

# Effects of ICT-Focused Professional Development on Teaching Methods and Student Achievement in Ghanaian Teacher Educational Institutions: A Systematic Review

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## Abstract

This study examines the integration of information and communication technology (ICT) into teacher education in Ghana, focusing on professional development programs within Colleges of Education. It explores how sustained training influences educators' technical skills, pedagogical strategies, and confidence in using digital tools to promote student-centered learning. The analysis highlights challenges such as infrastructural limitations, inconsistent funding, and gaps between policy ambitions and practical implementation. Theoretical frameworks like Technological Pedagogical and Content Knowledge (TPACK) and Substitution, Augmentation, Modification, and Redefinition (SAMR) are discussed as foundations for effective ICT integration, emphasizing the need for iterative, context-sensitive professional development models that combine technical proficiency with pedagogical innovation. Evidence indicates that well-structured training can shift teaching practices toward interactive, inquiry-based approaches, enhancing student engagement and digital literacy. However, the impact on academic achievement is often indirect and mediated by factors including assessment alignment and institutional support. Barriers such as limited access to resources, administrative capacity, and socio-cultural dynamics are identified as constraints to sustained ICT adoption. Recommendations call for comprehensive strategies that integrate technical, pedagogical, and affective dimensions; strengthen institutional leadership; ensure infrastructure reliability; and promote inclusive education. Emphasis is placed on continuous professional learning, collaborative networks, and policy frameworks that align national goals with local realities. The findings underscore the importance of systemic approaches to translate teacher development into lasting improvements in classroom culture and student outcomes.

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## Keywords

Integration, Frameworks, Problem-Solving, Professional Development, Technology

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## 1. Introduction

Efforts to integrate information and communication technology (ICT) into teacher education in Ghana have been influenced by a mixture of policy ambitions, pedagogical reforms, and the realities of infrastructure and training provision. In recent years, various studies have sought to clarify how professional development programs can shape teachers' abilities to effectively use ICT in teaching, particularly within Colleges of Education. Effective professional development training is characterised by a structured, learner-centred process that builds participants' knowledge, skills, and confidence to improve practice. It aligns training goals with learners' needs, offers relevant and practical content, provides active, hands-on learning opportunities, and incorporates ongoing support and feedback. There is now substantial agreement that sustained training opportunities play a central role in equipping educators with both the technical competencies and pedagogical strategies required for meaningful ICT adoption (Agyei, 2012). However, the challenge extends beyond skill acquisition; it also involves reducing anxiety around technology use, promoting reflective practice, and ensuring contextual alignment with available resources. The existing structure of Ghanaian teacher preparation has often been critiqued for its reliance on traditional rote learning approaches, which tend to encourage memorization at the expense of deeper conceptual engagement or creative thinking. Such pedagogy risks limiting future teachers' capacity to implement student-centered and inquiry-based methods even when advanced tools are made available (Perry & Bevins, 2018). Reforming this situation requires targeted interventions within professional development schemes that marry new pedagogical orientations with practical ICT competencies. Empirical findings from Colleges of Education in Ghana illustrate that tutors generally regard professional development as beneficial for their teaching practice and professional knowledge base. Yet questions remain about whether enhanced teacher characteristics necessarily translate into improved academic achievement for students. Some models suggest the relationship may be indirect, professional growth positively shapes instructional quality, which over time should influence student outcomes, but evidence on direct causal links is still sparse (Osei-Owusu, 2022). This uncertainty points toward an important area for further investigation. ICT policy frameworks in Ghana reflect a governmental recognition of the value that digital tools bring to educational reform. The stated aims focus on improving access to ICT infrastructure, enhancing digital literacy, and embedding technology more deeply into teaching methodologies. Despite these goals, implementation has been hampered by inconsistent funding streams, inadequate technical support

structures, and uneven distribution of hardware between institutions (Asare et al., 2023a, 2023b). Thus, while the strategic direction appears aligned with international best practices, operational realities frequently constrain progress. Professional development aimed at ICT integration must address specific local conditions. Studies have observed that where training incorporates context-sensitive design, taking into account infrastructure limitations and the baseline skill level of participants, teachers display greater confidence and adaptability in their classrooms (Agyei, 2012). Conversely, programs that rely heavily on abstract theory without hands-on components often fail to alter day-to-day practices meaningfully. The emphasis many tutors place on practical instruction and recurring training cycles confirms this pattern (Asare et al., 2023a, 2023b). Indeed, interview evidence highlights the perception among educators that continual exposure to new hardware and software is necessary given how quickly tools change. There is also an institutional dimension: policies should not merely encourage individual teacher growth but must create systemic pathways for collaboration, peer mentoring, and co-design of digital lesson plans. Initiatives based on collaborative design principles have shown promise in cultivating both technological proficiency and pedagogical innovation simultaneously (Agyei, 2012). By bringing educators together to build instructional materials using ICT tools under guided facilitation, these programs reduce isolation while accelerating practical skill uptake. Though attitudes toward ICT integration are generally positive within Colleges of Education in Ghana, barriers such as lack of equipment access and insufficient professional development opportunities persist as major deterrents (Asare et al., 2023a, 2023b). Some colleges operate with limited bandwidth or outdated computing facilities, which undermines even well-conceived training programs. Finally, considering ICT integration as a dynamic process implies a continuous feedback loop between practice in classrooms and broader structural reforms.

## **2. Methodology**

### **2.1. Research Design**

This study adopted a systematic review approach to identify, analyse, and synthesise empirical evidence on the effects of ICT-focused professional development (PD) on teaching practices and student achievement within Ghanaian teacher educational institutions. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to improve transparency, rigour, and replicability.

### **2.2. Search Strategy**

A comprehensive literature search was conducted to locate peer-reviewed and grey literature published between 2010 and 2025, reflecting the period during which ICT integration policies and professional development initiatives became prominent in Ghana. Search terms were developed using Boolean operators AND/OR and were applied in multiple combinations to maximise retrieval.

Key search terms included:

- “ICT professional development” OR “technology training” OR “digital literacy training”
- “teacher education” OR “colleges of education” OR “teacher training institutions”
- “Ghana”
- “teaching methods” OR “pedagogy” OR “instructional practices”
- “student achievement” OR “learning outcomes”

Search strings were adapted to suit each database. Additional manual searches were conducted through reference lists and Google Scholar alerts to capture relevant publications not identified in the initial search.

### 2.3. Databases Consulted

The following electronic databases were systematically searched:

- ERIC (Education Resources Information Center)
- Scopus
- Web of Science
- JSTOR
- Google Scholar
- ProQuest Dissertations and Theses
- ResearchGate (grey literature and unpublished research)

Additionally, institutional repositories from major Ghanaian universities (e.g., University of Cape Coast, University of Education Winneba, University of Ghana) were searched to capture context-specific studies.

