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RESEARCH ARTICLE

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Barriers and Support Needs in Integrating Digital Literacy into Science Teaching: Experiences of Junior High School Teachers in a Ghanaian Municipality

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Abstract

This study explored the barriers experienced by Junior High School (JHS) science teachers in integrating digital literacy into science teaching and the forms of support they considered necessary for strengthening practice. Guided by an interpretivist qualitative case-study design, nine science teachers from three educational circuits in the Effutu Municipality of Ghana were purposively selected. Data were generated through semi-structured interviews and classroom observations and analysed using reflexive thematic analysis. Four interconnected barriers emerged: inadequate digital infrastructure, limited preparation for science-specific digital pedagogy, insufficient institutional and technical support, and pressures associated with instructional time and curriculum coverage. Teachers identified continuous science-specific professional development, improved infrastructure and curriculum-aligned digital resources, stronger instructional leadership and technical assistance, and collaborative professional learning as essential supports. The findings distinguish teachers' access to digital devices from learners' opportunities for meaningful digital participation and show that technological competence alone does not ensure learner-centred digital science inquiry. The study contributes to understanding digital literacy integration as a multilevel support ecology requiring coordinated interventions across teacher, classroom, school, and municipal levels. These findings have implications for professional development, resource provision, and implementation of digital education policies in resource-constrained contexts.

Keywords: Digital literacy, Science education, Junior high school, Digital pedagogy, Professional development.

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INTRODUCTION

Digital technologies have transformed how scientific knowledge is accessed, represented, investigated, and communicated. Learners can use digital tools to view simulations, participate in virtual laboratories, watch instructional videos, and analyse data. These tools help learners visualise abstract scientific concepts and communicate evidence-based explanations. A meta-analysis by Hillmayr et al. (2020) found that digital tools enhance secondary school learning in science and mathematics when they are used appropriately to support content learning and teachers receive effective training in their use. While digital technologies provide the tools that facilitate teaching and learning, digital literacy refers to the knowledge, skills, and dispositions required to use those tools effectively, critically, and responsibly. Thus, digital literacy extends beyond knowing how to operate a computer or a mobile device. It encompasses the ability to locate and critically evaluate information, analyse and present data, develop digital content, and apply ethical principles to online activities. Therefore, access to digital devices alone does not necessarily translate into meaningful engagement with technology for scientific inquiry (Ng, 2012; UNESCO, 2023a). Digital literacy is one of the six essential competencies embedded in Ghana's Standards-Based Curriculum and is integrated across all subject areas, including science (National Council for Curriculum and Assessment [NaCCA], 2018). To support this expectation, the National ICT Competency Framework for Teachers outlines teachers' progression from basic digital operations to the purposeful integration of digital technologies into teaching and learning. In addition, the framework emphasises learner-centered instruction, digital assessment of student performance, professional collaboration among educators, and the ethical use of technology (UNESCO, 2023b). Consequently, science teachers play a central role in enabling learners to investigate scientific phenomena through digital technologies and to construct and communicate evidence-based scientific explanations.

Despite national and international policy commitments to promoting digital literacy and integrating technology into teaching and learning, challenges remain in translating these expectations into consistent school-level practices (NaCCA, 2018; UNESCO, 2023a; World Bank, 2026). Ghana's Standards-Based Curriculum identifies digital literacy as a core competency that should be developed across subject areas, requiring learners to use digital technologies to access, process, communicate, and create knowledge responsibly (NaCCA, 2018). However, this curricular expectation does not, in itself, require every learner to own a personal smartphone, tablet, or computer. Rather, Ghana's emerging National EdTech Strategy treats access to digital devices as a broader implementation and equity issue, proposing subsidised low-cost devices for learners and teachers, improved school connectivity, shared ICT facilities, and provision for regulated Bring-Your-Own-Device arrangements to complement government provision (World Bank, 2026). Consequently, learners' opportunities to use digital technologies for classroom learning are influenced by the availability of school infrastructure, connectivity, devices, socioeconomic conditions, and institutional arrangements governing technology use (Baako & Abroampa, 2024; Abroampa et al., 2025; World Bank, 2026).

Research has identified several factors that influence the extent to which teachers integrate digital technologies into their teaching, including access to digital devices and internet connectivity, the availability of electricity, the quality of school leadership, teachers' beliefs about the effective use of technology, opportunities for professional development, and the availability of technical support

(Baako & Abroampa, 2024). For example, many teachers in low-resourced schools rely on their own laptops or smartphones to facilitate students' access to the internet because of inadequate school infrastructure (Abroampa et al., 2025). These barriers create additional challenges for science education. Effective science teaching depends on the purposeful integration of digital technologies to support conceptual understanding, laboratory activities, scientific inquiry, and assessment.

