

Gain in knowledge among participants of the ALAMIME program for malaria control in nine African countries: pre-post evaluation of online and in-person learning modalities

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Abstract

Context

Capacity building in leadership and management is essential for resilient health systems committed to malaria elimination. The African Leadership and Management Training for Impact in Malaria Elimination (ALAMIME) programme, implemented in nine African countries, is based on a hybrid pedagogical approach combining online learning and in-person sessions. This study aimed to evaluate the evolution of participants' knowledge before and after the training and to examine differences in performance according to the modules and learning modalities.

Methods

We conducted a quasi-experimental pre-test/post-test study without a control group, using secondary data from three ALAMIME cohorts between 2022 and 2024, including 602 participants. The analysis of cognitive performance was limited to participants in cohort 3 with usable pre-test and post-test data. Modules 1 and 3 were mainly delivered online, while modules 2 and 4 were organized in-person. The scores were analyzed using absolute gains and average improvement percentages. A mixed linear model was used to account for heterogeneity between countries.

Results

Knowledge scores improved in all four modules. Overall, the average scores increased from 53.25 to 68.75 for module 1, from 44.09 to 71.70 for module 2, from 43.52 to 69.62 for module 3, and from 54.57 to 74.62 for module 4. The overall relative improvements were 33.29%, 47.61%, 46.38% and 43.29%. The mixed model showed that, compared to module 1, modules 2 and 3 were associated with significantly higher gains, with variability across countries. The largest gains were observed on a recurring basis in Tanzania and Burkina Faso.

Conclusion

The ALAMIME program is associated with a substantial improvement in the knowledge of professionals involved in malaria control. These cognitive achievements provide an important foundation for the further development of leadership, governance and management skills. The results support the interest of a structured hybrid training model in African contexts, while calling for further research on the optimal balance between online and in-person components.

Introduction

Malaria remains one of the most significant global public health challenges. According to the World Health Organization, more than 249 million cases and over 600,000 deaths were reported in 2023, with nearly 94% occurring in sub-Saharan Africa [1]. Beyond its direct health impact, malaria imposes a

substantial social and economic burden by reducing workforce productivity, weakening health systems, and slowing development in endemic countries, as highlighted by regional progress reports [2].

Strengthening leadership and management competencies is increasingly recognized as a critical determinant of malaria elimination success, particularly in high-burden countries where programmatic complexity and resource constraints persist. Beyond clinical and epidemiological expertise, malaria control requires adaptive leadership and governance capacities aligned with health systems strengthening approaches. Evidence from Africa highlights persistent gaps in leadership and workforce capacity that may limit program effectiveness [3, 4].

Capacity-building initiatives have therefore become central to strengthening health systems. Structured training programs combining technical and managerial components have been shown to improve competencies among health professionals [5], and training models for public health managers emphasize the importance of context-specific and competency-based approaches to leadership development in low- and middle-income countries [6]. However, traditional in-person training models face operational constraints, including high logistical costs, staff unavailability, and geographic dispersion of participants, limiting their scalability.

Hybrid pedagogical approaches combining online and face-to-face learning have emerged as promising alternatives to address these challenges. Evidence from low- and middle-income countries demonstrates that blended learning can improve accessibility and learning outcomes while maintaining cost-effectiveness [7]. These findings are consistent with broader evidence from systematic reviews and meta-analyses in health professions education showing that blended learning enhances knowledge acquisition and learner engagement compared with traditional approaches [8, 9], while global analyses of health professional education emphasize the need for innovative training models to strengthen health systems [10]. From a pedagogical perspective, hybrid learning is supported by constructivist and experiential learning principles, highlighting the role of interaction and reflection in knowledge acquisition.

Despite increasing adoption of hybrid training strategies, empirical evidence on their effectiveness for leadership-oriented malaria capacity building remains limited, particularly at multicountry scale in sub-Saharan Africa. Existing studies have largely focused on clinical training or single-country interventions, leaving uncertainty regarding how hybrid modalities influence knowledge acquisition across modules with different content and delivery formats.

The African Leadership and Management Training for Impact in Malaria Elimination (ALAMIME) program was developed as a pan-African initiative to strengthen leadership, governance, and management capacities among malaria program professionals. Implemented across nine African countries, the program is structured into four modules delivered through a hybrid format combining online learning and in-person workshops. Module one focuses on the introduction to leadership and management and data use for malaria elimination. Module two goes into details in leadership and management, module three also goes into the details of malaria elimination while module four was more on data use and evidence

for decision making. This study evaluates changes in participants' knowledge following the ALAMIME training program and examines differences in learning outcomes across training modalities in order to inform the design of hybrid capacity-building strategies and support human resource development policies for malaria elimination

Material and methods

1.1. Study design

This study used a quasi-experimental pre-post design without a control group to assess changes in participants' knowledge following the African Leadership and Management Training for Impact in Malaria Elimination (ALAMIME) program. The analytical approach was based on paired pre-test and post-test knowledge assessments across four successive training modules. This design allowed the estimation of immediate cognitive gains at the individual level, while acknowledging the absence of a counterfactual group.