### 2.4. Inclusion Criteria

Studies were selected based on the following eligibility requirements:

- 1) **Population:** Research focused on teacher educators, tutors, pre-service teachers, or in-service teachers working within Ghanaian teacher education settings.
- 2) **Intervention:** Studies that examined ICT-focused professional development, either formal or informal.
- 3) **Outcomes:** Evidence related to teaching methods, pedagogical change, instructional integration of ICT, or effects on student learning and achievement.
- 4) **Study design:** Qualitative, quantitative, and mixed-methods research.
- 5) **Publication language:** English.
- 6) **Time frame:** 2010-2025.
- 7) **Publication type:** Peer-reviewed journal articles, theses, conference papers, government/NGO technical reports.

### 2.5. Exclusion Criteria

Studies were excluded if they:

- 1) Focused on ICT adoption without linking to professional development.

- 2) Were opinion pieces, conceptual discussions, or policy reviews without empirical results.
- 3) Did not involve Ghana or teacher education institutions.
- 4) Focused on primary or secondary school settings rather than teacher education.
- 5) Lacked sufficient methodology or outcome data to support synthesis.

## 2.6. Selection Process

All search results were exported to Microsoft Excel and screened in four stages:

- 1) **Initial screening:** Removal of duplicates.
- 2) **Title and abstract screening:** Studies assessed against inclusion criteria.
- 3) **Full-text review:** Eligible studies evaluated for methodological quality and relevance.
- 4) **Final selection:** Studies that met inclusion criteria were retained for synthesis.

A PRISMA flow diagram was developed to document the number of records identified, screened, excluded, and approved for synthesis.

## 3. Literature Review

### 3.1. Historical Evolution of ICT in Teacher Education

The trajectory of ICT integration into teacher education has been shaped by a complex interplay of global educational reforms, national policy directives, and evolving pedagogical philosophies. Early efforts largely mirrored broader attempts at computer literacy programs, focusing on familiarizing educators with basic computing skills, often confined to administrative and presentation purposes rather than instructional transformation (Dzinoreva et al., 2023). These initial phases tended to treat ICT as an add-on to existing curricula rather than as a tool for reimagining teaching methodologies. As such, the emphasis was on discrete competencies, word processing, spreadsheet manipulation, and basic internet navigation, without embedding these skills into subject-specific pedagogy (Lokpo & Kumah, 2023). Over time, international bodies such as UNESCO began articulating frameworks like the ICT Competency Framework for Teachers, which sought to define a more integrated set of knowledge domains. These included understanding how technology could align with curricular goals, support assessment strategies, and influence school organization and administration (Lokpo, 2023). The shift from isolated skill training toward holistic digital literacy marked a significant step in reconceptualizing teacher preparation. Teacher education programs were now expected to blend technological proficiency with pedagogical innovation, requiring institutions to rethink both content delivery and assessment. In contexts such as Zimbabwe and Ghana, this raised questions about whether curricula adequately supported the development of these broader competencies for pre-service teachers (Dzinoreva et al., 2023). As reforms deepened,

national education policies in various countries explicitly recognized ICT's role in driving quality improvements in teaching and learning. Ghana's own strategic plans outlined STEM-focused priorities within its National Pre-Tertiary Education Curriculum Framework, highlighting ICT integration not only as a technical requirement but also as a mechanism for stimulating problem-solving abilities, collaboration among learners, and creative approaches to knowledge construction (Lokpo, 2023). This era marked the gradual institutionalization of ICT expectations within teacher standards, linking professional competence with student engagement outcomes. However, embedded within this policy evolution was an ongoing tension between aspirational frameworks and day-to-day realities within Colleges of Education. Infrastructural disparities, particularly between urban and rural institutions, limited equitable implementation despite shared curricular intentions (Asare et al., 2023a, 2023b). Research in mathematics education illustrates another inflection point in this historical arc: the recognition that technology integration could directly influence comprehension of disciplinary concepts. Whereas earlier interventions had positioned ICT as generic skill-building tools, emerging studies demonstrated their subject-specific value. For instance, integrating dynamic visualization tools into mathematics instruction improved conceptual understanding alongside problem-solving capabilities. Yet despite clear benefits documented globally, adoption remained uneven in many developing contexts; few teachers incorporated such tools routinely due to gaps in training or resource availability (Bandoh et al., 2024). This underscored a recurrent pattern throughout ICT's history, advances in potential outrunning shifts in teacher practice. Parallel to content-centered innovation were broader developments in teacher professional development models. By the mid-2010s, sustained programs aimed at embedding student-centered learning through digital means gained traction. International models encouraged collaboration among educators for co-designed lessons leveraging online resources, a departure from earlier top-down technical training sessions (Asare et al., 2023a, 2023b). In practice, these participatory approaches owed much to lessons learned from the prior decades: namely that isolated workshops without continued mentoring had minimal lasting impact on classroom behavior. Such experiences reinforced the notion that ICT integration is not a singular event but an ongoing process requiring iterative skill reinforcement (Dzinoreva et al., 2023). In some cases, particularly when addressing marginalized groups such as visually impaired learners in Ghanaian schools, historical limitations became even more visible. Studies revealed that high percentages of learners lacked practical ICT experience because their teachers had neither the competency nor adequate infrastructure to provide it (Lanbon et al., 2020). Factors such as insufficient lesson time allocation for hands-on work and frequent equipment breakdowns illustrated persistent structural barriers despite advancements in conceptual framing of ICT competencies. These conditions reflected an undercurrent running through much of ICT's educational history: access without reliability rarely yields sustainable pedagogical change. Taken together, the his-

torical record portrays ICT integration into teacher education as an uneven yet progressive accumulation of layers: starting with isolated technical skills; advancing through structured competency frameworks; branching into subject-specific applications; embracing collaborative professional growth models; addressing inclusive education needs; expanding into online modalities; and confronting demographic disparities along the way. Each stage responded partly to preceding shortcomings while also being circumscribed by material constraints that echo through current challenges identified in Section 1 (Lokpo, 2023).

