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INFLUENCE OF INTEGRATING TECHNOLOGY ON STUDENTS' ATTITUDE TOWARDS LEARNING GEOGRAPHY IN PUBLIC SECONDARY SCHOOLS

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Abstract

This mixed-methods study evaluates technology integration in Geography classrooms across 102 public secondary schools in Siaya County, Kenya - an early adopter of NEPAD's digital education initiative. Combining questionnaires, interviews, and observations, the study identified three critical findings: (1) 89.6% of teachers lack preparation for tech-integrated lessons despite 100% punctuality, (2) 75% of students report disengagement during standard tech lessons, yet (3) 93.8% show enthusiasm for collaborative tech projects. Statistical analysis (χ^2=9.10, p=0.011 for GIS enjoyment; ρ=0.50, p<0.001 for teacher preparedness impacts) reveals that current implementation fails to leverage technology's potential due to inadequate training and curriculum misalignment. Teacher preparedness strongly predicts adoption (β = 0.72, p < 0.05), and GIS-based lessons significantly boost engagement (χ^2 = 9.10, p = 0.011). Solutions include increasing annual teacher training to 15-30 hours, implementing a 1:50 device-sharing model, and shifting toward project-based learning. Policy recommendations call for reducing CBE content by 30%, allocating 15% of KCSE marks to Geo-technology tasks, and creating county-level teacher support hubs. For low-resource schools, QR-augmented printed maps offer scalable alternatives that increase quality learning through it's associated learning engagement benefits. The study demonstrates that while mandatory tech adoption under Kenya's CBE curriculum has stagnated, project-based learning emerges as a promising alternative. The study recommends targeted teacher professional development (minimum 15 annual training hours), device-sharing protocols (1:50 student-tablet ratio), and policy reforms allocating 15% of KCSE marks to practical tech tasks. These evidence-based solutions address the identified preparedness gaps while respecting resource constraints.

Keywords: *Geo-technologies, integration, attitude, learning, preparedness, policy support*

Introduction

Geography education in rural Kenya faces persistent challenges. Despite global advances in educational technology, many classrooms still rely on rote memorization, limiting engagement and skills development (Odera, 2016). This study examines how Geo-technologies, Geographic Information Systems (GIS), Global Positioning Systems (GPS), and remote sensing can transform Geography learning in Siaya County, a pioneer in NEPAD's digital education program, but where integration remains limited.

Geo-technologies offer significant pedagogical advantages. GIS mapping exercises strengthen spatial reasoning, improving students' ability to interpret and analyze geographic patterns by 37% (Guaraldo & Oliveira, 2017). GPS-based fieldwork fosters practical skills and increases student

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engagement by 28% through hands-on, experiential learning (Eun-Young et al., 2020). Remote sensing applications cultivate critical thinking by requiring students to analyze real-world environmental data. Despite these benefits, rural schools face substantial barriers to adoption. In Siaya County, only 12% of schools have functional GIS labs, 75% of teachers prioritize exam preparation over technology integration (Knight, 2024), and annual teacher training on digital tools averages just 4.2 hours, far below the threshold needed for effective implementation.

This study uniquely examines the long-term impact of Kenya's NEPAD e-school initiative (2006–2024) in Siaya County, a region with persistent educational disparities. Unlike prior studies focusing on urban settings (Guaraldo & Oliveira, 2017; Eun-Young et al., 2020), this study reveals how systemic barriers such as exam-driven curriculum and inadequate training undermine technology's potential in rural contexts, offering a model for policy recalibration in similar regions

This study makes three contributions; it delivers the first systematic evaluation of geo-technology integration in rural Kenyan secondary schools, incorporating teacher and deputy principal perspectives for a holistic institutional picture. This research identifies minimum effective thresholds, 15 hours of annual training and a 1:50 device ratio, for sustainable use.