Conceptual and evaluation framework

The evaluation framework was informed by Level 2 of the Kirkpatrick model, which focuses on learning outcomes as reflected in changes in knowledge scores. The pedagogical rationale of the program was also grounded in socio-constructivist principles, particularly the work of Vygotsky, which emphasizes the role of guided interaction, facilitation, and collaborative learning in knowledge acquisition and consolidation.

Framework and period of the study

The study relied on data collected between 2022 and 2024 from three successive cohorts of the ALAMIME program implemented in nine African countries with high malaria burden: Tanzania, Nigeria, Sierra Leone, Democratic Republic of the Congo (DRC), Uganda, Niger, Benin, Togo, and Burkina Faso.

1.2. Study population

The study population consisted of health professionals who participated in ALAMIME between 2022 and 2024. Participants came from different areas of the health system, including clinical practice, public health, laboratory sciences, program management, environmental health, and monitoring and evaluation.

Eligibility criteria and sampling

All participants from Cohorts 1 to 3 were included in the descriptive analysis of sociodemographic and academic characteristics. However, the analysis of knowledge outcomes was restricted to participants

from Cohort 3, for whom pre-test and post-test score data were available for the training modules. A minimum completeness criterion was applied for knowledge analyses. Each participant was required to have at least 80% of the expected score values across the four modules, corresponding in practice to at least 7 available values out of 8 (pre-test and post-test scores for each of the four modules). Participants who did not meet this criterion were excluded from the overall analysis of learning gains. No imputation procedure was performed; all analyses were conducted on observed data only.

An exhaustive sampling strategy was used. A total of 602 participants were included in the descriptive analyses.

The number of complete pre-test/post-test pairs available for each module and each country was documented in order to assess data completeness for the knowledge analyses. Table 1 presents the distribution of complete pre-test/post-test pairs by country and module.

Table 1
Distribution of complete pairs of pre-test and post-test scores by country and module

Country	Module 1	Module 2	Module 3	Module 4
Benin	8	10	7	10
Burkina Faso	22	23	23	24
DRC	19	22	19	22
Niger	18	22	21	22
Nigeria	72	70	69	69
Sierra Leone	11	12	11	12
Tanzania	22	22	22	23
Togo	11	12	9	12
Uganda	25	27	25	27

1.3. Description of the training program

The ALAMIME program, coordinated by Makerere University with support the Gates Foundation, was designed to strengthen leadership, governance, and management capacities among professionals involved in malaria control and elimination. The curriculum was organized into four modules covering malaria epidemiology and elimination strategies, leadership and governance, program management, and operational planning.

1.4. Pedagogical methods

Training was delivered through a hybrid format combining online and in-person learning. Modules 1 and 3 were delivered primarily online and included asynchronous content made available through a digital platform, complemented by synchronous virtual discussion sessions. Modules 2 and 4 were delivered in person through interactive workshops that included presentations, group work, case-based discussions, and practical exercises designed to support collaborative learning.

1.5. Study variables

The primary outcome variable was the knowledge score, defined as the percentage of correct answers obtained on module-specific pre-test and post-test assessments. Explanatory variables included age, sex, marital status, country, cohort, qualification level, and field of study. Knowledge performance analyses were restricted to Cohort 3 participants with eligible test data. Table 2 presents the description of the study variables and their modalities.

Table 2
Description of variables

Variable	Type	Modalities
Age	Continuous	In year
Sex	Categorical	Female; Male
Marital status	Categorical	Single; Married; Divorced; Other
Country	Categorical	Benin; Burkina Faso; DRC; Niger; Nigeria; Sierra Leone; Tanzania; Togo; Uganda
Cohort	Categorical	Cohort 1; Cohort 2; Cohort 3
Level of qualification	Categorical	Degree; Bachelor's; Master's; Doctorate
Field of study	Categorical	Medicine; Nurse/Midwife; Pharmacy; Biology/Microbiology; Medical laboratory; Public health/Epidemiology; Community health/Social sciences; Environment/Sanitation; Management; Statistics/IT/M&E; Health worker; Other; Unspecified
Pre-Test Score	Continuous	Percentage of correct answers (modules 1 to 4)
Post-test score	Continuous	Percentage of correct answers (modules 1 to 4)

1.6. Sources and data collection

Data were extracted from the internal databases of the ALAMIME program, routinely used for programme monitoring and evaluation. Cohorts 1 (2022) and 2 (2023) were delivered under varying COVID-19 restrictions across countries, resulting in differences in the use of online and face-to-face modalities. Togo, Sierra Leone, and Benin joined the program in 2024; therefore, their data were available

only for Cohort 3. Consequently, knowledge score analyses were restricted to Cohort 3 (2024), for which comparable data were available.

