retrospective fashion. The pre-intervention data was gathered during January to March 2025 and the post-intervention data collected from April to August 2025.

To evaluate the competency of HCPs before and after the training programme, structured knowledge questionnaires and tools for measuring procedural competency were used. An institution laboratory expenditure record analysis was also carried out to derive the repeat laboratory test operational costs due to pre-analytical errors.

Outcome Measures: The main outcome measures were overall pre-analytical laboratory redo rate, laboratory competency scores of laboratory personnel and operational expenditure due to repeat laboratory tests. The secondary outcome measures were monthly redo rates, effectiveness of intervention in the urban vs rural hospitals and percentage reduction of pre-analytical laboratory errors after implementing the competency based educational programme.

Statistical Analysis: The data were fed into the computer software Micro Soft Office Excell and analyzed using suitable statistical software. The continuous variables were summarised as mean ± standard deviation, median, minimum, maximum, frequencies and percentages as appropriate. Wilcoxon signed-ranked test was used to analyse the differences between competency scores before and after the intervention. Simple linear regression analysis was used to evaluate monthly redo rates and two-way analysis of variance (ANOVA) was used to compare redo rates between hospitals after the simple linear regression. A p-value of < 0.05 (two-tailed) was considered statistically significant.

Ethical Considerations: Before the research activities began, the appropriate institutional authorities gave permission to conduct the study. The goal and methodology of the investigation were explained to all the eligible healthcare staff and the participation in the educative programme was made voluntary. Written informed consent was obtained prior to competency assessment and training from each participant.

All laboratory records were anonymised and coded in order to protect confidentiality, that is no participant or patient with their personal information could be identified. Only the research team had access to the study data and all information was used only for the purposes of the research. The study was conducted following the ethical guidelines and principles involving human participants as detailed in the Declaration of Helsinki, and respecting the relevant institutional ethical principles and studies guidelines.

Results

Pre-analytical Redo Rates Before and After the Educational Intervention: During the study period, a total of 49,524 laboratory specimens from both healthcare institutions were included in the analysis. At baseline, the urban tertiary-care laboratory exhibited a relatively low pre-analytical redo rate of 0.2693%, whereas the rural secondary-care laboratory recorded a considerably higher redo rate of 4.0087%, indicating a greater burden of pre-analytical errors.

After the competency-based educational programme was introduced, a notable improvement in laboratory performance was observed at both sites. The urban laboratory reduced its redo rate from 0.2693% to 0.0700%, reflecting a 74.0% relative reduction in pre-analytical errors. Similarly, the rural laboratory achieved a decline in redo rate from 4.0087% to 1.6415%, representing a 59.1% relative reduction. Although the percentage of redo samples decreased substantially in the rural setting, the total number of repeat specimens increased because the laboratory processed a much higher volume of samples during the post-intervention period.

Table 1: Summarises the comparative pre- and post-intervention laboratory performance.

Hospital	Study Period	Total Specimens (n)	Redo Specimens (n)	Overall Redo Rate (%)	Mean Monthly Redo Rate (%)	SD (%)	Median (%)	Range (%)
Urban Laboratory	Pre-intervention (Jan–Mar 2025)	18,941	51	0.2693	0.2698	0.0470	0.2548	0.2322–0.3225
	Post-intervention (Apr–Aug 2025)	20,007	19	0.0700	0.0703	0.0195	0.0593	0.0300–0.0929
Rural Laboratory	Pre-intervention (Jan–Mar 2025)	3,692	148	4.0087	4.0816	1.1263	4.0750	2.9586–5.2111
	Post-intervention (Apr–Aug 2025)	6,884	169	1.6415	1.6697	0.2612	1.6000	0.6300–1.9587

Monthly Trend of Pre-analytical Redo Rates: Monthly monitoring demonstrated a consistent decline in redo rates throughout the post-intervention period.At the urban laboratory, redo rates progressively decreased from 0.09% in April to 0.03% in August 2025.Similarly, the rural laboratory demonstrated an overall downward trend from 1.96% in April to 0.95% in August, despite considerable fluctuations in monthly specimen volume.

Staff Competency Assessment: Following the educational intervention, competency scores improved significantly among both laboratory technologists and nursing personnel.

In the urban laboratory, technologists demonstrated an increase in mean competency score from 8.13 ± 1.41 to 16.83 ± 1.42, while nursing staff improved from 4.80 ± 1.52 to 14.73 ± 1.48.The rural laboratory also demonstrated substantial improvements, with technologists increasing from 2.80 ± 1.30 to 14.20 ± 1.79 and nursing personnel from 4.60 ± 2.12 to 11.60 ± 2.80.

