



Technological Knowledge and TPACK of SHS Biology Teachers in Ghana

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ABSTRACT

The study aimed to examine the technological knowledge (TK) and technological pedagogical content knowledge (TPACK) of senior high school (SHS) biology teachers in some municipalities in the Greater Accra Region, Ghana. Methods: Guided by two research objectives, the study employed an explanatory sequential mixed-methods design. The quantitative data in this study were obtained from 73 senior high school biology teachers in 31 senior high schools using a validated structured questionnaire, which was adapted from the Items for TPACK Survey (ITS). Data were collected using qualitative methods such as classroom observations and semi-structured interviews with two teachers who were purposively selected. Results: Teachers' self-reported technological knowledge was moderate ($M = 4.25$; $SD = 0.77$), while the availability of modern digital tools was limited, with 63% of the teachers stating that there was no access to ICT in their schools. The results showed that students' self-reported TPACK was found to be positive ($M = 4.22$, $SD = 0.76$); however, classroom observation data indicated that students rarely used technology in their biology lessons, and the use of technology was consistently low. The results of an independent-samples t-test revealed that there was no significant difference in TPACK between the two groups of teachers, professionally qualified and non-professionally qualified ($t = -1.20$; $df = 71$; $p = 0.24$; Cohen's $d = 0.19$). Implications: The results reveal a serious discrepancy between the perceived and real technological competency, which is partly due to the lack of ICT infrastructure and systemic deficiencies in pre-service and in-service teacher training. Policy issues related to the provision of ICTs, pre-service training of teachers, and in-service training of teachers are discussed.

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INTRODUCTION

Digital technologies have changed the paradigm for teaching and learning in the 21st century for secondary education (Haleem et al., 2022). The use of Information and Communication Technology (ICT) has great promise in the field of Biology, where concepts are abstract, processes are dynamic, and systems are complex. Compared to traditional textbooks, simulations of biological phenomena, virtual laboratories, interactive ecosystems, and multimedia presentations have been used as effective tools for putting otherwise invisible phenomena into the classroom for biology teachers (Mishra & Koehler, 2006; Guzey & Roehrig, 2009; Zhai et al., 2024). With the rapid transition to emergency remote learning due to the COVID-19 pandemic, the need for teachers to be digitally ready became even more urgent globally since there was significant variation in technological capacity across countries and districts (Bond et al., 2021).

This potential has been identified by Ghana's government, which has been implementing a series of policy initiatives such as the ICT for Accelerated Development (ICT4AD) Policy (2003) and the Ministry of Education's ICT in Education Policy (2008). In 2012, the 'One Teacher One Laptop' initiative (2012) also sought to provide teachers with digital resources to support their teaching. However, despite these investments, evidence from Ghana consistently reveals that technology use in classrooms is superficial, and that the use of technology is rare across the science subjects, especially when compared with other global evidence that the promise of educational technology is often not realised where technology infrastructure, teacher support, and pedagogy are not aligned with policy (Asempa, 2020; Tagoe et al., 2020).

A key understanding of this challenge is based on the Technological Pedagogical Content Knowledge (TPACK) framework proposed by Mishra and Koehler (2006), which adds technological knowledge to Shulman's (1987) Pedagogical Content Knowledge (PCK) model. TPACK focuses on three areas of knowledge that converge in successful technology-enhanced teaching: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). In particular, teachers who understand how to use and make digital tools effective, and how to connect technology, pedagogy, and content effectively (the integrated TPACK) are important in today's educational environment.

This study is based on the theoretical framework of TPACK developed by Mishra and Koehler (2006), which is an extension of the work of Shulman (1987) on pedagogical content knowledge. TPACK suggests that it is necessary to integrate three knowledge domains: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK), along with each of the compound intersections: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and TPACK as the overarching knowledge domain. The framework highlights that the domains are not additive but are interrelated in a dynamic way: True TPACK is the result of the dynamic interaction among the three domains (Koehler & Mishra, 2009). This framework is especially relevant to the current study because it offers a multi-dimensional perspective on which to study both teachers' self-perceptions of competence and their enacted practice. It also allows for a more in-depth analysis of TK as a critical prerequisite for TPACK enactment, particularly in Ghana, where resources are limited.