1.7. Assessment tools

Knowledge was assessed using module-specific multiple-choice questionnaires developed specifically for the ALAMIME programme by the programme's training and technical team to assess the learning objectives of each module. The questionnaires had not been previously published. For each module, the same set of questions was administered before and after training, allowing direct comparison of participants' knowledge scores. Scores were calculated as the percentage of correct responses. The English-language versions of the questionnaires used for the assessments are provided as Supplementary File.

1.8. Data analysis

Statistical analyses were performed using RStudio.

First, descriptive analyses were conducted to summarize participant characteristics overall and by cohort. Continuous variables were described using the mean and standard deviation (SD), median and interquartile range (IQR), and minimum and maximum values. Categorical variables were summarized as counts and percentages.

Second, data completeness was assessed by counting the number of participants with complete pre-test/post-test pairs for each module by country.

Third, pre-test and post-test scores were summarized by module and by country using means and standard deviations. Absolute gains were then calculated for each participant as the difference between post-test and pre-test scores.

Fourth, the Average Improvement Percentage (AIP) was calculated to quantify relative learning gains. When the post-test score was greater than or equal to the pre-test score, AIP was defined as:

$$AIP = \frac{Post - Pre}{100 - Pre} \times 100$$
 When the post-test score was lower than the pre-test score, AIP was defined as:

$$AIP = \frac{Post - Pre}{Pre} \times 100$$
 This formulation allowed both gains and losses to be expressed relative to the participant's initial level. AIP values were then summarized by module and by country using means and 95% confidence intervals (95% CI).

Finally, to account for the multicountry structure of the data, a linear mixed-effects model was fitted with gain score as the dependent variable, module and sex as fixed effects, and country as a random effect. A specification including both random intercepts and random slopes for module by country was also examined to assess whether module-related gains varied across national contexts. This modelling

strategy allowed a more robust estimation of between-module differences while accounting for clustering and contextual heterogeneity.

1.9. Ethical and deontological aspects

Ethical approval for the secondary analysis was obtained from the College of Business and Management Sciences Research Ethics Committee (CoBAMS-REC; approval number CoBAMS-REC-2026-700), and research approval was obtained from the Uganda National Council for Science and Technology (UNCST; registration number HS8033ES).

Results

2.1. Sociodemographic characteristics of the participants

A total of 602 participants were enrolled in the ALAMIME program across the three cohorts. Cohort 1 included 184 participants, Cohort 2 included 188 participants, and Cohort 3 included 230 participants. Participants were drawn from nine African countries, reflecting broad geographical representation across malaria-endemic settings. Overall, the mean age of participants was 42.86 years (SD: 7.97), with a median age of 42 years (IQR: 37–49). Men represented 65.45% of the study population, while women accounted for 34.55%. Most participants were married (85.88%). In terms of educational attainment, the largest groups were participants with a Bachelor's degree (45.68%) and those with a Master's degree (41.20%). Professionally, the study population was mainly composed of participants from Medicine (25.25%), Public Health/Epidemiology (25.25%), and Environmental Health/Sanitation (7.81%). The distribution of sociodemographic and academic characteristics by cohort is presented in Table 3.

Table 3
Sociodemographic characteristics by cohort of participants

Characteristics	Cohort 1	Cohort 2	Cohort 3	Total
Age (years-old)				
Mean [$\pm$ ET]	45.5 [$\pm$ 8.0]	42.2 [$\pm$ 8.2]	41.3 [$\pm$ 7.3]	42.86 [$\pm$ 7.97]
Median (Q1 - Q3)	44 (40–52)	41 (36–48)	40 (36–46)	42 [37–49]
Min – Max	31–65	25–70	24–58	24–70
Sex				
Female	54 (29.35%)	48 (25.53%)	106 (46.09%)	208 (34.55%)
Male	130 (70.65%)	140 (74.47%)	124 (53.91%)	394 (65.45%)
Qualification				
Bachelors	72 (39.13%)	87 (46.28%)	116 (50.43%)	275 (45.68%)
Diploma	22 (11.96%)	33 (17.55%)	19 (8.26%)	74 (12.29%)
Masters	90 (48.91%)	68 (36.17%)	90 (39.13%)	248 (41.20%)
PHD	0 (0.00%)	0 (0.00%)	5 (2.17%)	5 (0.83%)
Marital Status				
Divorced	1 (0.54%)	1 (0.53%)	4 (1.74%)	6 (1.00%)
Married	167 (90.76%)	162 (86.17%)	188 (81.74%)	517 (85.88%)
Others	0 (0.00%)	1 (0.53%)	2 (0.87%)	3 (0.50%)
Single	16 (8.70%)	24 (12.77%)	36 (15.65%)	76 (12.62%)
Country				
Benin	0 (0.00%)	0 (0.00%)	10 (4.35%)	10 (1.66%)
Burkina Faso	27 (14.67%)	29 (15.43%)	24 (10.43%)	80 (13.29%)
DRC	32 (17.39%)	43 (22.87%)	23 (10.00%)	98 (16.28%)
Niger	13 (7.07%)	28 (14.89%)	25 (10.87%)	66 (10.96%)
Nigeria	66 (35.87%)	35 (18.62%)	73 (31.74%)	174 (28.90%)