Detailed competency results are presented in [Figure 2]

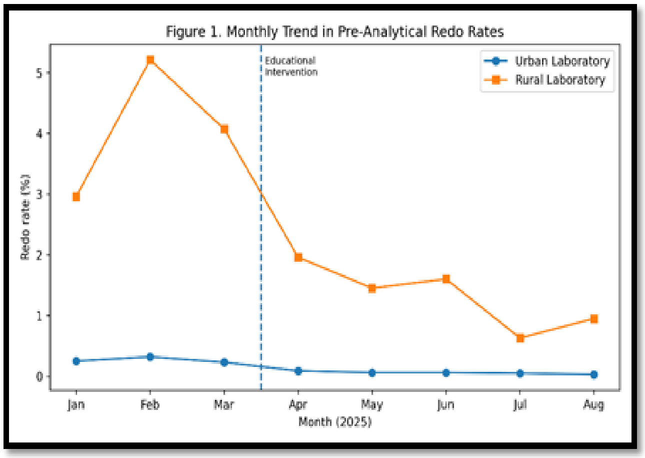
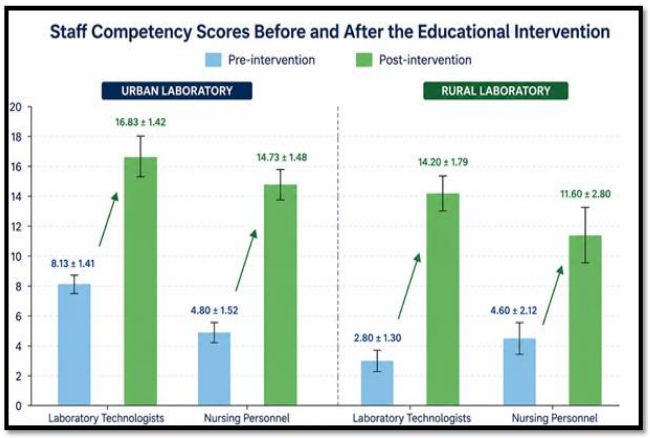


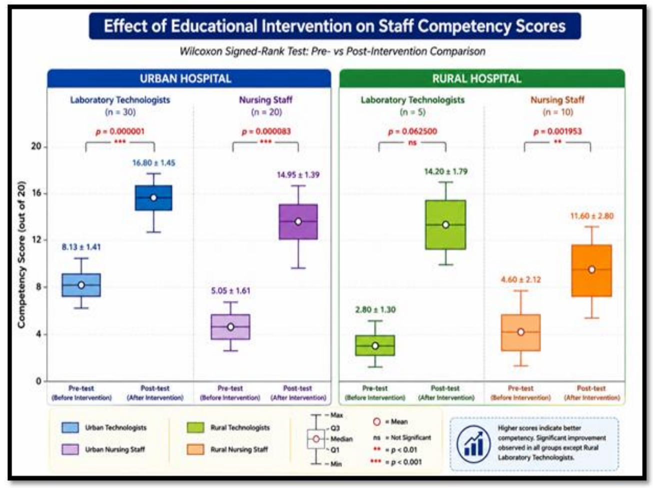
Figure 1: illustrates the monthly trend in redo rates.



Effect of Educational Intervention on Staff Competency: The Wilcoxon signed-rank test was used to evaluate changes in staff competency scores before and after the educational intervention (Table 5). In the urban laboratory, both laboratory technologists and nursing personnel demonstrated statistically significant improvements in competency scores following training. Mean scores increased from 8.13 ± 1.41 to 16.80 ± 1.45 among technologists ($p < 0.001$) and from 5.05 ± 1.61 to 14.95 ± 1.39 among nursing personnel ($p < 0.001$).

In the rural laboratory, nursing personnel also showed a statistically significant improvement in competency scores, increasing from 4.60 ± 2.12 to 11.60 ± 2.80 ($p = 0.0019$). Although laboratory technologists demonstrated a marked increase in mean scores from 2.80 ± 1.30 to 14.20 ± 1.79, the difference did not reach statistical significance ($p = 0.0625$), likely because of the small sample size ($n = 5$).