Technological Knowledge (TK) is the understanding that teachers have regarding the operation, assessment, and utilization of technology from the low-tech overhead to the high-tech interactive whiteboard, to the educational software, to the Internet (Koehler & Mishra, 2009). TK is an ongoing process and is not a predetermined endpoint, but rather the result of continued interaction with a variety of technological resources (Niess, 2005). The affordances of digital tools are important in science education as they provide special ways of representing phenomena in the biological domain. For instance, computer simulations are able to model molecular interactions, genetic inheritance, and ecological succession that chalk and talk cannot (Koehler & Mishra, 2009; Zhai et al., 2024). According to Angeli and Valanides (2015), a teacher's ICT-related knowledge allows the design of new learning scenarios and better representations of the content in certain areas. However, TK research in

developing countries continues to show a number of ongoing issues. Alazam et al. (2013) reported that the majority of secondary school teachers have recognized the importance of technology but are not competent or do not have access to using it effectively. Tagoe et al. (2020) conducted a study in Ghana and found that most teachers trained themselves, as opposed to through professional development, to develop the technological skills that were required; this usually results in teachers having inconsistent and context-specific competencies.

Since the publication of TPACK, more than 200 studies have relied on the framework across the world, and it has been used as the foundation of current research on technology integration in teachers' work, such as the recent meta-analysis on the relationship between TPACK and technology integration in the classroom (Janssen & Lazonder, 2021). TPACK has been correlated with more innovative lesson design, higher student engagement, and better conceptual learning outcomes in mathematics and science education (Niess, 2013; Koh et al., 2015). Importantly, Angeli and Valanides (2009) state that TPACK is transformative, rather than additive, since the use of technology in pedagogy and content is not merely digitisation of pedagogy and content, but is transformative. TPACK studies in Ghana are few in number and mostly focused on the areas of mathematics, social studies and general science (Eshun, 2014; Siemoh, 2015; Agyei, 2013). There was a significant gap in the discipline of biology education, since none of these studies focused on teaching this field.

It has been widely acknowledged in the field of educational technology research that the development of TPACK is not a goal that can be achieved without having adequate ICT infrastructure (Hew & Brush, 2007; Jimoyiannis, 2010). Limited funding, inadequate ICT tools, and a lack of time were cited as the main barriers to technology integration by Richmond Public Schools (2018), even by those teachers who showed positive attitudes towards technology. This is because, in developing country contexts, the lack of this infrastructure is the key factor that limits the implementation of TPACK (Buabeng-Andoh, 2012; UNESCO, 2023). Graham et al. (2009) reiterated that having a tool cannot be enough; rather, the meaningful and purposeful pedagogical application of technology must be accompanied by curricular objectives and the needs of the students. This difference between 'adopted TPACK' (knowledge of how to integrate technology) and 'in-use TPACK' (doing it) is important to consider in designing biology teacher professional development (Fisser et al., 2015).

Surprisingly, TPACK research in the specific context of Ghanaian senior high school biology education remains scarce (Eshun, 2014; Siemoh, 2015). The present study addresses this disciplinary and contextual gap by investigating two key dimensions of biology teachers' professional knowledge in the Ga-East, Ga-West, La-Nkwantanang, and Adenta municipalities of the Greater Accra Region. Specifically, it is guided by the following research objectives:

- To determine the technological knowledge (TK) of biology teachers in teaching the subject in Senior High Schools in the selected municipalities.
- To investigate the technological pedagogical content knowledge (TPACK) of biology teachers in teaching biology in the selected municipalities, including whether professional qualification significantly influences TPACK.

METHODS

Research Design

The study used an explanatory sequential mixed methods design (Creswell, 2014) where quantitative data were collected and analysed first, and the qualitative data were then collected to explain and enhance the quantitative data. It was chosen because, on the one hand, self-reported knowledge of TPACK is a dimension measured by questionnaires, and on the other hand, the practical implementation of TPACK in the classroom is measured with other complementary methodological tools.

Participants and Sampling

The accessible population consisted of 75 biology teachers from 31 different senior high schools (5 public and 26 private) in the Ga-East, Ga-West, La-Nkwantanang and Adenta local governments of the Greater Accra Region. Of the accessible teachers, 75 teachers were targeted, and two teachers were not included in the final analysis due to not being able to retrieve their questionnaires from their school after 2 visits. Therefore, all the responses from 73 biology teachers were analysed, and the response rate was 97.3% of the accessible population.