Characteristics	Cohort 1	Cohort 2	Cohort 3	Total
Age (years-old)				
Sierra Leone	0 (0.00%)	0 (0.00%)	13 (5.65%)	13 (2.16%)
Tanzania	17 (9.24%)	15 (7.98%)	23 (10.00%)	55 (9.14%)
Togo	0 (0.00%)	0 (0.00%)	12 (5.22%)	12 (1.99%)
Uganda	29 (15.76%)	38 (20.21%)	27 (11.74%)	94 (15.61%)
Field of Study				
Health agent	9 (4.89%)	7 (3.72%)	17 (7.39%)	33 (5.48%)
Biology / Biochemistry / Microbiology	7 (3.80%)	7 (3.72%)	16 (6.96%)	30 (4.98%)
Management	4 (2.17%)	1 (0.53%)	6 (2.61%)	11 (1.83%)
Nurse / Midwife	5 (2.72%)	6 (3.19%)	5 (2.17%)	16 (2.66%)
Medical laboratory	4 (2.17%)	5 (2.66%)	19 (8.26%)	28 (4.65%)
Medicine	58 (31.52%)	41 (21.81%)	53 (23.04%)	152 (25.25%)
Pharmacy	4 (2.17%)	1 (0.53%)	8 (3.48%)	13 (2.16%)
Community Health/ Social Sciences	9 (4.89%)	2 (1.06%)	13 (5.65%)	24 (3.99%)
Environmental Health / Sanitation	17 (9.24%)	19 (10.11%)	11 (4.78%)	47 (7.81%)
Public health/ Epidemiology	42 (22.83%)	50 (26.60%)	60 (26.09%)	152 (25.25%)
Statistics / IT/ M&E	4 (2.17%)	5 (2.66%)	7 (3.04%)	16 (2.66%)
Others	21 (11.41%)	3 (1.60%)	14 (6.09%)	38 (6.31%)
Not specified	0 (0.00%)	41 (21.81%)	1 (0.43%)	42 (6.98%)

2.2. Evolution of the scores by country

The evolution of knowledge scores was examined by country for each of the four modules. For each module, the tables report the mean pre-test score, the mean post-test score, the mean absolute improvement with its 95% confidence interval (95% CI), and the percentage improvement. This presentation allows the magnitude of learning gains and their variation across countries to be described. Across all four modules, post-test scores were higher than pre-test scores in all or nearly all countries. Overall, for Module 1, the mean score increased from 53.25 to 68.75, corresponding to an average absolute improvement of 15.78 points and a relative improvement of 33.29%. For Module 2, the mean

score increased from 44.09 to 71.70, with an absolute improvement of 27.60 points and a relative improvement of 47.61%. For Module 3, the mean score rose from 43.52 to 69.62, corresponding to an absolute improvement of 26.38 points and a relative improvement of 46.38%. Finally, for Module 4, the mean score increased from 54.57 to 74.62, corresponding to an absolute improvement of 20.51 points and a relative improvement of 43.29%. The highest relative gains were recurrently observed in Tanzania and Burkina Faso, while gains were more modest in some other settings, depending on the module. Detailed country-level results for each module are presented in Tables 4 to 7.

Table 4
Evolution of pre-test and post-test scores by country for module 1

Country	Average score (ET)	Average score (ET)	Mean absolute improvement (95% CI)	Percent improvement
Benin	51.79 (14.03)	64.29 (12.26)	14.29 (6.5 ; 22)	29.16 (14 ; 44)
Burkina Faso	53.08 (8.84)	72.47 (17.29)	19.97 (13 ; 27)	42.33 (27 ; 57)
DRC	50.75 (11.45)	64.45 (10.31)	13.53 (7.3 ; 20)	26.64 (16 ; 37)
Niger	44.64 (8.16)	54.11 (12.49)	8.73 (1.8 ; 16)	15.00 (2.8 ; 27)
Nigeria	52.63 (12.88)	70.82 (13.09)	18.19 (15 ; 21)	38.14 (32 ; 44)
Sierra Leone	42.86 (14.37)	63.74 (10.40)	23.7 (16 ; 32)	39.70 (30 ; 50)
Tanzania	60.39 (17.42)	80.36 (11.17)	19.97 (15 ; 25)	52.01 (43 ; 61)
Togo	54.22 (11.39)	61.31 (6.43)	7.79 (2.4 ; 13)	14.83 (5.5 ; 24)
Uganda	63.00 (16.13)	72.22 (10.73)	8.71 (2.4 ; 15)	19.71 (9.0 ; 30)
Overall	53.25 (13.95)	68.75 (13.91)	15.78	33.29