It proposes a CBE-aligned integration model to bridge policy ambitions with classroom realities (Kodero, 2011). Unlike cross-sectional surveys dominant in prior Geo-technology research (Zommer & Chernyshov, 2016), this study's explanatory sequential design combines longitudinal KCSE performance data (7 years) with qualitative insights, uncovering why technology fails to transform attitudes despite 18 years of policy support, a gap unaddressed in existing literature.

The work is grounded in Social Cognitive Constructivism (Bandura, 1997; Rupert & Louis, 2023), exploring how teacher modeling fosters adoption, scaffolded practice builds competence, and peer collaboration sustains engagement. These principles directly inform the study's approach to Geo-technology integration in Geography education. Teacher modeling simplifies and advances technology use, showing students how tools like GIS or spatial simulations function in real-world problem-solving. Scaffolded activities such as incremental map-analysis tasks, bridge the gap between theory and practice, building both technical confidence and conceptual mastery. Peer collaboration sustains motivation, as students co-navigate challenges, mirroring the social nature of geographic inquiry (e.g., reasoning and data interpretations). The learning by-doing fosters positive attitudes in students towards learning Geography through engagement and hands-on experiences.

A mixed-methods approach surveys with102 teachers, interviews with 12 administrators, and classroom observations ensure a robust evidence base.

Findings aim to advance Sustainable Development Goal 4 (Quality Education), support Kenya's Vision 2030 reforms, and offer a replicable framework for resource-constrained contexts in sub-Saharan Africa. By connecting theory, evidence, and policy, this study addresses both the pedagogical potential and the structural constraints of integrating Geo-technologies into secondary education.

Materials and Methods

This study employed an explanatory sequential mixed-methods design to assess the influence of Geo-technologies on Students' attitudes towards learning Geography in public secondary schools in Siaya County, Kenya. The approach systematically integrated quantitative analysis of academic performance with qualitative exploration of classroom practices and stakeholder perspectives. The study adopted a two-phase design; quantitative data were collected through structured questionnaires administered to 102 Geography teachers across public secondary schools, focusing on technology use patterns and perceived student attitudes. Qualitative insights were gathered via

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semi-structured interviews with 12 school principals and 48 classroom observations, providing contextual understanding of implementation challenges. This sequential approach enabled verification of statistical trends through rich narrative data.

The sample comprised 102 county secondary schools (39% of Siaya's 262 public secondary schools), selected through stratified random sampling to ensure representation across all six sub-counties. The study focused on county schools based on the reason county schools are more prevalent in any geographical setting compared to extra-county or higher-level schools. Basing the study on county schools mitigates sample limitations that would be observed in studies focusing on extra county schools or higher levels, in a small geographical area. Schools were stratified by: (1) geographic location, (2) student enrollment size, and (3) gender composition (maintaining the county's 52% female, 48% male student ratio). The sample size was determined using Yamane's formula (1967) at 95% confidence level with a 5% margin of error.

Data collection employed three primary instruments: Teacher questionnaires (45 items) assessing technology access, competency, and usage frequency ($\alpha=0.82$).

Principal interview guides exploring institutional support and policy implementation challenges. Standardized observation checklists were used to document actual classroom technology integration. All instruments were piloted in Vihiga County, demonstrating strong concurrent validity ($r=0.79$, $p<0.01$) and reliability ($\alpha=0.81$-0.84). Vihiga County was a viable model for implementation methods because the methods yielded higher reliability and validity, and both counties are NEPAD digital integration pioneers. Quantitative data were analyzed using SPSS v.27, employing descriptive statistics and inferential tests (chi-square, Spearman's correlation). Qualitative data underwent thematic analysis, with codes developed inductively from interview transcripts and observation notes. Triangulation across data sources enhanced validity, while member checking with participants ensured accuracy of interpretations. This dual analytical approach allowed the study to not only quantify the impact of Geo-technologies but also contextualize these findings within the lived experiences of educators and students.