The teachers who were selected for the qualitative phase were (a) professionally qualified, that is, they held a recognised qualification which was an additional qualification after their first degree, ensuring both groups had passed through formal teacher preparation and the qualification variable was held constant; (b) had at least three years of teaching experience in the SHS to enable them to reflect meaningfully on their teaching practice; (c) taught ecology topics that were part of the school calendar's observation period; and (d) were available for observation and willing to be interviewed. Two teachers were purposively selected: Edwin, with 3 years' experience in Biology Education, and Joy, with 3 years' experience in Agricultural Education. For classroom observation, two teachers were selected from these, one professionally qualified and the other a trainee, using the above criteria.

Ethical considerations. Ethical approval for the study was gained from the respective municipal education directorates and head teachers of the respective schools participating in the study, and written informed consent was obtained from all participants before data collection. No one was forced to participate, and the participants could stop at any time without losing any points. No personally identifying information was gathered during the questionnaires. To preserve the anonymity of the participants and to ensure confidentiality, the authors have used pseudonyms throughout this article; the names 'Edwin' and 'Joy' are not the names of the participants but pseudonyms that have been deliberately given to protect the participants' anonymity, and all potentially identifying information, such as school names and specific locations, has been omitted or anonymised.

Instruments

The quantitative instrument comprised Sections B, D, and F of the Items for TPACK Survey (ITS), adapted from Sahin (2011) and Archambault and Crippen (2009). Section B assessed ICT tool accessibility and professional training sources. Section D (six items) measured technological knowledge using a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Section F (five items) measured TPACK using the same scale. The qualitative instruments included a structured classroom observation checklist and a semi-structured interview guide, both developed to complement the quantitative findings by capturing enacted instructional behaviour. The semi-structured interview guide centred on the following questions:

1. How would you describe your ability to use modern digital technologies (e.g., computers, the internet, projectors, interactive whiteboards) for teaching?
2. Which of these technologies are available in your school for teaching biology, and how easily can you access them?
3. How do you use technology when planning and delivering your biology lessons?
4. In what ways does technology help you represent or explain difficult biology concepts to your students?
5. Can you describe an instance in which you used technology to extend students' learning beyond the classroom walls?
6. What challenges, if any, prevent you from using technology in your biology lessons?
7. How did your pre-service or in-service training prepare you to integrate technology into your teaching?
8. How do you share ideas about technology use with colleagues (e.g., during Professional Learning Community meetings), and what role do you play in such engagements?
9. What support or resources would help you integrate technology more effectively into your biology teaching?

The adapted instrument was reviewed by three experts in educational technology and biology education for content validity. A pilot administration with 10 biology teachers outside the study municipalities yielded a Cronbach's alpha of $\alpha = 0.83$ for the TK subscale and $\alpha = 0.81$ for the TPACK subscale, confirming satisfactory internal consistency (George & Mallery, 2003).

Data Analysis

Quantitative data were analysed using descriptive statistics (means and standard deviations) to characterise teachers' self-assessed TK and TPACK, and frequencies to describe ICT accessibility. An independent-samples t-test was employed to test the null hypothesis that no statistically significant difference exists in TPACK between professionally and non-professionally qualified biology teachers ($\alpha = 0.05$). Effect size was estimated using Cohen's d to supplement the significance test. Qualitative data were analysed using a textual matrix approach, integrating observational field notes and verbatim interview excerpts to triangulate quantitative findings.

RESULTS AND DISCUSSION

Technological Knowledge of Biology Teachers

Research Question 1 examined the technological knowledge of biology teachers in the selected municipalities. To address this research question, a structured questionnaire was administered, and results are presented in Table 1.