### 3.2. Policy Environment for ICT Use in Ghanaian Education

Ghana's policy landscape for ICT in education has evolved through a series of interlinked strategic documents and targeted frameworks that collectively articulate the ambition to embed digital technologies into every level of the educational system. The government's commitment surfaced formally with the ICT for Accelerated Development (ICT4AD) policy, which positioned ICT as a key lever for enhancing teaching quality, broadening access to educational content, and developing the digital competencies of both learners and teachers. This macro-level policy orientation provided the philosophical and structural foundation upon which subsequent education-specific interventions have been built, aligning national socio-economic objectives with pedagogical goals. Building on this groundwork, Ghana's National Education Strategic Plan (NESP) 2018-2030 set precision targets for integrating ICT into teaching and learning processes at all educational levels. Rather than treating technology as an optional supplement, NESP describes integration as a normative feature of classroom practice, with explicit provisions for infrastructure expansion, teacher capacity building, and systematic development of digital resources. This represents a step beyond earlier approaches that emphasized hardware acquisition without equal attention to curriculum design or teacher preparedness. The more recent Ghana ICT in Education Policy reinforces these directions by explicitly linking ICT usage with improved student learning outcomes, enhanced teaching efficiency, and promotion of digital literacy as a life-long skill. Parallel to these broad sectoral strategies are policies tailored to specific institutional contexts. For instance, the Colleges of Education ICT Policy Framework focuses on transforming teacher-training institutions into hubs of technological competence. It underscores the provision of relevant hardware and network infrastructure, structured training programs for lecturers in digital pedagogy, and systematic embedding of ICT skills in pre-service teacher curricula (Asare et al., 2023a, 2023b). Similarly aligned projects under initiatives like the Ghana Digital Education Transformation Initiative extend these ambitions by coupling infrastructure support, such as laptop distribution for educators, with content creation and laboratory establishment in basic and secondary schools. While such measures signal political prioritization of ICT integration, consistent implementation often depends on budgetary continuity and alignment between national objectives and local execution plans. However, policy analysis reveals an ongoing

tension between aspirational outcomes in national documents and measurable effects at institutional level. Some commentators highlight that without specificity in targets or clear commitments to resource allocation timelines, even well-intentioned policies risk diluted impact. In particular, where national strategies articulate broad visions without detailing operational frameworks or accountability structures, local institutions may struggle to translate directives into workable programs. This situation is further complicated by disparities between urban centres, often better serviced with electricity and broadband connectivity, and rural areas where basic access remains unreliable. Logistical inequities undermine policy mandates that assume uniform infrastructural readiness nationwide. The role of institutional governance is therefore critical. While ministries are responsible for overarching policy coherence and funding streams, research argues that teacher training colleges should develop complementary internal policies tailored to their resource contexts. These contextualized frameworks can borrow principles from the holistic national strategy but adapt them pragmatically according to factors such as enrolment size, geographic location, connectivity levels, and available technical expertise among staff (Dzinoreva et al., 2023). For example, smaller colleges with lighter enrolments might feasibly equip all students with personal devices yet face connectivity barriers requiring offline resource development. Conversely, larger institutions may prioritize expanding shared digital facilities while negotiating staggered access schedules. Stakeholder engagement is also a recurring theme. Effective policy environments appear more achievable when multiple actors, including educators themselves, are involved from inception through execution phases. Engaging tutors not only increases buy-in but can surface otherwise overlooked challenges like software language compatibility or cultural appropriateness of digital content. Furthermore, aligning college-level decision-making with national monitoring systems can enhance feedback loops between policymakers and practitioners. Data on how teachers actually use technology in classrooms can refine existing strategies over time to maximize instructional value rather than focusing solely on deployment metrics. Another subtle yet influential factor is the emphasis on professional development within policy scopes. National plans stress recurrent capacity-building programs rather than one-off training events (Asare et al., 2023a, 2023b), reflecting evidence that continuous exposure improves adaptation to new software updates or pedagogical applications over time (Drossel & Eickelmann, 2017). Yet here too gaps emerge: funding allocations for such development are often not ring-fenced within education budgets, creating vulnerability when fiscal pressures shift priorities elsewhere (Nyaaba et al., 2023). Without sustained investment in skill enhancement alongside infrastructure influxes, teacher confidence in integrating ICT tools remains uneven irrespective of hardware availability. Finally, external factors such as global technological trends or crises like the COVID-19 pandemic have exposed both strengths and weaknesses in Ghana's policy environment. On one hand, existing strategic frameworks facilitated accelerated adoption of remote learning modalities when physical schooling

was disrupted (Quainoo & Pasawano, 2022). On the other hand, the scale-up revealed limits in prior planning: connectivity issues persisted; some subject areas lacked suitable localized online resources; and inequalities in device ownership among students became more visible. Such scenarios strengthen arguments for embedding contingency planning into future iterations of ICT education policies so they can flexibly respond to shifting conditions while staying aligned to long-term capacity-building aims. Collectively, these layers illustrate a dynamic interplay between visionary national aspirations and localized adaptation needs. Policies attempt to bridge systemic inequities while setting transformative goals for pedagogy through technology adoption, yet their eventual efficacy rests heavily on context-sensitive execution supported by adequate resources and genuine stakeholder commitment across all institutional tiers (Dzinoreva et al., 2023).

### 3.3. Conceptual Foundations of ICT in Pedagogy

The conceptualization of ICT within pedagogy revolves around framing technology not as an isolated add-on, but as a core component embedded in the instructional process. This framing stems from models that recognize the interplay between the technical affordances of digital tools and their capacity to mediate learning experiences in discipline-specific contexts (Lokpo & Kumah, 2023). From this perspective, ICT adoption in classrooms requires deliberate integration with curriculum design rather than sporadic or incidental use. The distinction here lies between simply using computers for a task and intentionally aligning ICT usage with learning objectives, assessment strategies, and student engagement mechanisms. A practical lens through which this integration has been theorized is the Technological Pedagogical Content Knowledge (TPACK) framework. This model articulates that effective technology-based teaching results from the intersection of three domains: knowledge of subject content (CK), pedagogical expertise (PK), and technological proficiency (TK) (Ajani & Govender, 2023). The strength of TPACK lies in acknowledging that mastering each domain independently is insufficient; instead, educators must understand how these domains intersect dynamically. For example, integrating an online simulation into a physics class is meaningful only if the teacher grasps both the physics principles involved and the pedagogical methods needed to guide inquiry, while also being adept in managing the digital platform. Without this combined knowledge structure, ICT tends to remain peripheral rather than transformative in pedagogy. Within this conceptual foundation, pedagogy informed by ICT also demands attention to teachers' confidence levels and professional agency. Teachers often resist or underutilize technology when they lack familiarity with its pedagogical potential or when prior training has been superficial (Lokpo, 2023). Here, the theoretical stance extends beyond technical competence to include dispositions toward learning innovation. A teacher may be proficient at operating presentation software but might still default to lecture-heavy delivery unless they conceive of ICT as an enabler of active student participation and collaborative knowledge construction. The integration