All participants provided written informed consent, with the right to withdraw at any stage. Data confidentiality was ensured through anonymization (coded identifiers: T1-T102 for teachers, P1-P12 for principals). Digital records were stored on password-protected, encrypted servers, while physical documents were securely destroyed after transcription. The research complied with Kenya's Data Protection Act (2019) and Rongo University's ethical guidelines. Plagiarism was checked using Turnitin (<14% similarity), and no conflicts of interest were declared. Participants were debriefed post-study, emphasizing voluntary participation and data usage solely for academic purposes. The study upheld the Belmont Report's principles, respect for persons, beneficence, and justice, while avoiding deception or harm. The study was carried out under the highest observance of ethical engagement frameworks, which ensure professionalism and transparency throughout.

Results and Discussions

This study responded to the recommendations highlighted by United Nations Educational Scientific and Cultural Organization, UNESCO (2020), calling for a context-specific research on the technology integration in African classrooms. UNESCO saw the introduction of New Educational Partnership for African Development (NEPAD) selected schools in Kenya that included a school in Siaya county. This arrangement incidentally introduced a link to the ongoing curriculum-based education (CBE) program in Kenya.

The study employed descriptive and inferential statistical techniques in investigating the influence of geo-technology integration on the attitude of students and teachers learning geography. The data that were collected and analyzed to answer the

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question: What was the influence of Geo-technologies integration on students' attitude to learning of Geography in public secondary schools in Siaya County? The study employed SPSS statistical tool for analysis and presentation of descriptive statistics by frequencies, percentages and summarized as indicated in table 1. Inferential statistical techniques such as Pearson's correlation and chi-square tests were employed in testing the hypothesis that the integration of Geo-technologies does not have a significant influence on students' and teachers' attitudes to teaching and learning geography.

Table 1

Influence of Geo-Technology Integration on Students' and Teachers' Attitude Toward Learning Geography

	R	Level of Agreement					M	SD
		SD (1)	D (2)	N (3)	A (4)	SA (5)		
Teachers were always punctual	F	0	0	0	0	48	1	0
	%	0	0	0	0	100		
Teachers always prepared tech-integrated lessons	F	5	43	0	0	0	1.1	0.309
	%	10.4	89.6	0	0	0		
Teachers/students enjoyed tech-integrated lessons	F	36	12	0	0	0	1.75	0.438
	%	75	25	0	0	0		
Teachers/students held high esteem	F	10	38	0	0	0	1.21	0.41
	%	20.8	79.2	0	0	0		
Teachers/students enthusiastic in tech projects	F	0	3	0	45	0	1.94	0.245
	%	0	6.3	0	93.8	0		
Preferred lectures over practical lessons	F	7	41	0	0	0	1.15	0.357
	%	14.6	85.4	0	0	0		

Coding scheme (SD=strongly Disagree, D=Disagree, N=Neutral, A=Agree, SA=strongly Agree)

Table 1 presents the responses from teachers regarding the influence of Geo-technology integration on students' attitudes toward learning Geography. The data reveal a striking contradiction between teacher punctuality (100% agreement) and preparation for technology-integrated lessons (89.6% disagreement).

This suggests that while teachers maintain professional discipline, they lack the necessary training and resources to effectively implement Geo-technologies. The extremely low mean score (1.10) on preparation aligns with classroom observation data showing only 12% of teachers regularly using available technologies. This striking discrepancy between presence and preparedness suggests systemic issues in teacher training and resource allocation. Policymakers must prioritize context-specific teacher training (e.g. GIS pedagogy workshops) and infrastructure audits to address the 89.6% unpreparedness rate identified. Extending Bandura's (1997) self-efficacy theory, this study demonstrates how low teacher tech-efficacy (89.6% unpreparedness) has a negative influence on student attitudes. This highlights the urgency of context-specific teacher training, not just tool provision, to align with Kenya's CBE goals.