Consequently, although teachers may use digital technologies to prepare lesson materials, search for educational resources online, or deliver presentations, they are often unable to utilise them to support virtual experiments, modelling, data analysis, or student-generated explanations because of the constraints identified earlier. As a result, digital technologies are used primarily to support teacher presentation rather than to facilitate learners' active engagement in scientific inquiry and the construction of scientific understanding. Therefore, the primary challenge facing Junior High School (JHS) science teachers is not simply limited access to digital tools or inadequate teacher competence. Rather, they are expected to develop learners' digital literacy while working under conditions characterised by unreliable internet connectivity, limited access to student devices, inadequate science-specific digital resources, insufficient technical support, limited opportunities for ongoing professional development, and constrained instructional time. These interacting conditions create significant challenges for the meaningful integration of digital literacy into science teaching.

Although previous studies conducted in Ghana have examined teachers' digital competence and reported general trends in ICT use within classrooms, few qualitative studies have explored the material (e.g., hardware), pedagogical (e.g., planning and instructional strategies), institutional (e.g., school environment), and curricular barriers that practising JHS science teachers encounter when integrating digital literacy into science teaching. Furthermore, limited qualitative evidence exists regarding the forms of support that practising JHS science teachers require to implement digital literacy in sustainable ways.

This study addresses these gaps by providing a qualitative account of the barriers experienced by practising JHS science teachers in the Effutu Municipality as they integrate digital literacy into science teaching. In addition, classroom observations were used to complement the interview data by illustrating how the availability of digital resources influences learner-centred science teaching practices in classroom settings. Specifically, this study was guided by two main research questions:

a) What barriers do JHS science teachers experience when promoting digital literacy among learners during science lessons?

b) What forms of support do JHS science teachers consider essential for strengthening digital literacy integration in science education?

RELATED LITERATURE

Theoretical Underpinning

This study is guided by Activity Theory (Engeström, 2001) and Ecological Systems Theory (Bronfenbrenner, 1977, 1979), complemented by the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006) and the Digital Education Ecosystem framework (OECD, 2023). These perspectives are particularly relevant to the two research questions because they explain both the barriers teachers experience when integrating digital literacy into science teaching and the forms of support required to strengthen practice. Activity Theory explains human activity through interactions among the subject, tools, object, rules, community, and division of labour (Engeström, 2001). In this study, science teachers constitute the subjects, while digital devices, applications, simulations, and online resources represent mediating tools. Meaningful integration of digital literacy into science teaching constitutes the object. Curriculum requirements and school policies represent rules, while learners, colleagues, school leaders, technical personnel, and education officials constitute the community. Responsibilities for providing resources, training, equipment maintenance, and instructional support represent the division of labour.

Ecological Systems Theory complements Activity Theory by explaining how teachers' classroom practices are embedded within interacting layers of their educational environment (Bronfenbrenner, 1977, 1979). Teacher practice may be influenced immediately by classroom resources and school leadership and, more broadly, by municipal support, professional development systems, curriculum expectations, and national digital education policies. TPACK further explains the professional knowledge necessary for meaningful technology integration. Effective digital teaching requires interaction among technological, pedagogical, and content knowledge rather than technical competence alone (Mishra & Koehler, 2006). For science teachers, this includes knowing how digital technologies can support inquiry, experimentation, visualisation, data analysis, assessment, collaboration, and evidence-based explanation.

The OECD (2023) Digital Education Ecosystem framework extends this teacher-level perspective by emphasising the interconnected roles of technological infrastructure, human capacity, educational resources, institutional organisation, and governance. Together, these theories and frameworks provide a coherent basis for examining both the barriers confronting JHS science teachers and the support required for meaningful digital literacy integration.

Barriers to Integrating Digital Literacy into JHS Science Teaching

Research increasingly shows that meaningful digital literacy integration depends on the interaction of infrastructural, pedagogical, organisational, and curricular conditions rather than on access to technology alone. At the global level, a systematic review of ICT integration in secondary education identified inadequate resources, insufficient training, limited planning time, weak support, poor curriculum alignment, and lack of pedagogical change as recurring barriers to meaningful technology use (Msafiri et al., 2023). Similarly, international policy literature emphasises that effective digital education requires not only devices and connectivity but also teacher capacity, appropriate learning resources, institutional support, and coherent governance (UNESCO, 2023a; OECD, 2023).

Evidence from sub-Saharan Africa reflects these global patterns. In Kenya, Murithi and Yoo (2021) surveyed 351 public primary-school teachers and found that ICT facilities were generally inadequate. Although many teachers had received basic computer training, a considerable proportion lacked in-service preparation for pedagogical technology integration and experienced difficulty incorporating ICT into lessons. This demonstrates a distinction between possessing basic digital skills and being pedagogically prepared to use technology. In rural South African secondary schools, Shambare and Jita (2024) similarly found that Life Sciences teachers demonstrated stronger content and pedagogical knowledge than technology-related TPACK. Their findings showed that familiarity with technology did not necessarily translate into confidence in combining technology, pedagogy, and science content.

Ghanaian evidence reveals comparable constraints. Quaicoe and Pata (2020), studying 233 teachers from 45 primary and JHS schools, showed that teachers' reported digital literacy did not necessarily correspond with the frequency of their digital activities. Baako and Abroampa (2024) further found that ICT integration was influenced by interacting contextual factors, including school resources, infrastructure, professional development, community attitudes, and socioeconomic circumstances. Similarly, Abroampa et al. (2025) found that inadequate institutional resources compelled some Ghanaian basic-school teachers to improvise and rely on personally owned digital technologies. While such practices demonstrate teacher initiative, dependence on personal devices cannot guarantee equitable learner participation in digital learning.