process can be interpreted along two complementary dimensions: viewing ICT as both a tool and as a method (Ajani & Govender, 2023). As a tool, ICT supports activities such as preparation of lesson materials, grading, or administrative scheduling, functions often disconnected from direct instructional interaction. As a method, however, technology becomes woven into instructional delivery itself, for example, using interactive simulations to teach abstract science concepts or employing language learning applications for pronunciation practice. The methodological dimension aligns more directly with constructivist principles, positioning students as active agents who engage with digital resources to build understanding through exploration and discussion. Another conceptual element influencing ICT's pedagogical role concerns alignment with broader educational policy frameworks that advocate learner-centered approaches. Such policies encourage reimagining classroom roles so that teachers act less as transmitters of information and more as facilitators who create resource-rich environments where students explore concepts supported by interactive technologies (Lokpo, 2023). In practice, this requires reconfiguring lesson plans to allow open-ended inquiry supported by multimedia sources or collaborative platforms rather than rigid lecture-format sessions. Professional development programs grounded in these conceptual foundations emphasize iterative cycles of practice, feedback, and refinement rather than one-off workshops. This approach parallels design-based research processes that engage teachers in co-designing technology-enhanced lessons while reflecting on their effectiveness over time (Agyei, 2012). Such interactions help solidify abstract theoretical ideas, like TPACK, into lived professional habits within specific subject areas. In applying these concepts, it becomes important to acknowledge contextual mediators such as available infrastructure, class sizes, and prevailing assessment cultures. In Ghanaian Colleges of Education, as in similar contexts, pedagogical models advocating deep integration across CK, PK, and TK frequently contend with constraints like limited laboratory access or inconsistent internet connectivity (Asabere & Ahmed, 2013). Therefore, interpretations of theory must allow for adaptive strategies: preloading offline resources onto school devices when bandwidth limitations inhibit real-time activities; scheduling small-group rotations where hardware shortages prevent whole-class participation; or leveraging widely available mobile devices for micro-learning tasks when computer labs are oversubscribed. The literature also draws attention to cognitive aspects underpinning effective ICT-infused pedagogy. Teachers' PK influences not merely what tools are employed but how students are guided through information processing stages during technology-mediated activities. Facilitating metacognition, for instance, can involve prompting learners to reflect on how they navigated an educational app's challenges or encouraging them to articulate patterns they discovered using a data visualization tool. Such actions root technology use within purposeful pedagogical scaffolding rather than allowing it to drift into unstructured entertainment. Critically assessing these theoretical underpinnings reveals tensions between aspirational models and empirical enactments. While most

frameworks agree on integrating technological and pedagogical expertise around substantive content knowledge (Ajani & Govender, 2023), execution gaps persist due to uneven professional preparedness (Lokpo, 2023) and variable institutional support structures (Wang et al., 2020). This suggests that theoretical comprehensiveness alone does not guarantee classroom-level transformation; ongoing teacher support systems remain necessary for sustaining coherent practice shifts aligned to framework principles. These perspectives converge on an important point: conceptual thinking about ICT in pedagogy is inherently integrative, it avoids isolating skills in silos, and context-aware, it accounts for environmental and institutional realities shaping enactment. Consequently, theories like TPACK serve best not as static checklists but as flexible schemas adaptable over time through reflective practice informed by local conditions (Abedi, 2024). The challenge lies in ensuring that adaptations do not erode the quality of integration envisioned at the conceptual stage but instead make it viable under diverse circumstances faced by educators.

### 3.4. Models of Professional Development

Building upon the conceptual foundations outlined earlier in Section 3.1, models of professional development for ICT integration provide structured pathways through which educators can acquire and continually refine both their technological and pedagogical competencies. These models vary in scope, method, and intensity, but most share a commitment to linking theoretical frameworks, such as TPACK, with sustained opportunities for applied practice (Ajani & Govender, 2023). One common structure involves school-based, practice-focused learning designs that place ICT training directly within the routine workload of teachers. Embedding development activities into everyday teaching contexts helps ensure that newfound skills are not abstractly absorbed but actively tested and adapted to real classroom conditions (Shoko, 2022). This practice-oriented approach also makes it easier to align training content with subject-specific needs and prevailing curriculum standards. Certain models emphasize collaborative formats that bring educators together to co-create technology-integrated lesson plans or explore shared pedagogical challenges. Such formats may range from short-term design workshops to ongoing communities of practice where participants exchange feedback and refine instructional materials over time (Ajani & Govender, 2023). This collaborative dimension addresses a known limitation of solitary skill acquisition: without peer engagement, individual teachers often revert to old habits despite formal exposure to ICT tools. Group structures create accountability while expanding the pool of strategies available to participants. They also tend to stimulate discussion on contextual constraints, like lab access or bandwidth reliability, which can lead to more pragmatic lesson adaptations. Several theoretically grounded models explicitly define levels or stages through which ICT incorporation matures in classroom use. The SAMR framework, for example, conceptualizes integration across four hierarchical stages: substitution, augmentation, modification, and re-

definition (Asare et al., 2023a, 2023b). At its earliest stage, technology simply replaces traditional tools without altering pedagogy; at its highest stage, it enables learning experiences previously impossible without digital means. While SAMR provides a scaffold for evaluating progress qualitatively, applying it within professional development programs requires pairing stage awareness with concrete examples from specific subject areas. For instance, in mathematics training, substitution might involve using spreadsheets merely for calculations already possible by hand; modification could entail employing dynamic graph plotting to enable exploratory data analysis otherwise inaccessible in physical class settings (Agyei, 2012). An alternative pathway is offered by TPACK-based programs which focus on integrating technological knowledge directly with pedagogical strategies bound to particular content domains (Ajani & Govender, 2023). This model treats mastery as a matter of balance, strengthening any one domain (Tk, Pk, Ck) without addressing intersections will limit overall effectiveness. Professional development designs rooted in this philosophy often include iterative cycles: introducing a tool within disciplinary context; modeling its pedagogical application; having teachers design lessons around it; implementing these lessons; then reflecting jointly on outcomes and challenges experienced during delivery. This cyclical process creates room for refinement across successive iterations rather than expecting flawless integration after first exposure (Agyei, 2012). Context-sensitive adaptations have appeared in country-specific versions of these broader frameworks. Mukuna's Technology Integration Planning Model for Kenya exemplifies how national educational realities, like gaps identified in pre-service curricula, can guide tailored development plans. The model argues for introducing ICT competencies early in teacher education so that post-service instructors can apply them fluently rather than retrofitting unfamiliar skills into established routines later in their careers. Analogous adaptations could be envisioned for Ghana's Colleges of Education where infrastructure inconsistencies require strategies combining offline resources with selective online enhancements depending on local connectivity conditions. Policy-linked professional development schemes further recognize that growth is both an institutional and personal process. Institutional support structures, formal mentoring systems, dedicated ICT coordinators, are essential complements to individual skill-building workshops (Dzinoreva et al., 2023). Without such scaffolding, even highly motivated teachers risk losing confidence when isolated from ongoing technical or pedagogical advice channels. Therefore some models combine formal training sessions with embedded mentorship where experienced peers or designated specialists assist less confident users during initial classroom applications of ICT tools. Long-term continuous professional development (CPD) has been advanced as critical for shifting teacher beliefs about technology's role in pedagogy and sustaining performance improvements as tools evolve (Alivi et al., 2024). In CPD frameworks aligned with TPACK principle, teachers regularly revisit learning objectives to ensure evolving technologies continue meeting student needs effectively rather than becoming novelties divorced