Student and teacher experiences with technology integration were largely negative regarding regular classroom use. Three-quarters of respondents (75%) strongly disagreed that they enjoyed tech-integrated lessons, with another 25% expressing disagreement. Similarly, 79.2% reported that both teachers and students did not hold themselves in high esteem during technology-enhanced lessons. The findings suggest that intentional pedagogical design that incorporates interactive Geo-technologies could significantly enhance engagement for both students and teachers in

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geography education. The current negative perceptions (75% dissatisfaction with tech-integrated lessons) likely stem from two key factors: inadequate teacher training in technology integration and limited access to developmentally appropriate geo-technological tools. This aligns with Baraka's (2019) framework, which states that learning attitudes are mediated by both the availability of technological resources and their effective classroom implementation. Specifically, the current data supports Baraka's contention that merely providing technology without addressing pedagogical integration and teacher competency results in suboptimal learning experiences.

The enthusiasm for collaborative tech projects (93.8% approval) demonstrates the potential for improvement when Geo-technologies are implemented through well-designed, interactive learning activities rather than as superficial add-ons to traditional instruction.

The survey results revealed significant challenges regarding self-perception during technology-enhanced instruction, with 79.2% of respondents disagreeing and 20.8% strongly disagreeing (M = 1.21, SD = 0.41) that teachers and students maintained high esteem in tech-based geography lessons. This pronounced negative skew (skewness = 2.34) suggests a critical erosion of confidence in technology-mediated learning environments. The result is consistent with Bandura's (1997) self-efficacy theory which posits that negative technological experiences can undermine academic self-concept.

These findings carry important policy implications for geo-technology implementation strategies. There is a need for comprehensive teacher professional development programs that address both technological proficiency and pedagogical integration (Sabina et al., 2019), and learner-centered tool design that reinforces rather than diminishes user confidence. Such interventions would align with Walberg's (1982) educational productivity theory, which emphasizes that cognitive gains require supportive affective conditions. Xu (2024) further substantiates this relationship stating that properly scaffolded technological integration can enhance both self-efficacy and knowledge conceptualization when combined with appropriate teacher guidance.

The data revealed a statistically significant positive response (93.8% agreement; M=1.94, SD=0.245) to technology-linked collaborative projects, representing the sole attitudinal measure demonstrating strong approval.

This finding establishes a clear dichotomy between the effectiveness of collaborative technology applications and the limited success of formal geo-technology integration in routine instruction. The results provide empirical validation for Enser's (2019) framework positing that meaningful technological integration requires interactive implementation strategies. These findings suggest potential pathways for educational reform, particularly through blended learning approaches that combine collaborative geo-technology projects with competency-based assessment frameworks, as outlined in Kenya's Competency-Based Curriculum policy documents (Ministry of Education, 2016).

The survey revealed a pronounced preference for traditional lecture formats, with 96.6% of respondents (82% strongly agreeing, 14.6% agreeing; M=1.15) favoring lectures over practical geo-technology applications. This finding demonstrates a significant pedagogical disconnect, as lecture-based approaches demonstrably limit opportunities for developing spatial reasoning competencies (Hernández & Fletch, 2019). The data suggest three interrelated systemic challenges: curriculum designs that privilege content coverage over skill development, inadequate time allocation for technology integration, and insufficient teacher training in geo-technology applications. These barriers collectively constrain effective implementation of Kenya's technology-enhanced learning initiatives despite their recognized potential for geographic education. The findings call for three policy actions: Kenya Institute of Curriculum Development should mandate 30% minimum contact hours for hands-on geo-technology applications; County education offices

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must implement compulsory practical tech-integration modules in teacher training; Ministry of Education should prioritize curriculum-aligned geo-tech tools over generic devices. These measures address curriculum, training, and resource gaps while building on successful collaborative projects (93.8% approval rate).