Table 1. Self-Assessed Technological Knowledge of Biology Teachers (n = 73)

Technological Knowledge Item	M	SD
Technology as a tool for improving and easing human life	4.33	0.55
Positive attitude/outlook towards using technology	4.35	0.63
Familiarity with common technologies (smartboards, whiteboards, digital boards)	4.20	0.88
Knowledge of advanced ICT tools (computers, internet, digital video, projectors)	4.25	0.90
Ability to use computer software in educational settings	4.22	0.80
Technological competence to utilise cutting-edge resources effectively	4.12	0.85
Overall Mean of Means	4.25	0.77

Source: Field Survey (2024)

The mean of $M = 4.25$ ($SD = 0.77$) indicates that the technological knowledge of biology teachers is found in adequate levels. Positive attitudes towards technology were the highest-rated dimension, with a mean score of $M = 4.35$, $SD = 0.63$, and the ability to utilise cutting-edge resources was the lowest-rated, with a mean score of $M = 4.12$, $SD = 0.85$. This pattern is similar to that of both Zhao (2007) and Woodrow (1992), who stated that the effectiveness of technology in education is greatly influenced by users' attitudes toward learning and technology and that a positive technological orientation is the precondition for meaningful change in instructional practice.

The mean of practical technological competence ($M = 4.12$) was found to be lower than that of attitudinal dimensions ($M = 4.35$), which indicates that having a positive attitude towards technology does not necessarily mean having it at a high level of operation. The result is consistent with Alazam et al. (2013), who stated that there is a large gap between knowing about technology and using it purposefully in instructional situations.

Data on ICT training sources revealed that 47.9% of respondents had received formal training, 28.8% were self-trained, and 23.3% had received informal training. Notably, a combined 52.1% relied on informal or self-directed learning, indicating systemic gaps in formal professional development provision (Lawless & Pellegrino, 2007). This finding is consistent with Mishra and Koehler (2006), who noted that the inconsistency of structured professional development programmes frequently drives teachers towards self-learning as a default strategy.

ICT Tool Accessibility in Schools

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A critical contextual finding was the severely limited availability of modern digital tools in schools. Table 2 summarises accessibility data.

Table 2. Accessibility of Modern Digital Technologies (ICT) for Biology Instruction

Accessibility Status	Frequency	Percentage (%)
Modern Digital Technologies Accessible	27	37.0
Modern Digital Technologies Not Accessible	46	63.0
Total	73	100.0

Source: Field Data (2024)

A striking 63% of respondents reported that modern digital technologies were not accessible in their schools for biology instruction. Specific tool-level analysis revealed that while basic hardware and software (computers, CD-ROMs, MS Word, PowerPoint, and mobile devices) were accessible in most schools, advanced pedagogical tools including projectors, interactive whiteboards, digital cameras, wireless microphones, and biology animation software were largely unavailable. This structural deficit directly constrains even motivated teachers from translating their technological knowledge into instructional practice.

These findings corroborate Buabeng-Andoh (2012), who identified inadequate ICT infrastructure as the foremost barrier to technology integration in Ghanaian schools, and align with Koehler and Mishra's (2009) caution that the mere presence of technology is necessary but not sufficient for effective integration. The data suggest that Ghana's ICT policy aspirations have not yet been matched by the physical deployment of tools to where instruction occurs: the biology classroom.

Research Question 2 examined the TPACK of biology teachers across five dimensions. To address this research question, a structured questionnaire was administered, and results are presented in Table 3.

Table 3. Self-Assessed TPACK of Biology Teachers (n = 73)

TPACK Dimension	M	SD
Representing biology concepts using technology that is understandable to students	4.32	0.69
Improving teaching and learning of biology using technology	4.10	0.85
Integrating technology and biology curriculum content	4.23	0.78
Expanding classroom discussions beyond school walls via technology	4.18	0.74
Leadership in coordinating technology use in Professional Learning Communities (PLCs)	4.28	0.72

TPACK Dimension	M	SD
Overall Mean of Means	4.22	0.76

Source: Field Survey (2024)

The overall mean of $M = 4.22$ ($SD = 0.76$) indicates moderate-to-high self-reported TPACK. Teachers expressed the greatest confidence in using technology to represent biology concepts in student-accessible formats ($M = 4.32$) and in assuming technological leadership roles in Professional Learning Communities (PLCs) ($M = 4.28$). The lowest mean was for improving teaching and learning through technology ($M = 4.10$, $SD = 0.85$), suggesting residual uncertainty about the practical impact of technology on biology learning outcomes.