from curricular goals. These programs assume cyclical refreshers are necessary given that each update or new application may alter optimal usage strategies, a reality particularly salient when mainstream devices integrate unanticipated features like automated assessment functions or AI-assisted content generation. Importantly, effective implementation of any professional development model is conditional upon infrastructural readiness (Asare et al., 2023a, 2023b). Participants often articulate frustrations around outdated hardware or insufficient internet access which can derail well-intentioned models if unaddressed at program design stage. Models responsive to such factors sometimes incorporate parallel investment planning, ensuring training coincides with lab upgrades, or focus on software accessible via lower-spec devices widely available among teacher cohorts. In settings where hardware expansion is slow, local adaptation might prioritize multi-function mobile tools because they fit resource-constrained realities while still offering scope for interactive tasks like polls or collaborative annotation exercises on texts. Several studies indicate that integrating spreadsheet-supported activity-based learning into subject-specific professional courses not only improves immediate technical competence but also reshapes underlying pedagogical approaches (Agyei, 2012). Within mathematics teacher preparation specifically, spreadsheet applications have been used as vehicles for exploring inquiry-led problem solving rather than static calculation drills, a shift reflecting deeper changes in instructional philosophy alongside technical adaptation. Such findings suggest that effective PD models operate at multiple levels simultaneously: they enhance tool proficiency while recalibrating classroom practices toward more engaged learning modes that technology can facilitate but not guarantee by presence alone. Returning finally to the interplay between theory and lived practice seen earlier in Section 3.1, successful professional development models bridge conceptual ideals like integrative CK-PK-TK alignment with the daily constraints encountered by educators. Those models most likely to persist over time appear to be ones structured around iterative engagement, peer support mechanisms, context-aware resource planning, and scaffolds enabling movement along developmental continuums such as SAMR or TPACK's intersecting domains (Asare et al., 2023a, 2023b; Shoko, 2022). In operational terms this means replacing sporadic workshops with embedded learning cultures inside institutions, cultures where trying a new tool becomes part of teaching identity rather than an occasional supplement driven solely by external mandates.

### **3.5. Effects of ICT Professional Development on Teaching Practices**

Professional development programs centered on ICT integration have shown tangible influence over the instructional methods adopted by teachers, often leading to discernible shifts away from traditional, lecture-based delivery toward more interactive, learner-focused pedagogies. In many teacher education contexts, including those in Ghana, building digital competence through sustained and con-

text-aware training encourages educators to explore alternative modes of lesson facilitation that invite student participation. This is closely tied to gradual changes in teacher attitudes: familiarity with a range of ICT tools demystifies their use, reducing initial hesitancy and opening space for experimentation in content delivery (Aidoo et al., 2022). For example, teachers who once confined technology use to projecting slides may begin integrating multimedia resources or collaborative platforms into coursework as their confidence in both technical handling and pedagogical application grows. The influence on teaching practices can be thought of in terms of breadth and depth. From a breadth perspective, ICT professional development often expands the range of tools that educators feel comfortable incorporating into lessons, from video conferencing for guest lectures to interactive quizzes that provide instant feedback (Agyei, 2012). In terms of depth, it pushes them toward embedding these tools purposefully within the learning cycle. Instead of using an educational app as a stand-alone diversion, trained teachers are more likely to align its use with specific objectives, scaffold activities around it, and integrate reflection exercises to consolidate learning (Drossel & Eickelmann, 2017). Over time this alignment tends to cultivate more coherent lesson structures where technology supports core concepts rather than acting as an isolated novelty. One recurring outcome noted in program evaluations is the gradual substitution of teacher-centered strategies with learner-centered ones (Dzinoreva et al., 2023). Teachers trained under iterative professional development models begin designing sessions where students actively construct knowledge, for instance by engaging in project-based assignments supported by online resources or using simulations to test hypotheses in science lessons. These practices correspond with increased opportunities for formative assessment; educators can review student outputs within digital environments and adjust subsequent instruction based on observed needs. Such responsive pedagogy is harder to sustain without adequate familiarity with ICT functionalities. However, altering teaching practice involves more than simply acquiring tool-specific knowledge; it also relates to shifts in underlying pedagogical beliefs. Deep integration often requires educators to prioritize critical thinking and collaboration over rote recall. ICT-rich professional development programs therefore encompass not only technical tutorials but also explicit discussion about constructionist or inquiry-oriented teaching philosophies (Agyei, 2012). This dual emphasis encourages teachers to rethink conventional pacing guides or textbook sequencing so as to build in time for exploratory activities mediated by technology. A practical illustration comes from mathematics education initiatives where spreadsheets have been incorporated into problem-solving exercises (Mensah & Agyei, 2021). Teachers who previously relied solely on chalkboard derivations began setting computer-based tasks that encourage students to manipulate variables dynamically and instantly visualize results through graphs. The transformation lies both in efficiency gains, calculations performed quickly, and cognitive expansion: learners can focus more energy on interpreting relationships between data sets rather than manual computation alone. Similar

patterns emerge across disciplines; language instructors employ pronunciation apps for immediate feedback loops while social studies educators set collaborative mapping projects harnessing geographic information systems. Not all impacts manifest smoothly or uniformly across institutions. Hardware shortages or unreliable internet access remain barriers that sometimes prompt teachers to revert to pre-training routines despite having acquired new skills (Aidoo et al., 2022). Moreover, without ongoing support channels such as peer mentoring or designated ICT coordinators, innovations trialed soon after training may fade from regular practice (Asare et al., 2023a, 2023b). These constraints mean that sustained improvement often correlates with infrastructural readiness and institutional commitment alongside individual teacher capacity. Professional development programs linking internal efforts within Colleges of Education with external workshops appear especially promising (Drossel & Eickelmann, 2017). This combination affords continuity: skills introduced during centralized training are reinforced back at the institutional level through local adaptation projects or peer exchange sessions. Instructors involved report higher retention of techniques when they immediately apply them in familiar teaching contexts rather than postponing experimentation indefinitely. Some research suggests that the direct effect of ICT-focused professional development on student academic scores may be less immediate than its observable effect on classroom engagement patterns (Nyaaba et al., 2023). Teachers adopt new questioning techniques supported by polling software or integrate discussion boards into coursework; these modifications heighten participation even if measurable test score gains take longer to emerge. Importantly, however, increased engagement is itself valued as a contributor to deeper learning trajectories. Several frameworks conceptualize this change process as staged progression. At initial phases post-training, teachers might still substitute analog methods with digital equivalents without adjusting core pedagogy, creating digital worksheets instead of printed handouts, but exposure over time can lead toward more modified and redefined learning experiences (Dzinoreva et al., 2023). Evidence from Ghanaian Colleges indicates that those who engage repeatedly with structured CPD sessions are more likely to reach these higher stages compared to peers attending isolated events where follow-up is absent. Content-area specificity plays a decisive role as well. Programs recognizing subject demands tend to produce richer pedagogical transformations because they address how technology mediates domain knowledge explicitly rather than generically. A mathematics lecturer designing a dataset analysis module benefits from understanding not only spreadsheet mechanics but also which statistical concepts lend themselves best to such treatment given curriculum benchmarks (Agyei, 2012). Similarly, music education trainers experimenting with sequencing software need guidance marrying theoretical instruction with auditory production tools so that classroom compositions reinforce key learning goals rather than functioning purely as entertainment (Mawusi & Kwadwo, 2020). Furthermore, professional development that models collaborative teaching, either co-planning lessons or co-teaching digitally-