This distinction between access to technology and meaningful instructional use is particularly important in science. Digital literacy in science involves more than searching for information or displaying presentations; it can include simulations, experimentation, data analysis, modelling, collaboration, and evidence-based reasoning. Globally, Hillmayr et al. (2020), in a meta-analysis of 92 studies in secondary mathematics and science, found that digital tools positively influenced learning, but teacher training significantly affected their effectiveness. Likewise, Hinostroza et al. (2024) found that digital technologies can support different phases of inquiry, although their use across inquiry processes remains uneven. In Ghana, Abedi (2024) found that teachers predominantly used technology for lesson preparation and direct instruction, while learner-centred and constructivist applications were limited. These findings indicate that the challenge concerns not only access but also the quality and pedagogical purpose of technology use.

Institutional, technical, curriculum, and time pressures further compound these challenges. Lomo et al. (2025) found that Ghanaian headteachers supported ICT integration through teacher training, supervision, resource mobilisation, and equipment maintenance. However, their efforts were constrained by inadequate funding, weak stakeholder support, electricity and connectivity problems, and high maintenance costs. Thus, barriers are interdependent rather than isolated. Nevertheless, much Ghanaian research focuses on general ICT integration across basic education. Limited qualitative evidence explains how infrastructure, science-specific pedagogical preparedness, technical support, institutional conditions, instructional time, and curriculum pressures interact within actual JHS science classrooms.

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Support Needs for Strengthening Digital Literacy Integration

The literature identifies professional development, improved infrastructure, technical assistance, instructional leadership, and collaborative professional learning as important supports. Global evidence suggests, however, that these measures are most effective when implemented in complementary ways. Hennessy et al. (2022), in a systematic review of technology-supported teacher professional development in low- and middle-income countries, highlighted the importance of facilitators, expert peers, interpersonal interaction, and context-sensitive professional learning. Similarly, international evidence indicates that technology integration improves when teachers receive appropriate pedagogical preparation and sustained institutional support rather than isolated technical training (Msafiri et al., 2023; Hillmayr et al., 2020; OECD, 2025).

Sub-Saharan African studies reinforce this conclusion. In Kenya, Murithi and Yoo (2021) found that basic computer literacy training did not necessarily prepare teachers to integrate technology pedagogically; 58.4% of the surveyed teachers reported that they could not plan and integrate technology into their lessons. Similarly, Shambare and Jita (2024) concluded that rural South African science teachers required professional development that deliberately integrates technological, pedagogical, and science-content knowledge. They also emphasised reliable internet access, appropriate devices, technical support, and collaborative teacher learning. These findings suggest that professional development should operate within a wider support environment rather than as a stand-alone intervention.

Ghanaian research reaches similar conclusions. Appianing (2025), studying 71 JHS integrated science teachers, identified inadequate infrastructure, limited teacher preparation, inaccessible technical support, and erratic electricity as major constraints. The study consequently recommended strengthening both teacher capacity and technological infrastructure. Amemasor et al. (2025), through a systematic review of 23 peer-reviewed studies, also highlighted hands-on training, collaborative learning, mentoring, and institutional support as important elements of professional development for digital instructional integration. Furthermore, Abedi et al. (2024) found that Ghanaian teachers often conceptualised technology primarily as a productivity tool for existing teaching practices. This suggests that professional development should address not only technological skills but also teachers' pedagogical beliefs about how technology can support learner-centred learning.

Professional development alone, however, cannot compensate for unreliable electricity, poor connectivity, insufficient learner-accessible devices, or limited science-specific digital resources. Similarly, school leadership cannot fully overcome structural resource shortages without municipal or system-level assistance. Collaborative professional learning communities may enable teachers to share resources, co-design lessons, demonstrate successful practices, and identify low-cost or offline alternatives. However, such collaboration requires protected time, appropriate leadership, and institutional support. Thus, sustainable support should be coordinated across teacher, classroom, school, and system levels.

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Synthesis, Research Gap and Conceptual Framework

Across global, sub-Saharan African, and Ghanaian literature, there is broad agreement that meaningful digital literacy integration depends on interactions among teacher knowledge, infrastructure, curriculum demands, instructional time, leadership, technical support, professional learning, and collaboration. However, three gaps remain. First, Ghanaian studies have largely examined general ICT integration rather than the distinctive requirements of digital literacy in JHS science. Second, barriers are often investigated separately, providing limited qualitative understanding of how material, pedagogical, institutional, technical, and curricular conditions interact in teachers' everyday science practice. Third, limited evidence examines which combinations of support practising JHS science teachers consider both necessary and feasible, particularly within the Effutu Municipality.

The present study addresses these gaps through semi-structured interviews and classroom observations. Its conceptual framework proposes that teachers' technological, pedagogical, and science-content knowledge interacts with infrastructural, curricular, institutional, and support conditions. Depending on how these factors combine, they may constrain or enable movement from basic technology use towards learner-centred digital inquiry, experimentation, evidence analysis, collaboration, and scientific knowledge construction. Figure 1 illustrates these relationships and guides the interpretation of the two research questions.