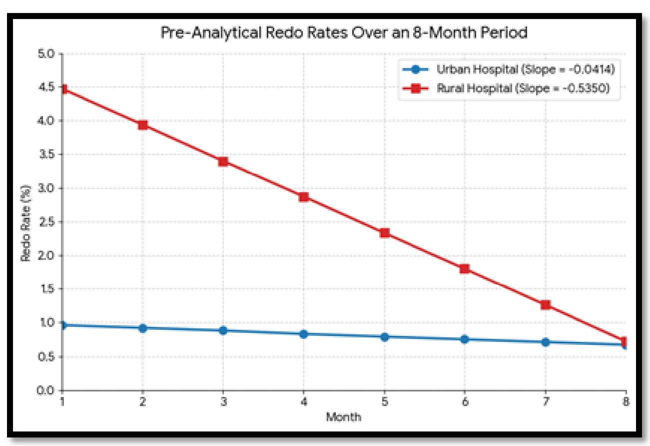
Overall, the findings indicate that the structured educational intervention significantly improved staff competency, with statistically significant improvements observed in three of the four study groups. Pre- and post-intervention competency score distributions are presented in [Figure 2], and the Wilcoxon signed-rank test results are summarised in [Figure 2].



Trend Analysis: Linear regression analysis demonstrated a significant downward trend in pre-analytical redo rates following implementation of the competency-based educational intervention in both hospitals (Figure 3). In the urban laboratory, the regression model showed a significant monthly decline in redo rates (slope = −0.0414, $p = 0.0028$), explaining 79.9% of the observed variation ($R^2 = 0.799$). Similarly, the rural laboratory demonstrated a significant reduction in redo rates over time (slope = −0.5350, $p = 0.0132$), with the model explaining 66.8% of the variation ($R^2 = 0.668$).

Although the rural laboratory exhibited a higher baseline redo rate than the urban laboratory, both institutions demonstrated a sustained reduction in pre-analytical errors throughout the study period. These findings indicate that the structured educational intervention was associated with a progressive improvement in laboratory performance across both healthcare settings.

[Figure 4] Linear regression analysis showing monthly trends in pre-analytical redo rates before and after implementation of the structured educational intervention in the urban and rural laboratories. Regression lines demonstrate statistically significant reductions in redo rates over time in both institutions.



Cost Analysis: The economic impact of the competency-based educational intervention differed substantially between the two study hospitals (Table 6). In the urban teaching hospital, the number of repeat (redo) laboratory specimens decreased from 51 during the pre-intervention period to 19 following the intervention, representing a 62.7% reduction. Correspondingly, the estimated expenditure associated with repeat testing declined from 14,763 to 5,500, resulting in a net cost saving of 9,263. Post-intervention competency assessment demonstrated that 53.3% of laboratory technologists and 5.0% of nursing personnel achieved the predefined "well-trained" competency level. The mean competency score increased by 8.7 points among technologists and 9.7 points among nursing personnel.

In contrast, the rural hospital recorded an increase in the absolute number of repeat specimens from 148 to 169 during the post-intervention period. This increase occurred despite a reduction in the overall redo rate because of a marked increase in specimen workload. Consequently, expenditure attributable to repeat laboratory testing increased from 9,58,213 to 1,094,175, corresponding to an additional operational cost of 1,35,963. Although competency scores improved following the educational programme (mean improvement: 11.4 points among technologists and 6.7 points among nursing personnel), no participant achieved the predefined "well-trained" competency category.

Overall, the intervention was associated with substantial operational and financial benefits in the urban laboratory, whereas the rural laboratory demonstrated improvements in staff competency without a corresponding reduction in total expenditure related to repeat testing.

Table 2: Comparative Cost Analysis and Staff Competency Outcomes Before and After the Educational Intervention

Outcome Measure	Urban Medical College & Hospital	Rural Hospital
Pre-intervention redo specimens	51	148
Post-intervention redo specimens	19	169
Relative change in redo specimens (%)	−62.7	+14.2
Pre-intervention expenditure (₹)	14,763	958,213
Post-intervention expenditure (₹)	5,500	1,094,175
Net financial impact (₹)	9,263 saved	135,963 additional cost
Technologists classified as well-trained (%)	53.3	0.0
Nursing personnel classified as well-trained (%)	5.0	0.0
Mean improvement in technologist competency score	+8.7	+11.4
Mean improvement in nursing competency score	+9.7	+6.7

Discussion

The results obtained from the present study reveal that the educational programme based on SCP was effective in enhancing the pre-analytical laboratory quality in both the participating healthcare institutions. Laboratory redo rates have decreased, staff competency has increased and monthly quality indicators have improved since the implementation of the intervention. The results show that judicious education programs can reinforce laboratory practices and enhance the quality of pre-analytical procedures. The larger effect size in the urban lab however, implies that institutional support structures, quality assurance mechanisms, and organizational structures are also crucial to unlocking the potential for educational interventions.