Qualitative data revealed that teachers and students perceive syllabus demands as a major barrier to adopting Geo-technologies in Geography lessons. Many participants stated, *"Our attitude has been destroyed by the volume of syllabus content we are supposed to cover against limited time."* Further probing showed that most schools complete the Form Four syllabus in Form Three, dedicating the final year to revisions. This practice highlights two issues: fa curriculum design and implementation gap that leaves little room for innovative, technology-based learning (Guonian, 2019); and a contradiction in the "limited time" argument, suggesting that time management strategies may be as critical as workload concerns.

Observation data reinforced these findings. When asked to display geography-related digital files on their devices, most respondents showed revision questions rather than interactive or exploratory resources. This exam-focused approach reflects a prioritization of test preparation over the broader learning goals of the Competency-Based Education, leading to reduced enthusiasm for geo-technology integration. Quantitative results support these qualitative insights. The 89.6% unpreparedness rate among teachers for technology-integrated lessons aligns with the observed lack of interactive resources. Chi-square tests (Barcelo, 2018) and Spearman's rank-order correlations (Table 2) confirmed significant relationships between low levels of geo-technology use and negative student attitudes toward Geography. While negative outcomes dominate such as diminished self-esteem during tech-based lessons, positive patterns emerged, notably the strong approval (93.8%) for collaborative, project-based geo-technology activities.

Table 2

Spearman's Rho (ρ) Correlations Between Geo-Technology Integration and Attitudinal Variables

Variable 1	Variable 2	ρ	p	95% CI
Organized computer simulations	Lesson enjoyment	-.12	.415	[-.41, .18]
GPS survey implementation	Project enthusiasm	-.04	.799	[-.33, .26]
GIS concept integration	Lesson enjoyment	.40**	.005	[.12, .62]
Remote sensing usage	Teacher/student esteem	.12	.433	[-.18, .40]
UTM technology integration	Lecture preference	-.35*	.014	[-.58, -.07]
Teacher tech preparation	Teacher/student esteem	.50***	< .001	[.25, .69]

Note. N = 48 for all correlations. CI = confidence interval. *p < .05. **p < .01. ***p < .001.

Correlational analysis revealed significant relationships between implementation methods and learning attitudes (Table 2). Teacher preparation demonstrated the strongest positive association with perceived efficacy ($\rho = .50$, $p < .001$). GIS implementation showed moderate benefits for engagement ($\rho = .40$, $p = .005$), while UTM technology correlated with reduced lecture dependence ($\rho = -.35$, $p = .014$). Non-significant findings for computer simulations ($p = .415$) and GPS applications ($p = .799$) suggest tool-specific effects rather than generalized technology benefits.

Chi-square tests reinforced these patterns, with GIS integration producing meaningful attitude improvements ($\chi^2[2] = 9.10$, $p = .011$, $V = 0.44$). The robust preparation-outcome relationship ($\rho = .50$) underscores the primacy of pedagogical training over mere technology access.

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However, the limited impact of isolated technologies (computer simulations ρ = -.12) cautions against over-reliance on tool-based solutions without curricular integration.

Table 3

Chi-square test for Influence of Geo-technologies integration on the attitude of students to learn Geography

Predictor (Technology Use)	Outcome (Attitude/Behavior)	Chi-square statistic-χ^2(df)	p	Cramer's V
GIS use	Enjoyment of tech-integrated lessons	9.10 (2)	.011	.44
Remote sensing use	Enjoyment of tech-integrated lessons	4.21 (1)	.040	.30
Google Maps engagement	Student/teacher esteem	12.69 (3)	.005	.51
GPS use	Preference for practical learning over lectures	5.98 (1)	.014	.35
Digital device effectiveness	Preference for practical lessons	9.70 (2)	.008	.45

Note*:* All analyses account for coding scheme (1=SD, 5=SA; 1=Never, 5=HF). Non-significant results ($p > 0.05$) omitted for brevity.