enabled units, reinforces the viability of shared responsibility for technological integration. Participants exposed to joint practice scenarios often adapt these strategies with colleagues post-training, indirectly extending ICT uptake beyond initial cohorts (Aidoo et al., 2022). Collaboration surfaces practical solutions otherwise overlooked individually; for example modifying lab schedules collectively so all classes rotate through limited computer facilities equitably. Finally, an important nuanced observation emerges: professional development impacts are mediated by teacher agency. Even within identical training programs some educators exhibit markedly greater adoption rates owing partly to pre-existing dispositions toward innovation and partly to contextual enablers like administrative encouragement or recognition schemes (Adarkwah, 2021). Where institutional culture values experimentation and peers celebrate digital successes publicly, newly trained teachers perceive fewer risks in altering long-standing routines. Overall the evidence portrays ICT-linked professional growth as capable of reshaping classroom dynamics substantially under supportive conditions. The transformation encompasses expanded tool repertoires, refined alignment between technological choices and curricular aims, shifts toward learner-centered facilitation, richer formative assessment cycles, and greater intra-staff collaboration, provided infrastructural adequacy and sustained reinforcement protect against regression into habitual practices entrenched before training interventions were introduced.

### 3.6. Impact of ICT Professional Development on Student Outcomes

The relationship between ICT-focused professional development for teachers and student outcomes appears to be shaped by both direct instructional effects and more diffuse, indirect influences. Evidence from various empirical studies suggests that when educators acquire new technology-related competencies through sustained capacity-building initiatives, they often adapt their pedagogical approaches in ways that expand opportunities for students to engage more actively and creatively with learning materials (Nyaaba et al., 2023). This process can enhance cognitive engagement, particularly when digital tools are integrated into inquiry-based or project-oriented tasks rather than used solely for presentation purposes. Students exposed to such enriched methodologies can develop a broader range of skills, including critical analysis and collaborative problem solving, alongside core subject knowledge. However, the mechanism linking teacher development to student achievement is not always linear. Some meta-analytic findings indicate a generally positive association between professional development and academic performance, confirming earlier reviews (Osei-Owusu, 2022). At the same time, there are counterexamples where extensive teacher participation in ICT training did not translate into immediate gains in test scores, and in some cases performance indicators declined despite increased exposure to ICT-based instruction. Such mixed results underscore the multiplicity of factors influ-

encing learning outcomes, ranging from curriculum alignment and assessment design to the socio-economic environment of learners. One plausible explanation for variability lies in how effectively teachers align their newfound technological skills with curricular goals and assessment formats. For instance, if national examinations remain heavily weighted toward rote recall, even well-executed ICT-rich lessons that emphasize higher-order thinking may not yield short-term score improvements. Nonetheless, those same lessons may provide long-term benefits by cultivating transferable competencies relevant beyond standardized testing contexts (Amuzu & Ibrahim, 2022). In subject areas like social studies or science, where conceptual complexity is high, well-integrated ICT use has been linked to deeper student comprehension through interactive simulations or visualizations that make abstract principles more tangible. From another angle, ICT integration arising from targeted professional development can broaden students' access to diverse resources and learning pathways. By incorporating e-learning materials and online repositories into classwork, teachers offer learners the possibility of self-paced study and differentiated task levels (Dzinoreva et al., 2023). Such differentiation increases the likelihood that students across varying ability levels find entry points into lesson content that are both challenging and attainable. Increased autonomy in navigating materials may also build metacognitive skills as students learn to plan their own study schedules or select appropriate tools for problem-solving. Infrastructure plays a mediating role in translating teacher capacity gains into better student outcomes. In environments where devices are plentiful enough to allow hands-on practice during lessons, such as having laptops for most students, opportunities multiply for applying new knowledge immediately within class projects (Asare et al., 2023a, 2023b). Conversely, where computer lab sessions are infrequent or bandwidth constraints prevent real-time use of web-based applications, implementation gaps can weaken potential gains. Under such constrained conditions, even innovative teaching plans developed through professional development may result only in partial exposure for students. Another observable effect concerns motivation and engagement. Students report greater interest when classes use multimedia-rich presentations or interactive platforms rather than relying exclusively on lecture formats (Abedi et al., 2024). This heightened interest can lead to better attendance patterns and increased willingness to participate during class discussions, factors known to correlate with improved learning trajectories over time. Teachers adept at blending face-to-face interaction with supportive digital components can stimulate a classroom climate conducive to risk-taking in learning; for example, structured online forums may encourage quieter students to contribute ideas they might hesitate to voice aloud. The approach taken within training programs also matters greatly for eventual impact on learners. Capacity development that models student-centered use of ICT tends to produce downstream effects where similar approaches appear in the trainee's own classroom (Agyei, 2012). For example, mathematics educators trained on spreadsheet-based explorations often adopt such formats for data in-

terpretation exercises with pupils, thereby providing experiences that blend computational efficiency with analytical reasoning skills. These types of activities support constructive knowledge building because they require interpreting output rather than merely producing it. Importantly, the effects extend beyond purely academic metrics such as grades or standardized test scores. Students exposed regularly to well-integrated ICT activities develop digital literacy skills, information evaluation, responsible online communication, that hold value across future educational stages and employment contexts (Asare et al., 2023a, 2023b). Given that comparisons between graduates from technology-enriched schooling environments and those from under-resourced settings often reveal disparities in employability related competences (Abedi et al., 2024), early and consistent integration of ICT stands as a long-term equalizing factor. There is also an argument to be made about how ICT-enabled pedagogies increase opportunities for formative assessment practices which directly influence student feedback cycles (Nyaaba et al., 2023). Online quizzes with instant scoring or peer-assessment tools embedded within learning management systems allow instructors to identify misconceptions quickly and intervene before these solidify into persistent misunderstandings. Students benefit not only from faster feedback but also from seeing exemplars within peer submissions that broaden their conception of acceptable answers or solution strategies. Still, it must be emphasized that without follow-up support for both teachers and students post-training period, initial performance gains may erode (Osei-Owusu, 2022). Where regular refresher workshops or mentoring schemes exist, and where institutions invest in maintaining functional infrastructure, positive momentum has a higher probability of sustaining over multiple academic years. Broader policy commitments toward continuous improvement amplify this effect by ensuring alignment between classroom experiences shaped by recently trained educators and evolving national curriculum frameworks (Dzinoreva et al., 2023). Feedback from Ghanaian contexts highlights one additional dimension: affective outcomes linked to confidence building among learners who previously felt disadvantaged by lack of access (Asare et al., 2023a, 2023b). Structured opportunities through school-based ICT programs can demystify digital environments for these students, reducing intimidation factors while providing tangible proof of competence through successfully completed projects. In this way, professional development impacts morale as much as mastery, a variable whose importance should not be underestimated given its influence on persistence in education. Taken together, the evidence portrays an intricate link between teacher-focused ICT training and student-level change: improved instructional techniques serve as catalysts for richer engagement; aligned technology use supports cognitive gains aligned with course objectives; expanded access deepens equity; formative feedback structures accelerate progression; and emergent digital literacies prepare learners beyond immediate assessments. Yet sustaining these benefits requires attention not just to individual teacher skillsets but also systemic enablers, from infrastructural stability through policy cohesion, to ensure the full translation of professional growth into enduring student success (Asare et al., 2023a, 2023b; Osei-