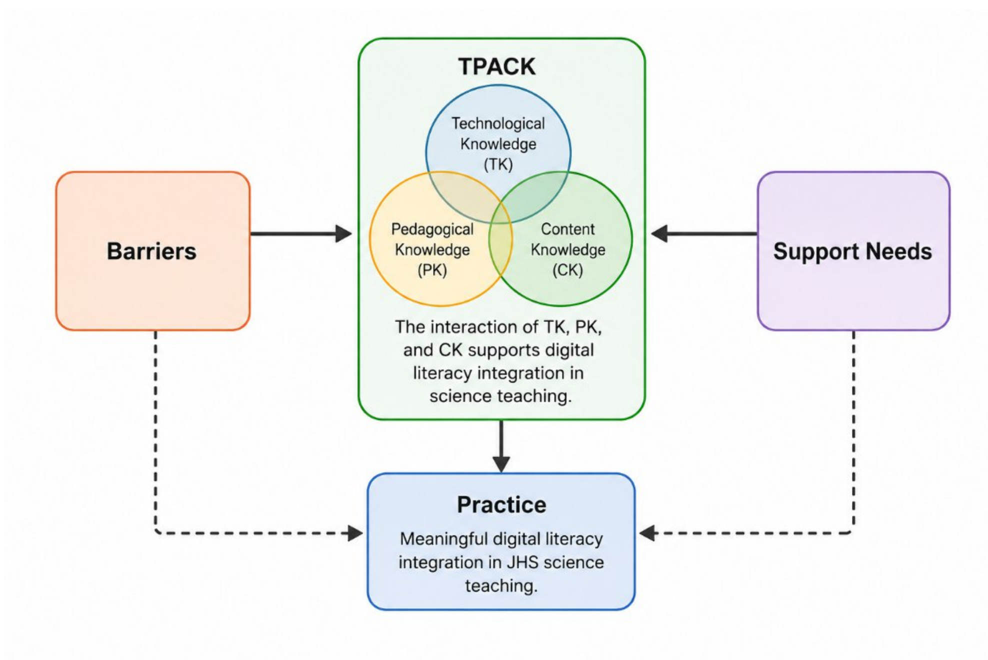

Figure 1: Conceptual Framework for the Study

As illustrated in Figure 1, the conceptual framework proposes that teachers' Technological Pedagogical and Content Knowledge (TPACK) influences their practice of integrating digital literacy into JHS science teaching. However, the extent to which teachers are able to translate their TPACK into meaningful classroom practice may be shaped by the barriers they encounter and the support available to them. Barriers may constrain the effective application of teachers'

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technological, pedagogical, and content knowledge, whereas appropriate support can facilitate and strengthen its application in classroom practice. Thus, the framework conceptualises TPACK, barriers, and support needs as key factors influencing teachers' digital literacy integration practices in JHS science teaching.

METHODOLOGY

Research Approach and Design

This study was guided by an interpretivist research paradigm, which views reality as socially constructed and emphasises understanding participants' meanings and experiences within their specific contexts (Creswell & Poth, 2018). This paradigm was appropriate because the study sought to explore JHS science teachers' experiences, perceived barriers, and support needs regarding the integration of digital literacy into science teaching. Consequently, a qualitative approach was adopted to capture the contextual and experiential nature of teachers' instructional practices.

Within this interpretivist qualitative framework, a case study design was employed. The case study approach enabled an in-depth exploration of digital literacy instructional practices within the bounded context of JHS science education in the Effutu Municipality, Ghana (Creswell & Poth, 2018). This design was particularly suitable because it allowed the researcher to examine how material, pedagogical, institutional, and curricular conditions influenced teachers' integration of digital literacy within their natural classroom environments.

This research used a qualitative interpretive paradigm to examine how teachers' perceptions of support and barriers to implementing digital literacy in education were shaped by their personal and social contexts (e.g., schools, teacher preparation, municipal or state policies) rather than solely through the lens of individual experience.

Population and Sampling

Nine science teachers, three from each of the three circuits in the Effutu Municipality, were selected as participants. They were contacted through the School Improvement Support Officer and their school head, and all nine agreed to participate. The nine JHS science teachers were purposively selected from the three educational circuits in the Effutu Municipality, with three teachers drawn from each circuit. The selection of the nine teachers was intended to ensure representation across the municipality while capturing variation in teaching experience and frequency of digital technology use (Palinkas et al., 2015). Three participants held a Master of Philosophy degree in Science Education, while six held Bachelor of Education degrees, with specialisations in Mathematics Education (2), Science Education (3), or Basic Education (4). Regarding teaching experience, five participants (55.6%) reported having taught for between 10 and 15 years, while four (44.4%) had taught for more than 15 years. The Effutu Municipality was also an area of particular interest to this study because it has benefited from investments in digital technologies, including teacher laptops provided through the One Teacher-One Laptop and Teacher's Mate 1(TM1) laptops programme. This context provided an appropriate setting for exploring how teachers experience such digital technology provision and how they support the integration of digital literacy practices within science classrooms. As such, it is an appropriate

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location for exploring challenges teachers face, and the support needs they deem appropriate for the effective use of these tools. To protect confidentiality and minimise the possibility of deductive identification, the information is reported in aggregate rather than linking individual teachers' school names, qualifications, specialisations, teaching experience, or circuit locations. Participants were identified during data collection and reporting using codes such as TR1–TR9 (Teacher 1 to Teacher 9).