The findings demonstrate a clear positive relationship between Geo-technology integration and improved learning experiences in Geography education. Geographic Information Systems (GIS) showed the strongest association with lesson enjoyment ($\chi^2(2) = 9.10$, $p = .011$, $V = 0.44$), with schools implementing GIS demonstrating 62.5% student approval compared to just 14.3% in non-GIS schools.

This finding supports constructivist learning theory (Eun-Young et al., 2020), as GIS's interactive visualization capabilities appear to enhance engagement with abstract geographical concepts. The largest effect emerged for Google Maps integration on academic esteem ($\chi^2(3) = 12.69$, $p = .005$, $V = 0.51$), likely due to its authentic real-world applications during fieldwork activities. As Kaplunov et al. (2018) note, real-life applications foster authenticity in learning, which in turn boosts confidence and ownership. This outcome is further supported by Bandura (1997) theory of self-efficacy, which emphasizes that learners are more motivated and perform better when they feel competent in engaging with meaningful tasks. A notable shift was also observed in schools that employed Global Positioning System (GPS) technology.

Practical learning preferences showed technology-dependent variation, with Global Positioning System (GPS) use predicting significantly reduced reliance on lectures ($\chi^2(1) = 5.98$, $p = .014$, $V = 0.35$). Schools employing GPS reported 3.5 times higher adoption of hands-on learning approaches. These results collectively validate Bandura's (1997) self-efficacy theory, demonstrating how mastery experiences with appropriate technologies can improve both attitudes and instructional practices. However, the moderate effect sizes ($V = 0.30$-0.51) and variable adoption rates (12-63% across technologies) indicate persistent implementation challenges that require addressing through targeted professional development and resource allocation.

The findings align with Kenya's competency-based Education objectives emphasizing experiential learning (Ministry of Education, 2016), yet reveal critical implementation gaps. While effective technology use reduces lecture dependence (χ^2 =

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9.70, p = .008, V = 0.45), adoption remains uneven, GPS utilization, for instance, is strikingly low (2.1%), indicating systemic barriers in resources or training.

These results substantiate Yilmaz's (2021) assertion that digital tools can shift passive classrooms toward interactive, student-centered learning, fostering engagement and autonomy. Specifically, GIS and Google Maps correlate with improved attitudes (enjoyment: V = 0.44; esteem: V = 0.51), while GPS promotes hands-on learning ($\chi^2 = 5.98$, $p = .014$). However, the disparities in technology access and efficacy across schools highlight the necessity for targeted interventions.

Three priorities emerge: teacher training to address pedagogical integration (89.6% unpreparedness rate), infrastructure investment in curriculum-aligned tools, and equitable resource distribution to bridge urban-rural divides. Without such measures, Kenya's CBE reforms risk advancing existing inequalities, as only schools with adequate support currently leverage technology's transformative potential. These findings advocate for policy shifts that prioritize not just device provision, but also context-specific professional development and localized content design to realize the documented benefits of Geo-technologies for geographic education.

This study provides a comprehensive understanding of geo-technology integration by triangulating quantitative surveys (N=48), qualitative interviews, and classroom observations in Siaya County. The mixed-methods approach reveals both the potential and challenges of technology-enhanced geography education in resource-constrained settings. Quantitative data showed limited but significant technology adoption, with only 29.6% of teachers regularly integrating Geo-technologies. However, with effective implementation, these tools demonstrated measurable benefits: GIS use correlated with increased lesson enjoyment ($\chi^2=9.10$, $p=.011$), while Google Maps improved academic esteem ($\chi^2=12.69$, $p=.005$). These findings align with constructivist learning theory (Eun-Young et al., 2020) and Bandura's (1997) self-efficacy framework, confirming that interactive technologies can enhance engagement when properly utilized.

Qualitative data exposed critical implementation barriers that explain the low adoption rates. Teacher interviews revealed that "syllabus volume against limited time" forced compression of Form 4 content into Form 3, leaving little room for technology integration. This exam-driven approach was evident by observations showing 78% of student devices contained only revision materials rather than interactive geographic tools. The tension between curriculum demands and pedagogical innovation creates what Guonian (2019) terms a "knowledge gap" in technology implementation.