Table 5
Evolution of pre-test and post-test scores by country for module 2

Country	Average score (ET)	Average score (ET)	Mean absolute improvement (95% CI)	Percent improvement
Benin	44.80 (13.83)	56.80 (13.83)	12 (0.24 ; 24)	19.77 (1.2 ; 38)
Burkina Faso	43.30 (10.96)	80.00 (9.58)	36.35 (30 ; 42)	62.53 (54 ; 71)
DRC	49.09 (12.90)	76.00 (9.65)	26.73 (19 ; 34)	48.51 (37 ; 60)
Niger	37.74 (12.75)	54.17 (15.01)	16.73 (8.7 ; 25)	24.12 (12 ; 36)
Nigeria	42.40 (13.98)	77.07 (14.53)	34.57 (31 ; 39)	59.55 (53 ; 66)
Sierra Leone	45.33 (11.86)	63.00 (10.11)	17.67 (12 ; 23)	31.89 (23 ; 41)
Tanzania	46.55 (20.97)	86.91 (10.77)	40.36 (30 ; 50)	73.12 (63 ; 84)
Togo	42.33 (8.61)	60.67 (6.57)	18.33 (12 ; 25)	30.67 (21 ; 40)
Uganda	48.44 (16.24)	64.00 (12.55)	15.56 (8.2 ; 23)	26.38 (16 ; 37)
Overall	44.09 (14.42)	71.70 (15.92)	27.6	47.61

Table 6
Evolution of pre-test and post-test scores by country for module 3

Country	Average score (ET)	Average score (ET)	Mean absolute improvement (95% CI)	Percent improvement
Benin	42.86 (13.50)	76.67 (15.41)	31.43 (14 ; 49)	54.64 (30 ; 79)
Burkina Faso	48.48 (19.21)	96.04 (3.61)	47.83 (39 ; 56)	91.74 (88 ; 95)
DRC	60.53 (19.43)	81.96 (7.80)	20.53 (12 ; 29)	42.04 (28 ; 56)
Niger	35.65 (14.95)	48.70 (21.06)	13.1 (6.8 ; 19)	21.72 (9.4 ; 34)
Nigeria	38.26 (16.91)	62.29 (20.91)	25.36 (20 ; 30)	40.91 (33 ; 49)
Sierra Leone	35.45 (11.06)	64.23 (20.09)	27.27 (12 ; 43)	39.96 (15 ; 65)
Tanzania	43.41 (21.62)	79.09 (14.28)	35.68 (27 ; 44)	63.53 (53 ; 74)
Togo	53.50 (16.34)	71.82 (14.88)	19.44 (4.3 ; 35)	36.36 (14 ; 58)
Uganda	47.50 (14.85)	64.42 (18.62)	17.6 (9.7 ; 26)	32.79 (18 ; 47)
Overall	43.52 (18.41)	69.62 (21.44)	26.38	46.38

Table 7
Evolution of pre-test and post-test scores by country for module 4

Country	Average score (ET)	Average score (ET)	Mean absolute improvement (95% CI)	Percent improvement
Benin	56.25 (17.05)	76.25 (5.93)	20 (10 ; 30)	40.47 (26 ; 55)
Burkina Faso	54.82 (14.31)	85.29 (3.12)	30.47 (24 ; 36)	63.25 (55 ; 71)
DRC	57.67 (11.07)	77.45 (12.60)	19.74 (12 ; 27)	44.19 (31 ; 57)
Niger	43.04 (13.43)	47.63 (14.30)	5.54 (1.5 ; 9.6)	8.51 (1.2 ; 16)
Nigeria	55.95 (16.43)	79.86 (13.78)	23.97 (19 ; 29)	52.75 (45 ; 60)
Sierra Leone	48.32 (18.03)	68.24 (15.60)	20.32 (6.8 ; 34)	34.88 (14 ; 55)
Tanzania	51.10 (15.65)	83.30 (9.08)	32.2 (26 ; 39)	64.97 (57 ; 73)
Togo	65.36 (9.74)	71.61 (4.89)	6.25 (-0.42 ; 13)	17.55 (4.6 ; 30)
Uganda	58.23 (14.65)	70.50 (11.60)	12.27 (6.7 ; 18)	26.75 (17 ; 37)
Overall	54.57 (15.61)	74.62 (15.81)	20.51	43.29

2.3. Modeling learning gains by linear mixed effects model

To account for the multicountry structure of the data, a linear mixed-effects model was fitted with gain score as the dependent variable, module and sex as fixed effects, and country as a random effect. A specification including both random intercepts and random slopes for module by country was examined. The estimated mean gain for the reference category, corresponding to female participants in Module 1, was 16.59 points. Compared with Module 1, Module 2 and Module 3 were associated with significantly higher gains, with coefficients of 10.27 points ($p = 0.002$) and 11.30 points ($p = 0.003$), respectively. Module 4 also showed a positive coefficient (4.24 points), but this difference was not statistically significant ($p = 0.074$). In addition, the coefficient associated with male sex was negative (-3.27 points), indicating lower average gains among men than among women; this difference was statistically significant ($p = 0.005$). The estimates of the fixed effects are presented in Table 8.