Positionality

The researcher is a science educator at the University of Education, Winneba, and therefore possesses familiarity with Ghana's Basic Education System and Science Curriculum, which provided valuable contextual understanding for the study. However, this insider position also presented potential challenges, including the possibility of researcher assumptions and power dynamics, as participants might perceive the researcher as an authority figure. In line with Berger's (2015) emphasis on reflexivity, the researcher engaged in practices to minimise these influences by using open-ended questions to elicit participants' experiences, maintaining reflexive notes during interviews, triangulating interview and observational data, and keeping an audit trail to enhance transparency and ensure that interpretations remained grounded in participants' accounts.

Data Collection

Teachers completed individual semi-structured interviews to explore their professional background, barriers to implementing digital literacy in their teaching practice, their reliance on specific digital resources, and the support available or required. All consenting teachers received a 30- to 45-minute individual interview in a private area at their school. After completion of each interview, the recordings were transcribed and analyzed. Non-participant observation was conducted in each of the nine classrooms as the teachers taught a single lesson. During this time, the observer used a checklist to determine whether accessible digital resources were present and whether the learning environment was conducive to their use.

Trustworthiness

Lincoln and Guba's (1985) credibility requirements were met through an expert evaluation of the interview/observation protocols, pilot testing with two teachers outside the study sample, and a comparison of interviews and observations. The dependability of the research was ensured by documenting an audit trail for all data collection/coding/analytics. Data confirmability was supported by writing reflexive memos and also providing the participants with the opportunity to read their own transcripts.

Data Analysis

This study used Braun & Clarke's (2006, 2021) reflexive thematic analysis, an iterative six-step process comprising familiarization, coding, generating preliminary themes, developing and reviewing themes, refining themes, and producing reports. The researcher applied inductive and deductive coding to the data and identified explicit statements as well as the implicit meaning embedded within them. Interview transcripts were coded, and observations were described. A comparison of evidence across datasets was conducted to assess whether there was agreement, expansion, or disagreement, and, if so, similar codes were grouped into candidate patterns, which were then refined into themes associated with the research questions. Reflexive memos documented all analytical choices and possible alternate analyses.

The observation data were analyzed statistically and reported in percentages. The availability of digital resources was calculated using the nine observed teachers/classrooms as the denominator. For each resource, the number of classrooms in which the resource was observed was divided by the total number of classrooms observed (N = 9) and multiplied by 100. For example, science software or applications were available in two of the nine classrooms; therefore, the percentage availability was calculated as $(2/9) \times 100 = 22.2\%$. This represents 22.2% Yes (available) and, correspondingly, 77.8% No (not available). Similarly, the availability of laptops in eight classrooms represented 88.9%, while mobile phones observed in all nine classrooms represented 100%. Percentages were rounded to the nearest whole number in the table for ease of presentation

Ethics

Ethical Approval (SGS-EC-007-25) was obtained from the Institutional Ethical Review Board of the University of Education, Winneba. Permission to conduct the research was granted by the Education Directorate of the Effutu Municipality, and all participants took part voluntarily. Participants were informed about the purpose and procedures of the study and were assured that they had the right to decline participation or withdraw from the study at any stage without penalty. Informed consent was obtained prior to data collection. Measures were also taken to protect participants' confidentiality and anonymity throughout the research process.

RESULTS/FINDINGS

The findings are presented in relation to the two research questions that guided the study. Table 1 summarizes classroom observation data on the availability of digital resources across the nine observed lessons. The observation data are presented alongside the interview data.

Table 1: Classroom Observation Data on the Availability of Digital Resources

Digital Resource	Yes, n (%)	No, n (%)
Science software/apps	2 (22.2)	7 (77.8)
Desktop computer	4 (44.4)	5 (55.6)
Projector	5 (55.6)	4 (44.4)
Television/white screen	3 (33.3)	6 (66.7)
Laptop	8 (88.9)	1 (11.1)
Mobile phone	9 (100.0)	0 (0.0)
Tablet	1 (11.1)	8 (88.9)

Source: Field Data, 2025

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Barriers to Digital Literacy Integration (Research Question 1)

Four barriers were evident in participants' accounts. These barriers are subsequently presented.

Inadequate Digital Infrastructure

Teachers distinguished between having personal access to digital devices and having the broader infrastructure required for students to engage meaningfully with digital learning. Although most teachers reported owning either a laptop or a mobile phone, classroom-level integration of digital literacy was constrained by unreliable internet connectivity, limited access to student devices, inadequate display equipment such as projectors, inconsistent power supply, and limited availability of science-specific digital resources. These challenges meant that access to personal digital devices did not necessarily translate into opportunities for learners to participate in technology-supported scientific inquiry.