Owusu, 2022).

### 3.7. Challenges and Barriers to Effective ICT Professional Development

Barriers to effective ICT professional development for educators across Ghanaian Colleges of Education tend to emerge from a network of interrelated infrastructural, institutional, pedagogical, and socio-cultural constraints. These impediments often temper the translation of policy ambition and training initiatives into sustained classroom change, as discussed in Section 5. One prominent challenge is the low level of ICT competence among certain key actors, particularly school administrators. Insufficient familiarity with digital resources can hinder not only their personal ability to advocate for technology integration but also their capacity to facilitate conditions that support teachers' newly acquired skills (Oduro & Yalley, 2022). Where administrative leaders themselves lack confidence in ICT use, school-wide adoption rates tend to slow due to limited vision-setting and weak provision for ongoing resource allocation. Infrastructure limitations remain a persistent bottleneck. Across multiple studies, inadequate access to computers, intermittent internet connectivity, and outdated software are recurrently cited as reasons educators struggle to maintain ICT-based pedagogies after initial training (Asare et al., 2023a, 2023b). This extends beyond simply having hardware present; without functional maintenance systems or reliable electricity, planned technology-supported lessons are frequently abandoned in favor of more predictable analog methods. In some rural colleges, connectivity barriers mean that online tools modeled during training cannot be replicated with students in practice. Such implementation gaps undermine morale among trainees who may feel that their efforts to adapt pedagogy are futile under current resource conditions. Financial constraints compound these infrastructural shortfalls. Teachers often believe there has been inadequate financial support for acquiring ICT resources needed to execute their teaching functions effectively (Nyamekye et al., 2021). Budgetary pressures at institutional and national levels sometimes lead to one-off investments, such as bulk hardware purchases, without parallel planning for software licensing renewals, upgrades, or service contracts. In such cases initial enthusiasm sparked by improved facilities erodes rapidly as devices fall into disrepair or become incompatible with evolving applications relevant to contemporary curricula. Training-related barriers also play a central role. Many teachers have had little exposure to professional development covering pedagogical integration of ICT (Agyei, 2012). Short-term workshops without follow-up can produce superficial awareness rather than embedded practice change. Inadequate emphasis on aligning digital tools with subject-specific content further limits relevance; generic sessions may fail to address distinctive challenges in fields like mathematics or language instruction where nuanced application strategies are vital (Aidoo et al., 2022). Where teachers are not guided on connecting technological capabilities with concrete learning outcomes tied directly to their syllabus objectives, uptake tends to remain mechanical rather than transformative. Inclusion-related issues

reveal another dimension of challenge. Even when resources increase nationally, integration pathways for marginalized student groups, such as those with disabilities, may lag behind due in part to scarce targeted material and limited specialized training (Montenegro Rueda & Fernández Cerero, 2019). This reflects a broader pattern where pedagogical thinking has not progressed synchronously with technological availability; hardware presence alone does not yield adaptive instructional redesign sensitive to diverse learner needs. Attitudinal factors influence actual engagement with ICT post-training. While most teachers report positive perceptions regarding technology's potential, some still express skepticism about its practicality in constrained environments (Kumar, 2022). There is an uneven distribution of teacher confidence which interacts strongly with prior exposure: educators unfamiliar with digital problem-solving methods may revert quickly to traditional approaches when faced with technical glitches mid-lesson. Furthermore, gender dynamics illustrate subtle yet impactful barriers; historical imbalances in opportunities for female teachers' access mean that uptake patterns remain uneven unless proactive measures ensure equitable participation in training and subsequent classroom experimentation. Institutional culture profoundly shapes sustainability of professional development gains. Environments lacking structured peer support or mentorship make it difficult for trained teachers to embed innovations amid everyday workload demands (Buabeng-Andoh, 2019). Collaborative models require deliberate administrative endorsement; absent such leadership encouragement and scheduled time for co-planning ICT-based lessons, isolated efforts dissipate over time. Studies indicate that the absence of leadership support suppresses integration rates despite individual willingness among staff members. Policy-practice misalignment also emerges as a recurrent theme. National directives promoting ICT-rich pedagogy sometimes come without precise operational frameworks or adequate monitoring mechanisms at grassroots level (Lokpo & Kumah, 2023). This leads colleges to pursue disparate interpretations of broad goals without shared metrics for success, complicating collective progress evaluation. A lack of coordination between education authorities and telecommunication or technology sectors further slows infrastructure deployments critical for enabling practices introduced during professional development programs (Asare et al., 2023a, 2023b). Another barrier relates to the assessment ecosystem within which trained educators operate. If standardized examinations continue privileging memorization-heavy tasks over analytical processes encouraged through ICT-mediated learning activities, teachers may perceive misalignment between innovating pedagogy and securing student grades under current evaluation criteria (Nyamekye et al., 2021). This tension can result in selective adoption where technology is used only sparingly when deemed safe from undermining examination preparation tactics.