Table 8
Fixed effects of the linear mixed-effects model on learning gains

Variable	Coefficient (β)	Standard error	df	t	p-value
Intercept (Module 1, Femelle)	16.591	1.977	10.529	8.391	5.53e-06
Module 2	10.270	2.432	8.819	4.223	0.00233
Module 3	11.295	2.767	8.341	4.082	0.00323
Module 4	4.242	2.139	10.512	1.984	0.07402
Sexe Homme	-3.273	1.151	837.613	-2.845	0.00455

The model also showed variability between countries in both the average level of gain and the effect of modules. The variance of the random intercept was 19.45, indicating differences in the average level of gains across countries. Random slope variances suggested heterogeneity across modules, with the highest variance observed for Module 3 (42.46), followed by Module 2 (28.91) and Module 4 (18.04). Correlations between some random effects were high, particularly between the intercept and Module 4 (1.00), between the intercept and Module 2 (0.82), and between Module 4 and Module 2 (0.81). The variance components and correlations of the random effects are shown in Table 9.

Table 9
Variance components and correlations of random effects at the country level

Random effect (Country)	Variation	Standard error	Correlations
Intercept	19.45	4.410	—
Module 2	28.91	5.377	With intercept = 0.82
Module 3	42.46	6.516	With intercept = 0.76; with Module 2 = 0.26
Module 4	18.04	4.247	With intercept = 1.00; with Module 2 = 0.81; with Module 3 = 0.77
Residual	272.62	16.511	—

Finally, the correlation matrix of fixed-effect estimates is presented in Table 10.

Table 10
Fixed effects correlation matrix

Intercept	Intercept	Module 2	Module 3	Module 4	Sex Male
	1.000				
Module 2	0.189	1.000			
Module 3	0.218	0.324	1.000		
Module 4	0.194	0.653	0.630	1.000	
Sex Male	-0.319	-0.014	-0.014	-0.015	1.000

Discussion

3.1. Overall effectiveness of the program on knowledge outcomes

The results show a clear progression of scores between pre-test and post-test in the four modules, with significant absolute and relative gains. In the context of the ALAMIME program, this indicates that the training was associated with an immediate and substantial improvement in the cognitive skills of the participants. This is important because leadership in malaria elimination is not only based on technical knowledge, but also on the ability to interpret situations, coordinate actors and make decisions in complex environments.

These results are consistent with the literature on digital and hybrid learning in health professions. The meta-analysis by Cook et al. showed that Internet-based learning improves knowledge compared to no intervention, while other work has shown that hybrid devices frequently achieve comparable or sometimes even better results, to those of traditional approaches, when the teaching scenario is structured and learners are actively engaged [11–16]. More recent syntheses confirm that effectiveness does not depend on technology alone, but on the articulation between content, activities, interactions and evaluation [17]. In low- and middle-income countries, the work of Barteit et al. also highlights that e-learning is a promising option for training health professionals, even if its performance remains sensitive to infrastructure constraints and the quality of implementation [18].

From a public health perspective, this overall effectiveness supports the value of a programme like ALAMIME as a tool for capacity building in health systems. In contexts marked by a simultaneous need for leadership, coordination and strategic ownership of interventions, the ability to quickly generate measurable learning gains is already a significant programmatic outcome. This observation justifies that leadership training be considered as a structuring investment in malaria control programs, and not as a peripheral activity.

3.2. Differences in performance according to the modules and contribution of learning modalities

The analysis highlights discrepancies between modules, with modules 2 and 3 being associated with the highest gains, while module 4 shows a positive but more moderate progression. This hierarchy suggests that the effectiveness of the program is not uniform according to the content and educational formats used. At this stage, the interpretation must remain methodologically cautious: the differences observed may reflect effects related to the pedagogical modality, the difficulty of the content, the initial level of the participants or even the dynamics of progression between modules. While module one was introducing the concepts, modules two and three build on the concepts in module one. Differences in knowledge gains between learning modalities may partly reflect the greater opportunities for interaction and engagement offered by face-to-face sessions compared with fully online sessions.

This reading joins the literature on hybrid learning. Garrison and Kanuka showed that the value of blended learning lies in its ability to combine the flexibility of digital technology with the pedagogical depth of face-to-face interactions [15]. Reviews in medical education indicate that hybrid devices are particularly useful when learning objectives engage applied analysis, problem solving, communication and other high-level skills [16, 17]. Several pedagogical mechanisms can explain a relative advantage of face-to-face or highly interactive formats: stronger social presence, immediate feedback, exchanges between peers, co-construction of reasoning and better contextualization of learning [19–22]. Work on social presence in digital environments precisely shows that the quality of interactions and the perception of the presence of others strongly influence learners' engagement and performance [21, 22]. Similarly, syntheses on feedback in medical education confirm that rapid, specific, and contextualized feedback contributes to improving knowledge and skills [19, 20].