TR4 explained that, "We have laptops, but using them reliably for lesson time to access the internet is challenging. In some cases, our network is weak and therefore can't be used effectively for educational purposes." Similarly, TR7 highlighted the challenge of limited student access to digital resources, stating that, "As there are not enough digital tools for both the teacher and the students, even when I am able to create an activity, not all learners are able to participate due to limited availability of educational resources." These accounts demonstrate that teachers' willingness to integrate digital literacy practices was constrained not only by individual access to devices but also by the availability of shared classroom resources necessary for learner-centred digital engagement.

Limited pedagogical preparedness

Participants reported they could search the web, create typed documents, and use presentations. However, they were unable to apply technology to their scientific inquiries, investigative practices, or assessments to actively engage pupils. One participant (TR2) stated, "While I am able to utilize PowerPoint and find information via a search engine online, I continue to struggle with utilizing technology within my science instructional practices as a means of supporting students' practical science investigations." The primary reason cited by participants for this disparity between the training received and its application was that the training focused primarily on demonstrating the ability to operate the device(s), rather than providing examples of how to utilize the device(s) effectively during science instruction.

Insufficient institutional and technical support

TR9 said that “when a technical problem occurs, we normally try to find a solution on our own because there is no technician available” so they can teach their students. TR5 pointed out that professional development for teaching is sporadic (e.g. “we would like to see training from the Education Directorate happen at least regularly since technology is changing rapidly

Time constraints and curriculum demands

Participants reported that, in addition to hectic schedules, preparing digitally enhanced lessons required extra time to find the necessary materials, test technology, and create alternative plans.

TR3 said, "It actually takes us much longer to get a lesson ready with the use of digital tools than it does without, so this has added even more stress to an already stressful job." The pressure to cover curriculum content was evident in their decision-making process. To this, TR1 said, "Sometimes we will prioritize completing the syllabus over the use of digital learning experiences simply because it can be difficult to find the time to plan out these types of projects."

Support Needs for Digital Literacy Integration (Research Question 2)

Four interconnected forms of support were also identified and are presented in the subsequent sub-sections under the four themes.

Continuous, subject-specific professional development

The teachers needed hands-on, ongoing support in the form of training in using technology in their day-to-day science instructional activities (e.g., investigation, assessment, and inquiry), rather than simply learning how to operate the hardware. TR3 stated, "Teachers want to see consistent professional development that will show them how they can utilize technology in science lessons rather than just showing them how to run a computer." TR6 emphasized that “Teachers require continued training in order to stay current with emerging digital teaching practices due to rapid changes in technology."

Improved infrastructure and science-specific resources are also required.

Teachers saw reliable internet access, electricity to power devices, functional devices for students and teachers, and curriculum-aligned digital content as critical. For instance, TR7 said, "teachers could have the opportunity to get students much more involved with the use of technology for learning if there were a reliable internet connection at every school and sufficient digital equipment available." TR2 added, "Science requires videos, simulations, and interactive resources. Without these materials, it becomes difficult to teach digital literacy effectively."

Instructional leadership and institutional support.

Participants expected headteachers to promote experimentation and collaborative learning and to secure municipal support for teachers; in this respect, TR5 said that "our headteachers should encourage us to use digital technologies and organize school-based workshops where teachers can learn from each other”. Teachers indicated they wanted to see greater backing from the municipality. "The Municipal Education Office needs to establish programmes of continuing education and assign technical officials in each school so they will be able to call on them when there is an issue with their programme." (TR 9).

Collaborative professional learning communities.

Teachers believed their fellow teachers could show how they had been using digital tools effectively and share available resources with each other. Throwing more light on this, TR1 stated, “Teachers can learn a great deal from one another. As long as teachers are seeing examples of colleagues’ use of digital tools, then those colleagues will feel more comfortable trying the same methods themselves.” TR8 also said that the communities of practice would allow teachers to “trade ideas” and find better ways to integrate technology into the students’ science classes.

Participants envisioned these communities of practice as areas for co-creating lessons, exchanging resources, showing other effective practices, and collaborative problem-solving. These types of areas would give teachers an opportunity to collectively identify free or offline applications and modify digital activities to meet the needs of classrooms with limited connectivity.

The accounts provided by participants for both research questions revealed the same basic structure. While there has been significant growth in the number of devices (laptops and mobile phones) owned by teachers (near universal), this has not resulted in similar numbers of student opportunities to engage directly in digital science learning, nor the pedagogical, institutional, and time-based factors required to support direct student engagement in digital science learning.

DISCUSSION

The study identified four interconnected barriers to digital literacy integration in JHS science teaching: inadequate digital infrastructure, limited preparation for science-specific digital pedagogy, insufficient institutional and technical support, and pressures associated with instructional time and curriculum coverage. These findings add to evidence on the challenges of digital technology integration in Ghanaian basic schools. Consistent with Quaicoe and Pata (2020), the results reveal a gap between teachers' reported digital knowledge and their actual classroom practices. However, the present study shows that this gap cannot be explained by teacher competence alone. It is also shaped by the material, institutional, pedagogical, and curricular conditions within which science teaching occurs. This supports Baako and Abroampa (2024), who found that technology integration is influenced by interacting contextual factors such as infrastructure, school resources, and professional development opportunities. Similarly, Abroampa et al. (2025) reported that inadequate school-level technological resources often compel Ghanaian basic-school teachers to rely on personal devices and improvised alternatives.