Although the respondents showed positive self-evaluations, there was a significant difference between the findings of the qualitative data gathered through classroom observation. The observed biology lessons were conducted without the inclusion of any technological tools by either Edwin or Joy. Edwin taught lessons on 'Zones of the Earth' and 'Ecological Factors' that used only verbal explanations and chalkboard drawings, and made no use of simulations, multimedia, or digital representations. Lessons on 'Interaction in Nature' and 'Use of the Rain Gauge' by Joy also did not use any of the available digital devices. As Joy said: 'I know it is not the right way, but... my school didn't have the TLMs that I needed to get that. This explanation is not so much about a lack of TPACK knowledge but a lack of structure in the provision of ICTs, which is in line with Hew and Brush (2007).

Edwin's case presented an additional dimension: even where he possessed technological awareness, the absence of TK enactment in his instructional practice represented a missing pillar in the TPACK structure. Research demonstrates that the integration of Technology Knowledge into teaching creates collaborative inquiry opportunities for students (Mishra & Koehler, 2006). By not leveraging technological tools to visualise habitats or ecological zones through virtual simulations, video content, or interactive media, Edwin limited students' conceptual engagement with the subject matter.

These findings reinforce the distinction articulated by Petra et al. (2015) between 'adopted TPACK' and 'in-use TPACK.' Teachers may construct positive self-assessments of their TPACK competence based on awareness and prior training, yet fail to operationalise this knowledge in classrooms due to infrastructure limitations, entrenched pedagogical habits, or low self-efficacy in translating knowledge into practice.

Hypothesis Testing

The study tested the null hypothesis (H_0) that no statistically significant difference exists in TPACK between professionally and non-professionally qualified biology teachers. Table 4 presents the independent-samples t-test results, supplemented with Cohen's d as a measure of practical effect size.

Table 4. Independent Samples t-Test for TPACK by Professional Qualification Status

Variable	Group	n	M	SD	df	t	p	Cohen's d
TPACK	Professionally Qualified Teachers	35	19.50	3.20	71	-1.20	0.24	0.19
	Non-Professionally Qualified Teachers	38	20.10	3.00				

Source: Field Survey (2024). Note: Significance level $\alpha = 0.05$. H_0 not rejected ($p > 0.05$). Cohen's $d = 0.19$ indicates a trivial effect size (Cohen, 1988).

The t-test result ($t = -1.20$, $df = 71$, $p = 0.24 > 0.05$) showed that there was no statistically significant difference in the TPACK of the professionally and non-professionally qualified biology teachers. Thus, the null hypothesis was not rejected. The mean scores for non-professionally qualified teachers ($M = 20.10$, $SD = 3.00$) versus professionally qualified teachers ($M = 19.50$, $SD = 3.20$) differed slightly, with the mean score for the non-professionally qualified teachers being higher, but this difference was not significant at the 0.05 level. Cohen's $d = 0.19$ also further suggests that there is virtually no practical effect because there is only a small difference between the scores for professionally qualified teachers compared to those of non-professionals.

This is an important finding, as it questions whether there is a substantial link between formal teacher certification and TPACK competence. It implies that the existing teacher preparation system in Ghana (certified or non-certified teachers) does not systematically promote TPACK. This is similar to Eshun's (2014) argument, which suggests that the training of pre-service biology education in Ghana does not guarantee that the trainee will have meaningful TPACK in spite of his or her qualification category.

Chai et al. (2011) and Niess (2013) also reported that pre-service teacher education courses often focus on technology skills rather than on its incorporation into pedagogy and content instruction. Graham et al. (2012) also state that the basic knowledge underlying classroom technology use is seldom discussed in pre-service and in-service programmes, a scenario that is not quite different from the situation in the Ghanaian context in this study.

DISCUSSION OF FINDINGS

The objective of this study was to look at the technological knowledge and TPACK of SHS biology teachers in the Ga-East, Ga-West, La-Nkwantanang and Adenta municipalities, which allowed for an integrated reading of the quantitative and qualitative strands. Taken together, the results paint a clear and grim picture: teachers whose own attitudes towards technology seem to be detached from the reality of having very few technological resources to draw on in their system and consequently teaching without any technology at all. The study's most significant conclusion is the difference between what is perceived as technological competency and what is actually experienced in the classroom. The difference between perceived technological competency and actual instructional practice, as predicted in the survey data and verified in the classrooms, is the study's central finding.