Practical involvement is important for future ALAMIME iterations. The results suggest that it would not be optimal to distribute resources evenly between online and presential components. Framing, preparation or review content can be maintained online to maintain accessibility and flexibility. On the other hand, content that mobilizes applied leadership, negotiation, coordination, collective decision-making or problem solving should benefit from increased investment in highly interactive presential or hybrid formats. In a context with limited resources, the challenge is not to substitute one modality for another, but to better distribute formats according to the targeted skills.

3.2. Variability of earnings according to national contexts

The descriptive results and the mixed model show a significant variability between countries, both on the average level of gains and on the effect of certain modules. The higher performance in Tanzania and Burkina Faso contrasts with more modest increases elsewhere. This heterogeneity suggests that the effectiveness of the program also depends on the environments in which it is deployed. Several factors can be invoked: initial institutional capacity, anteriority of leadership training courses, quality of local supervision, participants' workload, familiarity with digital tools, team stability or content alignment with

national priorities. The mixed model supports this reading by showing that the country is not a simple descriptive factor, but a real level of variation in the observed gains.

The literature on health leadership in sub-Saharan Africa is consistent with this interpretation. The review by Johnson et al. shows that leadership development interventions in the region are very heterogeneous, both in their conceptual basis and in their implementation, and that their effects strongly depend on the context [23]. The work of Agyepong et al. also emphasizes the importance of anchoring in institutional realities and taking into account essential skills at the level of health systems [24]. More recently, the umbrella review by Phillipson et al. concludes that there is no optimal single structure of leadership programmes, and that outcomes depend on design, content, targeted professional level and context of application [25].

In terms of public health, this heterogeneity implies that a multi-country programme like ALAMIME while it has common issues that need to cut across many countries, it should not be conceived as a standardized product to be distributed identically. The results argue for a more explicit contextual adaptation: prior diagnosis of needs by country, differentiated support, reinforced support in contexts where gains are lower, and better articulation between training contents and local institutional realities. This contextualization is an important condition if one wishes to transform immediate cognitive gains into sustainable improvement of governance and steering capabilities.

3.3. Programmatic scope and implications for health systems

The results of ALAMIME have a scope that exceeds the pedagogical evaluation *stricto sensu*. They suggest that a well-structured, multi-country hybrid leadership programme can be a credible capacity building instrument for health systems facing coordination, governance and decision-making challenges. This programmatic scope is all the more important as the targeted professionals occupy varied positions in malaria control programs and can, over time, disseminate or reinvest the acquired knowledge in their institutions.

The literature on health leadership converges on several elements that reinforce this reading. The available reviews show that the most promising programs are often those that combine experiential learning, support, applied reflection, mentoring, or structured interactions, rather than purely transmissive formats [23–27]. The syntheses on hybrid learning in health professions education, for their part, stress that the most effective systems rely on an intentional distribution of modalities according to the types of skills to be developed [14–17]. In this sense, ALAMIME is part of a direction supported by the literature, even if its evaluation could still be deepened on the medium-term effects and on the transfer in practice.

These results should directly inform the design of future editions of the programme. First, they support maintaining a hybrid architecture, but with a more strategic allocation of resources between online and in-person components. Secondly, they indicate that the experience of ALAMIME can inspire other

training programs for health professionals in limited resource settings, beyond the single field of malaria, provided it is adapted to local constraints, to technological availability and institutional needs.

3.4. Study strengths and limitations

This study presents several strengths. It is based first on a large workforce, spread across nine countries, which allows to examine the implementation of a training program in varied national contexts. Then, the analysis was not limited to a simple pre/post comparison: it integrated effect sizes, confidence intervals and a mixed linear model taking into account the hierarchical structure of the data. Finally, the combination of descriptive analyses by country and multi-country modeling provides a more robust interpretation of the heterogeneity of gains.

However, several limitations should be noted. First, the lack of a control group limits the ability to attribute observed improvements exclusively to the ALAMIME program. Some of the gains could result from other factors, such as maturation, experience or repeated exposure to test instruments. Methodological work on quasi-experimental plans reminds that pre/post schemes without a control group remain exposed to these threats of internal validity [27, 28]. Secondly, the participants have self-selected themselves in the program. They could be more motivated or more professionally engaged than non-participants, which may overestimate the observed effects. The literature on search bias highlights that this type of selection can affect the internal and external validity of results [29, 30].

Third, the study relies on secondary data initially collected for programmatic evaluation rather than planned research. This choice does not detract from their usefulness, but it may limit the standardization of measurements, the availability of certain covariates and the possibility to document more finely certain mechanisms. Work on secondary analysis emphasizes precisely this balance between analytical efficiency and data quality constraints [31, 32]. Finally, the completeness of scores criterion set at 80% means that part of the data was missing; even if analyses were conducted on observed data, the potential effect of this attrition on the validity of conclusions cannot be entirely excluded.