Both hospitals were analysed and compared in terms of the discrepancy of improvement. The urban tertiary-care laboratory saw a 74.0% decrease in the redo rate while the rural secondary-care laboratory saw a 59.1% decrease in the redo rate. The volume of specimens collected increased significantly in the rural hospital following training, while this was not the case for personnel in the urban hospital. This increased workload had an adverse effect on the programme, despite a performance boost by staff. The above observations suggest that quality improvement can be achieved only by implementing education programs that are accompanied by effective workflow management, consistent supervision, routine implementation of standard operating procedures, and a quality assurance system.

The positive impact on staff competency after the educational programme has been observed, which is corroborated by the evidence from previous studies, that competency-based training has a positive effect on compliance with recommended preanalytical laboratory procedures. Furthermore, the significant decrease across months of redo rates after the intervention indicated that the intervention's effect was long lasting and not short-lived. This exemplifies internationally accepted laboratory quality standards, such as those of ISO 15189 and the CLSI recommendations, which recommend regular competency testing, regular monitoring of quality indicators, and ongoing professional development as critical components of laboratory quality management.

The economic analysis was also shown to be relevant to the practice of staff competency investment. This saved money in the urban lab, which could be measured in the drop in repeat testing. However, the overall expenditure at the rural laboratory increased due to the increase in specimen workload, while the rural quality indicators of the lab improved following intervention. Combined, these findings indicate that competency based education is best suited when implemented within a comprehensive programme of quality improvement which includes ongoing staff training and development, adherence to standard operating procedures, regular quality audits, monitoring of performance and ongoing organisational commitment. An integrated approach should yield sustained improvement in the quality of laboratories, operational efficiency, and patient safety.

Strengths: This present study has several strengths which contributes to the credibility and usefulness of the results obtained. One of the strengths lies in the comparison of the same competency based educational intervention in two Health Care Institutions, with varying organisational and service delivery environments, enabling the effectiveness of this educational intervention to be explored in actual practice. A further benefit is the comprehensive evaluation strategy, linking laboratory indicators with competency assessment of HCWs, over time and economic evaluation to deliver a wider understanding of the impact of the intervention. Performance in the laboratories was monitored over an extended period of 8 months which allowed for assessment of improvements over time, not just those occurring directly after training. Furthermore, the involvement of the nursing staff and laboratory technologists highlighted the collaborative nature of pre-analytical phase of the testing process, which also enhanced the value of research for application in routine laboratory quality improvement programmes and patient safety practices.

Limitations: Although strong, there are a number of limitations of the study that need to be taken into account when considering the findings of the study. The design is retrospective quasi-experimental which means determining “cause-effect” relationship between the educational intervention and the observed improvement is not possible. Additionally, with relatively few laboratory technologists at the rural hospital, the small sample size restricted statistical power for comparisons of in-depth subgroups. The results of the investigation should not be fully generalizable to other laboratories with different organizational features or health care systems. Moreover, the study mostly included the lab-related quality indicators, operational outcomes, but not clinical outcomes with respect to the patients or indirect healthcare costs.

Recommendations: Future initiatives in the laboratory to improve the quality of the new quality improvement should also include the educational programs based on competency development and pre-analytical orders that are well defined, periodic evaluation of the competency level of staff, organizational structures of audit and feedback, and continual evaluation of quality indicators. Larger and more comprehensive multicentre prospective studies are recommended to assess the long-term efficacy, sustainability and cost-benefit effects of such measures. Further research should also be conducted to measure patient-centered outcomes and determine how applicable these quality improvement techniques can be in a variety of healthcare environments.

Conclusion

A competency-based education program using a structured framework resulted in increased staff competency and continued reduction in pre-analytical laboratory errors in both healthcare environments. The urban laboratory experienced a 74.0% decrease in redo rates, as well as measurable saving due to the reduction in repeat testing, whereas the rural laboratory experienced a 59.1% decrease despite having more specimens to process in the post-intervention period. The findings suggest that competency-based training can be useful for enhancing laboratory performance but it is important to accompany it by a comprehensive quality management system, regular performance monitoring, continuous measurement and control of quality indicators and organizational support. This holistic approach can contribute to the promotion of quality in the laboratory, operational efficiency and support the safety of patients.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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