This interpretation is further enriched by the qualitative phase in three ways. First, it shows that the competencies surveyed exist as beliefs but are non-existent as practices. Edwin and Joy were both comfortable with digital devices in general, but in four lessons of ecology they didn't even turn on a projector. The observed topics – Zones of the Earth, Ecological Factors, Interaction in Nature, and Use of the Rain Gauge – are exactly the kind of topic content for which technology has unique representational power: the Zones of the Earth can be represented in a spatial and layered manner; the interactions in nature are dynamic and systemic; and the use of the rain gauge can be demonstrated with animations and data-logging tools. Teachers therefore chose to do completely without technology in these lessons, rather than as a stylistic option; both teachers reduced the representational bandwidth from which the students could receive these concepts, using only verbal explanations and chalkboard illustrations (Koehler & Mishra, 2009; Zhai et al., 2024).

Secondly, interviews indicate that non-use is not a motivational reason. Joy's forthright admission, 'I know it is not the right way, but... my school did not have the necessary TLMs to help me achieve that,' is analytically rich. It displays a teacher who is familiar with the pedagogical standard, who compares her practice with that standard, and who states that this difference is due to the lack of teaching and learning material, and not because of her unwillingness to teach with technology. This is the language of constrained agency: competence held in suspension by structure. It is consistent with Hew and Brush (2007) and with Buabeng-Andoh's (2012) conclusion that inadequate infrastructure is the foremost barrier to ICT integration in Ghanaian schools, and it cautions against professional development reforms that address teachers' knowledge while leaving untouched the material conditions of their classrooms.

Third, the qualitative data expose the fragility of TK as a pillar of the TPACK structure. Edwin's case is especially instructive: he possessed technological awareness and a positive disposition, yet the non-enactment of TK meant that neither TPK nor the integrated TPACK could be expressed in his lessons, since the integration of technology into teaching is what creates opportunities for collaborative inquiry and enriched representation (Mishra & Koehler, 2006). In effect, the observed lessons show TPACK as a dormant capacity awaiting the conditions for its expression. This vividly illustrates the distinction between 'adopted TPACK' and 'in-use TPACK' (Fisser et al., 2015) and confirms that self-reported TPACK, however encouraging, cannot be read as evidence of technology-enhanced instruction. International evidence points in the same direction: recent meta-analytic work indicates only a modest association between teachers' self-assessed TPACK and their observed technology integration (Janssen & Lazonder, 2021), and the present study suggests that in resource-constrained settings the disjunction may be even sharper, because infrastructure functions as a hard boundary condition on enactment (Hew & Brush, 2007; UNESCO, 2023).

The training profile of the respondents reinforces this systemic reading. That 52.1% of teachers acquired their technological capabilities through informal or self-directed learning rather than through structured pre-service or in-service programmes indicates that the development of TK has been left largely to chance (Lawless & Pellegrino, 2007; Mishra & Koehler, 2006). It is plausible that this fragmentation also contributes to the inflation of self-assessments: teachers who teach themselves about technology may master the vocabulary of digital tools without the calibrated feedback that would temper confidence into demonstrated proficiency (Alazam et al., 2013). At the same time, teachers' strongest TPACK self-ratings concerned representing biology concepts ($M = 4.32$) and leadership within Professional Learning Communities ($M = 4.28$), suggesting that the collegial structures through which TPACK could be developed and enacted collectively already exist in embryo. PLCs therefore represent a ready-made vehicle for TPACK-oriented professional development, provided they are equipped and mandated to prioritise technology integration.

The hypothesis test further situates these findings. The absence of a significant difference in TPACK between professionally and non-professionally qualified teachers ($t = -1.20$, $p = 0.24$, $d = 0.19$) suggests that formal certification, as currently constituted, is not a reliable proxy for technological pedagogical content knowledge. Neither pathway, university-based teacher education nor the alternative routes through which non-professionally qualified teachers enter SHS classrooms, systematically develops TPACK. This resonates with Eshun's (2014) critique of Ghanaian pre-service biology education, with Chai et al.'s (2011) and Niess's (2013) observations that technology remains confined to standalone skill courses, and with Graham et al.'s (2012) finding that the foundational knowledge underpinning classroom technology use often goes unaddressed in teacher preparation. The marginally higher (though statistically insignificant) TPACK mean among non-professionally qualified teachers may reflect more recent curricular exposure or the compensatory effects of informal learning, but its trivial effect size ($d = 0.19$) counsels against over-interpretation.