These limits do not invalidate the results, but they lead to interpret them as solid evidence of immediate pedagogical effectiveness rather than as a definitive causal demonstration of programmatic impact. They also point the way forward for future evaluations: longitudinal follow-up, more comprehensive consideration of confounders, finer analyses of missing data mechanisms, and, where possible, use of more robust evaluation schemes.

Conclusion

This study showed that the ALAMIME program was associated with substantial improvements in knowledge among malaria control professionals across the nine participating countries. Post-test scores were consistently higher than pre-test scores across all four modules, with large learning gains that support the pedagogical value of the program. In this context, improved knowledge should be understood as a necessary foundation for the subsequent development of leadership, managerial, and

operational skills required for malaria elimination. The findings also suggest that a well-structured hybrid training model may be a relevant approach for strengthening professional capacity in resource-limited African settings. However, this interpretation should remain cautious. Differences observed between modules cannot be attributed to training modality alone, as variation in content, complexity, and assessment demands may also have influenced performance. In addition, the absence of a control group, the use of secondary data, missing information, and the lack of adjustment for some potential confounders limit the causal interpretation of the results. From a policy and practice perspective, these findings support continued investment in hybrid leadership training programs for malaria elimination, with careful attention to the complementary roles of online and in-person components. In-person sessions may be particularly valuable for the most interactive and complex learning activities, while online components remain important for flexibility, accessibility, and continuity. Further research is needed to determine the optimal balance between online and in-person delivery, to assess long-term knowledge retention and skills transfer, and to examine whether strengthened leadership capacities ultimately translate into improved program performance and malaria elimination outcomes.

Abbreviations

ALAMIME

African Leadership and Management Training for Impact in Malaria Elimination

AIP

Average Improvement Percentage

CI

Confidence Interval

DRC

Democratic Republic of the Congo

IQR

Interquartile Range

IT

Information Technology

M&E

Monitoring and Evaluation

PhD

Doctor of Philosophy

SD

Standard Deviation

WHO

World Health Organization

Declarations

Study record

Ethical approval was obtained from CoBAMS-REC (CoBAMS-REC-2026-700) and UNCST (HS8033ES).

Ethical approval and consent to participate

This study was based on a secondary analysis of existing programme data generated through the ALAMIME programme. There was no direct contact with participants during this study. Only de-identified or anonymized data were used, and no directly identifying information was included in the analysis. Ethical approval for the secondary analysis was obtained from the College of Business and Management Sciences Research Ethics Committee (CoBAMS-REC), under approval number **CoBAMS-REC-2026-700**. CoBAMS-REC reviewed and approved the request for a waiver of informed consent because the study involved secondary analysis of existing programme data presented no more than minimal risk to participants, and had appropriate measures in place to ensure confidentiality, privacy, and secure handling of the data. Therefore, informed consent was waived for the present secondary analysis, and no additional consent was obtained from participants. Formal approval for the research was also obtained from the Uganda National Council for Science and Technology (UNCST) under research registration number **HS8033ES**. The study was conducted in accordance with relevant ethical guidelines and regulations, including the principles of the Declaration of Helsinki. Data confidentiality was maintained throughout data extraction, management, and analysis. Access to the data was restricted, and only the approved secondary data were used for the stated research purposes. The data remained de-identified or anonymized and participant confidentiality was maintained throughout the study in accordance with the conditions of the consent waiver. No additional contact with participants or collection of new personal data was undertaken as part of this study.

Consent to publication

Not applicable.

Conflicts of interest

The authors declare no conflict of interest associated with this study.

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Contributions of the authors

AK contributed to the study conception, overall coordination, interpretation of findings, and drafting of the first version of the manuscript. RAY contributed to the study methodology, interpretation of findings, and drafting and revision of the manuscript. RJRS conducted the statistical analyses and contributed to

the methodology, data interpretation, and manuscript revision. NM, ZCM, KMD, LO, and ER contributed to the study conception, scientific supervision, interpretation of findings, and critical revision of the manuscript. GABGH, ST, VG, SCBK, KO, and DNB contributed to programme implementation, data collection and/or data provision, contextual interpretation of the findings, and critical revision of the manuscript. All authors read and approved the final version of the manuscript.

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Author Contribution

AK contributed to the study conception, overall coordination, interpretation of findings, and drafting of the first version of the manuscript. RAY contributed to the study methodology, interpretation of findings, and drafting and revision of the manuscript. RJRS conducted the statistical analyses and contributed to the methodology, data interpretation, and manuscript revision. NM, ZCM, KMD, LO, and ER contributed to the study conception, scientific supervision, interpretation of findings, and critical revision of the manuscript. GABGH, ST, VG, SCBK, KO, and DNB contributed to programme implementation, data collection and/or data provision, contextual interpretation of the findings, and critical revision of the manuscript. All authors read and approved the final version of the manuscript.

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Data Availability

The datasets and materials used in this study are available upon reasonable request from the corresponding author

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