An important contribution of the study is the distinction between teachers' access to digital devices and learners' opportunities to participate in digitally supported learning. Although most teachers had access to laptops or mobile phones, this did not necessarily provide learners with opportunities to use technology during science lessons. Teacher access may support lesson preparation, information searches, and presentations. However, meaningful digital literacy requires learners to use digital technologies for investigation, data analysis, collaboration, and the construction of scientific explanations. Consequently, initiatives that provide devices to teachers should not be evaluated solely according to the number of devices distributed. Their value should also be considered in terms of the opportunities they create for learners to engage meaningfully with digital technologies.

The findings also highlight the difference between general digital competence and science-specific digital pedagogy. This distinction reflects the TPACK framework, which proposes that effective technology integration requires the interaction of technological, pedagogical, and content knowledge (Mishra & Koehler, 2006). Teachers may therefore be confident in operating computers, searching online, or preparing presentations without necessarily knowing how to use digital tools to support scientific inquiry. Hinostroza et al. (2024) similarly found that technologies are often used in conventional ways rather than for activities such as evidence gathering, investigation, feedback, and hypothesis testing. Thus, the educational value of videos, simulations, and other digital resources depends on how they are incorporated into learning activities. Learners need opportunities to manipulate variables, collect and analyse evidence, and construct explanations from their findings. Accordingly, teachers' preparedness should be judged not only by their technical confidence but also by their ability to use technology purposefully within science pedagogy. This finding reinforces the need for sustained, practical, and science-specific professional development.

Institutional and technical conditions further influenced teachers' ability to sustain digital practices. Equipment failure, poor connectivity, limited maintenance, and lack of technical assistance disrupted technology-supported lessons. These findings are consistent with Appianing (2025) and Baako and Abroampa (2024), who demonstrated that technological and organisational support affects teachers' use of digital technologies. Likewise, Lomo et al. (2025) showed that school leaders' efforts to support technology integration may be constrained by financial, technical, and maintenance challenges. Therefore, instructional leadership and technical support should be viewed as integral components of digital teaching rather than as peripheral administrative services. For example, school clusters or municipal education authorities could provide shared technical and pedagogical support for connectivity, equipment maintenance, and teacher mentoring.

Time and curriculum demands also shaped teachers' decisions about technology use. Preparing digitally enhanced lessons required additional time to identify resources, test equipment, and develop alternatives in case technologies failed. At the same time, teachers were expected to cover prescribed curriculum content and manage other instructional responsibilities. Therefore, limited technology use should not simply be interpreted as poor time management. Instead, it reflects the interaction of workload, curriculum pacing, class size, planning demands, and unreliable technology. Without adequate planning time and technical support, digital literacy integration may become an additional responsibility for teachers rather than a sustainable component of science teaching.

In response to these challenges, participants emphasised the need for continuous, hands-on, and science-specific professional development. They preferred professional learning that demonstrates how technology can support inquiry, assessment, experimentation, and other science activities rather than training limited to basic computer operation. This finding is consistent with evidence that coaching, collaborative learning, practical engagement, and follow-up support contribute to sustained changes in teachers' digital practices (Hennessy et al., 2022; Popova et al., 2022; Amemasor et al., 2025). However, professional development should reflect the technological realities of teachers' classrooms. Where sophisticated equipment and high-speed internet are unavailable, training could incorporate low-cost, open-source, and offline digital resources that can be used within existing school conditions. Professional development should therefore be accompanied by improved infrastructure, curriculum-aligned digital materials, and accessible technical assistance.

Participants also considered instructional leadership and collaborative professional learning important for sustaining digital literacy integration. School leaders can support teachers by allocating resources, protecting planning time, organising professional learning, and facilitating access to technical assistance. Similarly, professional learning communities can enable teachers to exchange resources, demonstrate successful practices, jointly design lessons, and solve classroom problems. This finding aligns with Dille and Røkenes (2021), who emphasise the value of teacher interaction and shared learning in professional communities. Peer mentoring can provide additional support for continued digital integration (Amemasor et al., 2025). Nevertheless, professional learning communities should complement rather than replace formal professional development. Their effectiveness also depends on administrative support and sufficient time for meaningful collaboration.

Taken together, the findings suggest that meaningful digital literacy integration requires a multilevel support ecology. At the teacher level, science-specific professional development can strengthen the knowledge required for purposeful technology integration. At the classroom level, reliable infrastructure and learner-accessible resources can enable active participation in digital scientific inquiry. At the school level, instructional leadership, technical assistance, and professional learning communities can create supportive conditions for implementation. At the municipal level, coordinated professional development, maintenance services, technical support, and follow-up can help translate national digital education expectations into classroom practice.