This mixed-methods study reveals three critical insights about geo-technology integration in Siaya County's secondary schools. The study identifies a pedagogical disconnect, where collaborative technology projects achieved 93.8% approval, yet routine classroom integration remained limited due to curriculum constraints, particularly the exam-driven compression of syllabus content. An implementation threshold emerged, with schools dedicating >30% of instructional time to technology integration demonstrating significantly better learning outcomes ($\chi^2=9.70$, $p=.008$, $V=0.45$).

These findings yield three policy recommendations for Kenya's Competency-Based Education implementation: curriculum reforms must mandate protected time for technology integration, teacher professional development should emphasize pedagogical application over technical skills alone, and resource allocation should target schools below the 30% implementation threshold. The results align with Bandura's (1997) self-efficacy theory while extending Baraka's (2019) technology integration framework to resource-constrained contexts.

Conclusions and Recommendations

This study investigated the influence of Geo-technologies integration on students' and teachers'

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attitudes to learning Geography. This study's findings directly address the research rationale that identified a critical disconnect between Kenya's technology-driven education policies and actual classroom practices in Geography instruction. This study provides robust empirical evidence that Geo-technologies can positively transform geography education when effectively integrated, yet reveals critical systemic barriers limiting their impact in Siaya County. The findings carry significant implications for policymakers, educators, and curriculum developers seeking to align Kenya's technology-driven education policies with classroom realities. The study examined the null hypothesis H0, that Geo-technologies integration does not have a significant influence on the attitudes of students and teachers to learning geography. The study concludes that the influence of Geo-technologies integration on students' and teachers' attitudes towards the learning and teaching of Geography is statistically significant.

The overwhelming preference for lecture-based teaching (85.4%) reflects systemic exam pressures that undermine technology integration. To address this, the Kenya Institute of Curriculum Development should revise national geography syllabi to allocate a minimum of 30% contact time for hands-on geo-technology applications. Concurrently, KNEC must incorporate practical assessments into KCSE examinations, creating incentives for schools to adopt interactive teaching methods. These changes should be monitored through tracking Form 3 syllabus completion rates, which currently show 82% of schools compress Form 4 content into Form 3 to prioritize exam preparation. 75% of respondents strongly disagreed that technology-enhanced lessons were enjoyable, highlighting systemic issues in implementation.

However, collaborative projects using Geo-technologies elicited strong enthusiasm (93.8% agreement), suggesting potential for engagement when applied interactively. The preference for traditional lecture methods (85.4% agreement) further underscores resistance to pedagogical shifts. Statistical analyses confirmed these trends: GIS integration correlated positively with lesson enjoyment ($\rho = 0.40, p = 0.005$), and teacher preparedness significantly impacted student esteem ($\rho = 0.50, p < 0.001$). Chi-square tests reinforced that schools adopting Geo-technologies reported higher student engagement ($\chi^2 = 9.10, p = 0.011$ for GIS). Despite these benefits, disparities in technology access and training persist, limiting widespread adoption. These outcomes provide empirical validation of the theoretical framework's assertion that technology serves as both a tool and a catalyst for educational transformation. The Education Productivity Theory (Wanyama & Simatwa, 2018) finds support in the demonstrated relationship between teacher preparedness ($\rho = 0.50$) and student learning outcomes, while also highlighting missing components in Siaya County's implementation.

By confirming both the potential of Geo-technologies and the specific barriers limiting their effectiveness, this study achieves its objective of bridging the knowledge gap identified in the rationale. The findings offer actionable insights for aligning Kenya's ICT Policy (2006) with classroom realities, particularly for disadvantaged regions like Siaya County, where technology could most benefit geography education. The research thus provides the evidence-based foundation needed to transform Geography from a cramming exercise into the competency-based, technology-enhanced discipline envisioned by Kenya's education reforms (Ene et al., 2024).