Taken as a whole, therefore, the findings reframe the problem of biology teachers' technology integration in Ghana as a system problem rather than a teacher problem. Teachers' attitudes are positive, their self-assessed knowledge is moderately high, and their awareness of good practice is intact; what is missing is the connective tissue — infrastructure in schools, structured professional development, and preparation programmes that treat technology integration as integral to biology pedagogy rather than as an optional add-on. Ghana's successive ICT-in-education initiatives (ICT4AD, the ICT in Education Policy, and the 'One Teacher One Laptop' initiative) have proceeded on the assumption that placing tools and aspirations into the system is sufficient; this study, like the wider literature (Buabeng-Andoh, 2012; UNESCO, 2023), indicates that without corresponding investment in school-level infrastructure and teacher development, such policies produce aspiration without enactment.

LIMITATIONS OF THE STUDY

There are some limitations to this study. Convenience sampling in the four municipalities (even within the Greater Accra region) limits the generalisability of the findings to other regions and school types. Second, the quantitative measures were self-reported, and thus may have been affected by social desirability and self-perception biases, as indicated by the discrepancy between survey and actual use. Third, the qualitative phase was limited to two teachers and four lessons; though this is suitable for an explanatory follow-up, this limitation reduces the extent of the qualitative evidence. Fourth, because of its cross-sectional structure, the study does not allow for drawing causal conclusions regarding the connections between qualification, TPACK, and integration. Despite these shortcomings, the combined findings of the quantitative and qualitative components provide some credibility to the central finding of a knowledge–practice gap.

CONCLUSION AND RECOMMENDATION

The present study examined the technological knowledge and TPACK of biology teachers in some municipalities of the Greater Accra Region of Ghana. The results show a complex and somewhat paradoxical picture: teachers say that they have moderate levels of technological knowledge and TPACK on self-assessment instruments, while technology is not found in biology instruction in classrooms. Limited infrastructure for the use of ICTs in schools is the main reason for this discrepancy between what is reported and what is observed: 63% of teachers reported that they do not have access to modern tools for the teaching of biology.

The hypothesis was not supported, however, as no significant differences were found between professional qualification and TPACK ($t = -1.20$, $p = 0.24$, $d = 0.19$), suggesting that neither certified nor non-certified biology teachers are well-prepared to integrate technology into their teaching based on their professional preparation pathway. This raises questions about the effectiveness of pre-service and in-service training for the development of teachers' capacity to teach with technology.

It is not possible to have effective TPACK without a policy. The use of tools without knowledge can lead to misuse, and knowledge without the use of tools can be inert competence. Therefore, the Ghanaian education system has to consider both aspects by equipping teachers with both conceptual and practical TPACK frameworks and ensuring that the classrooms are set up with the digital infrastructure to implement these frameworks.

1. The Ministry of Education and the Ghana Education Service should accelerate ICT infrastructure deployment in SHS biology classrooms, prioritising projectors, interactive whiteboards, biology simulation software, and stable internet connectivity.
2. Regional and district education directorates should design TPACK-specific professional development programmes for in-service biology teachers that go beyond tool familiarity to address context-specific, biology-content-aligned technology integration strategies.
3. Pre-service biology teacher education programmes should restructure their curricula to embed technology integration within content and methodology courses, rather than treating ICT as a standalone skill module.
4. School leadership should appoint dedicated ICT coordinators with responsibility for supporting biology and science teachers in technology-integrated lesson planning and delivery.
5. Future policy evaluations of Ghana's ICT in Education Policy should include school-level audits of actual ICT tool availability and in-classroom usage rates to bridge the gap between policy intent and classroom reality.
6. Further research should investigate the effect of teachers' TPACK levels on student academic achievement in biology using longitudinal comparative designs, and explore institutional and motivational factors mediating TPACK enactment in under-resourced school contexts.

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