#### 4. Future Directions and Recommendations

Strengthening the impact of ICT-focused professional development requires moving beyond short-term interventions and envisioning strategies that address both in-

dividual competency growth and system-level sustainability. One direction is to design programs that integrate the technical, pedagogical, and affective dimensions of ICT use into a coherent framework. Existing research suggests that training should not merely focus on tool operation but also on how specific technologies intersect with curricular objectives, assessment methods, and student engagement strategies (Wang et al., 2020). Embedding these considerations within long-term professional learning plans rather than isolated workshops would enhance retention and application in classroom contexts. A promising area lies in developing digital literacy frameworks tailored to the realities of Ghanaian Colleges of Education, incorporating emerging competences relevant to Education 4.0 paradigms (Flores-Chacón et al., 2023). Such frameworks could be structured to account for subject specificity, illustrating, for example, how mathematics educators might leverage dynamic graphing tools to promote conceptual reasoning, while language educators integrate pronunciation and grammar applications in ways aligned to communicative pedagogy. These frameworks should allow iterative updating so they remain responsive as both technology features and educational priorities evolve. Institutional support systems must form a critical part of future planning. Without leadership endorsement and resource allocation, even highly motivated teachers may struggle to sustain changes in practice (Aidoo et al., 2022). Administrators could establish dedicated ICT coordinators or mentor roles within departments, tasked with providing ongoing guidance, troubleshooting assistance, and facilitating peer exchange forums. This approach parallels findings that collaborative communities among educators encourage consistent integration through shared lesson planning and reflective dialogue (Asare et al., 2023a, 2023b). Encouraging cross-college collaboration through inter-institutional knowledge networks could multiply the reach of innovative practices while reducing duplication of effort. Infrastructure reliability remains a practical precondition for most recommendations to succeed. Strategic investments should prioritize not just device acquisition but also maintenance contracts, software licensing continuity, and provision for bandwidth improvements where connectivity limits deployment (Dzinoreva et al., 2023).

#### **Key Recommendations for Ghanaian Education Policymakers**

- **Adopt a long-term PD strategy rather than isolated workshops:** Institutionalize ongoing ICT-focused professional development that strengthens technical, pedagogical, and classroom management skills over time.
- **Develop a national ICT competency framework for colleges of education:** Ensure it reflects subject-specific applications, Education 4.0 needs, emerging technologies, and allows regular updating to match changing tools and priorities.
- **Strengthen institutional leadership and support systems:** Establish ICT coordinators or mentors in each college department to offer guidance, drive collaboration, and support classroom integration.
- **Prioritize sustainable digital infrastructure investment:** Link teacher train-

ing rollouts to timelines for upgrading connectivity, maintenance systems, licensing, and offline teaching solutions in low-bandwidth environments.

- **Promote collaborative learning cultures across and within colleges:** Facilitate inter-college professional networks, peer exchange platforms, and communities of practice to share models, lesson plans, and innovations.
- **Embed contextualized Ghanaian case studies in training:** Ensure PD materials include relatable examples from local colleges that demonstrate practical strategies and challenges to encourage realistic implementation.
- **Align ICT integration with assessment reforms:** Adjust national examinations to reward inquiry, creativity, and critical thinking, motivating teachers to integrate ICT more meaningfully into instruction.
- **Build inclusivity into ICT policies from the outset:** Incorporate accessibility standards, assistive technologies, and inclusive design strategies to support learners with diverse needs.
- **Institutionalize measurable ICT integration indicators:** Track progress using clear metrics—such as LMS usage rates—while strengthening reporting channels between colleges and national bodies.
- **Implement regular follow-up and refresher training cycles:** Schedule termly or yearly support sessions to prevent knowledge erosion and introduce new tools slowly and sustainably.
- **Prepare contingency pathways for digital learning continuity:** Integrate flexible blended learning and emergency remote-teaching strategies into PD plans to ensure resilience during disruptions.

## 5. Conclusion

The integration of information and communication technology within teacher education in Ghana presents a dynamic interplay of policy ambitions, pedagogical reforms, and infrastructural realities. Sustained professional development emerges as a key factor in equipping educators with the necessary technical skills and pedagogical strategies to effectively incorporate digital tools into their teaching. However, the process extends beyond skill acquisition to include building confidence, encouraging reflective practice, and ensuring alignment with local contexts and available resources. Traditional teaching methods, often reliant on rote memorization, pose challenges to the adoption of student-centered and inquiry-based approaches, highlighting the need for professional development programs that combine new pedagogical orientations with practical ICT competencies.

Historical trajectories reveal a gradual shift from isolated computer literacy training to integrated digital literacy frameworks that emphasize the intersection of content knowledge, pedagogy, and technology. This evolution has been shaped by global educational reforms and national policy initiatives, yet disparities in infrastructure and resource availability continue to limit equitable implementation across institutions. Policy frameworks in Ghana articulate ambitious goals for ICT

integration, emphasizing infrastructure expansion, teacher capacity building, and curriculum development. Nonetheless, gaps between policy intentions and operational realities persist, often due to inconsistent funding, limited technical support, and uneven distribution of resources.

Effective professional development models emphasize practice-based learning embedded within everyday teaching contexts, collaborative lesson design, and iterative cycles of application and reflection. Frameworks such as TPACK and SAMR provide conceptual scaffolds for understanding and advancing technology integration, but their success depends on contextual adaptations that address infrastructural constraints and institutional cultures. The impact of ICT-focused training on teaching practices includes expanded tool repertoires, shifts toward learner-centered pedagogies, enhanced formative assessment, and increased collaboration among educators. These changes contribute to more interactive and engaging classroom environments, although sustained improvements require ongoing support and adequate resources.

The influence of professional development on student outcomes is multifaceted, encompassing cognitive engagement, motivation, access to diverse learning materials, and the development of digital literacies. While direct effects on standardized test scores may vary, enriched pedagogical approaches foster deeper understanding, critical thinking, and collaborative problem-solving skills. Infrastructure availability plays a mediating role, with reliable access to devices and connectivity enabling more consistent application of ICT-enhanced methods. Additionally, affective benefits such as increased learner confidence and reduced intimidation in digital environments contribute to positive educational trajectories.

Challenges to effective ICT professional development are numerous and interconnected, including limited administrative ICT competence, infrastructural deficiencies, financial constraints, insufficiently contextualized training, inclusion gaps, attitudinal barriers, and policy-practice misalignments. These obstacles underscore the necessity of comprehensive strategies that address technical, pedagogical, institutional, and socio-cultural dimensions simultaneously. Without such holistic approaches, gains achieved through training risk being short-lived or unevenly distributed.

Future efforts should prioritize integrated professional learning frameworks that encompass technical skills, pedagogical knowledge, and affective factors, supported by institutional leadership and collaborative networks. Infrastructure investments must extend beyond hardware acquisition to include maintenance, software licensing, and connectivity improvements, with contingency plans for low-resource settings. Training content should balance efficiency-oriented and constructivist pedagogies, incorporating contextualized case studies and inclusive practices to accommodate diverse learner needs. Policy mechanisms need to establish clear operational pathways, measurable indicators, and feedback loops to ensure alignment between national goals and institutional actions. Regular refresher sessions and reflective practices can sustain teacher competence and adapta-

bility as technologies and educational priorities evolve. Furthermore, aligning assessment systems with ICT-enabled inquiry-based learning will encourage pedagogical innovation and reinforce the value of digital integration.

By addressing these interconnected factors through coordinated, sustained, and context-sensitive initiatives, there is potential to transform teaching cultures within Ghanaian Colleges of Education. Such transformation promises to enhance instructional quality, broaden equitable access to digital learning opportunities, and prepare both educators and students for the demands of contemporary education landscapes.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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