This interpretation is consistent with the OECD's (2023) Digital Education Ecosystem perspective, which emphasises the interdependence of technology, human capacity, educational resources, and institutional arrangements. Therefore, sustainable digital literacy integration is unlikely to result from isolated interventions. Rather, it requires coordinated support across teacher, classroom, school, and system levels.

IMPLICATIONS FOR RESEARCH AND PRACTICE

This study contributes to ongoing discussions on extending the TPACK framework (Mishra & Koehler, 2006) and the digital education ecosystem perspective (OECD, 2023) by providing empirical evidence of how teacher-level pedagogical knowledge interacts with multiple levels of educational environments to influence the integration of digital literacy. The findings suggest that technology integration models, particularly those developed for low-resource settings, should recognise these multi-level relationships rather than viewing teachers' ability to integrate technology in isolation. Additionally, the study demonstrates the value of combining observation and interview data in examining digital literacy integration by revealing differences between teachers' self-reported confidence in using technology and the opportunities available for students to engage with digital tools during classroom activities.

Practically, at the individual teacher level, teachers would benefit from sustained, subject-specific professional development focused on developing skills related to inquiry, simulation, data analysis and visualisation, digital assessment, and collaborative learning rather than focusing only on operating digital devices. At the classroom level, meaningful digital literacy integration requires reliable internet connectivity, electricity availability, accessible devices for learners, display facilities, and curriculum-aligned science resources.

At the school level, administrators can strengthen instructional leadership by providing adequate time and resources for resource coordination, protected planning time for teachers, mentoring, and professional learning opportunities. At the municipality level, education officials need to provide technical support, equipment maintenance, follow-up training, and equitable resources distribution

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to schools under their supervision. Therefore, evaluating digital education policies should move beyond simply documenting the number of devices provided to teachers and instead consider the quality of learners' engagement with digital tools. Sustainable digital education practices require coordinated investments in pedagogy, infrastructure, leadership, technical support, and collaborative learning opportunities.

CONCLUSION

This study demonstrates that the integration of digital literacy into JHS science teaching is shaped by interacting infrastructural, pedagogical, institutional, and curricular conditions. Although teachers generally had access to mobile phones and laptops, these technologies were used mainly for lesson preparation, information searching, and teacher-led presentation. Learners consequently had fewer opportunities to use digital tools for scientific investigation, evidence analysis, collaboration, communication, and knowledge construction. Meaningful digital literacy integration therefore requires more than teacher access to devices; it requires conditions that enable learners to participate actively in technology-supported science learning.

The study contributes to knowledge in three important ways. First, it extends existing research on the digital divide by distinguishing between teachers' access to digital technologies and learners' opportunities for meaningful digital participation. This distinction suggests that technology provision should not be evaluated only by the number of devices available to teachers, but also by the extent to which such provision expands learners' opportunities to engage in digitally supported scientific inquiry. Second, the study highlights a science-specific pedagogical dimension of digital literacy integration**.** Teachers' ability to operate digital devices does not necessarily translate into the capacity to use technology for experimentation, simulation, data analysis, assessment, and evidence-based reasoning. This reinforces the need to view digital competence and science-specific digital pedagogy as related but distinct aspects of teacher capability.

Third, the study advances an understanding of digital literacy integration as a multilevel support ecology**.** Successful implementation depends on coordinated conditions at teacher, classroom, school, and municipal levels. At the teacher level, sustained science-specific professional learning is required; at the classroom level, learners need access to appropriate digital resources; at the school level, instructional leadership, technical assistance, and collaborative professional learning are essential; and at the municipal level, coordinated training, maintenance, resource provision, and follow-up are required. This perspective contributes to existing technology-integration frameworks by showing how teacher knowledge interacts with material and institutional conditions within a resource-constrained Ghanaian JHS science context.

Overall, the findings indicate that isolated interventions are unlikely to produce sustainable digital literacy integration. Providing devices without pedagogical development, or offering professional development without adequate infrastructure and technical support, may have limited impact. Sustainable integration therefore requires coordinated investment in teacher capability, learner access, infrastructure, instructional leadership, technical assistance, and collaborative professional learning. By demonstrating how these elements interact in JHS science classrooms, the study provides context-specific evidence that can inform the design, implementation, and evaluation of digital education initiatives in Ghana and comparable resource-constrained educational settings.

FURTHER RESEARCH

Future research could extend this study by examining digital literacy integration among JHS science teachers across multiple municipalities and educational contexts in Ghana. Such studies would provide broader insights into how contextual differences, including variations in infrastructure, school leadership, and available support systems, influence teachers' digital literacy practices.

Additional studies could also employ longitudinal designs to examine how teachers' digital literacy practices develop over time and how sustained interventions influence classroom implementation. In addition, future research could incorporate repeated classroom observations, lesson artefacts, and perspectives from multiple stakeholders, including students, head teachers, technical officers, and municipal education officials, to develop a more comprehensive understanding of digital literacy integration in science education.

Finally, potential studies may also examine the effectiveness of coordinated support interventions that combine access to hardware and software, subject-specific professional development, technical assistance, and instructional leadership in promoting meaningful learner engagement with digital technologies during science inquiry activities.

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