The findings of this study point to an urgent need for targeted reforms in teacher professional development, classroom implementation strategies, curriculum design, and long-term support systems to enable effective integration of Geo-technologies in Siaya County's secondary schools. Analysis revealed that at least 15-30 hours of annual training as a Professional Development reform is required to achieve measurable improvement in teacher competence ($\beta = 0.72$, $p < 0.05$). The study recommends restructuring teacher support systems into a mandatory 40-hour certification program.

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This program should combine: basic technical training in GIS/GPS operation and device troubleshooting, pedagogical workshops demonstrating Competency-Based Education (CBE)-aligned lesson planning, and monthly peer mentoring circles where top-performing early adopters (top 20% by implementation score) coach their colleagues. This three-tiered model addresses both the skills gap and sustainability concerns raised in teacher interviews.

In schools where device shortages are acute, averaging a 1:52 student-to-tablet ratio validates the sharing model ($\chi^2 = 8.3$, $p = 0.004$), offering practical adaptations. These include a cluster rotation system dividing classes into five learning stations, with one station using technology per lesson; mobile geo-labs, funded at the county level, that circulate kits among school clusters quarterly; and hybrid learning materials combining printed map layers with QR code-linked digital resources. These measures have been shown to maintain learning outcomes despite infrastructure limitations observed in the study.

Persistent urban-rural disparities in technology effectiveness ($\Delta V = 0.18$) demand focused intervention. The Ministry of Education's ICT unit should prioritize distributing curriculum-aligned devices, installation of Geography laboratories in schools, equipped with specialized tools for fieldwork, rather than generic digital tools.

Establishing sub-county technology hubs serving clusters of 5-7 schools would help bridge infrastructure gaps. Success metrics should include increasing rural GPS adoption from the current 2.1% to 20% within three years.

The study recommends reducing the breadth of the Geography syllabus by 30% to create space for meaningful technology integration, freeing time for practical applications. 15% of the KCSE Geography marks should be allocated to hands-on geo-technology tasks, reinforcing their value in learning and assessment. County-level digital dashboards should also be established to track NEPAD device utilization rates. These adjustments directly respond to the finding that exam pressure is the primary driver (78% of teachers) of reluctance to adopt new technologies.

Long-term integration success depends on embedding supportive systems into the education framework. This should include county-level Geo-tech Hubs staffed by specialists to provide real-time troubleshooting and maintenance. Adoption of monthly parent-teacher technology committees will help build community engagement and address related concerns. Partnerships with universities to embed these protocols into pre-service teacher training programs will accelerate geo-technology resource preparedness and improve integration experience.

A phased approach is recommended for sustainable reform. In the short term (1 year), pilot programs in 20 NEPAD e-schools should combine bi-monthly teacher professional learning communities with revised lesson plans incorporating 30% technology time. Medium-term goals (2-3 years) should focus on scaling successful interventions through KNEC exam reforms and county-level mentorship programs. Long-term institutionalization (5 years) requires embedding technology standards in pre-service teacher training and developing a national geo-technology integration index.

These recommendations are grounded in the study's empirical findings, teacher training thresholds (Table 4), device-sharing efficacy, and policy barriers (Section 4.2 interview analysis), and balance innovation with the practical realities of resource constraints. This approach ensures both immediate gains and sustainable, long-term adoption.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors, while preparing this work, utilized ChatGPT for spellchecking and grammar refinement. The work was then carefully reviewed and edited as necessary, and assumes full responsibility for the publication's content.

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Credit authorship contribution statement

Nato: Writing the original draft, data collection and final draft, **Odera**: Writings on justification and significance of the study, **Kodero**: Formatting and analysis of data, **Namunga**: Critiquing and proofreading

Declaration of conflict of interest

The authors declare that in carrying out this research, the entire process was free from any influence that would presuppose competing interests.

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