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Investigation of Preservice Elementary Teachers’ Conceptual Understanding of Integrated Science Concepts

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Abstract

Science education prepares learners to engage meaningfully with an increasingly complex and technology-driven world. Integrated science, as a multidisciplinary approach, supports the development of scientific literacy and responsible citizenship and fosters an appreciation for scientific inquiry and promotes collaboration in problem-solving from the early stages of learning. This study employed a cross-sectional survey design to investigate the conceptual understanding of selected integrated science concepts among 255 preservice elementary teachers. A two-tier diagnostic test was used to evaluate preservice elementary teachers' knowledge of basic electronics, chemical equations, and infectious and non-infectious diseases. Data were analysed using descriptive statistics and independent samples t-tests. The findings of the study revealed that preservice elementary teachers demonsrated partial scientific understanding of science concepts repleted with factual difficulties and alternative conceptions. No statistically significant difference was observed between the overall mean scores of male participants ($M = 14.84$, $SD = 6.45$) and female participants ($M = 14.68$, $SD = 6.23$), $t(253) = 2.21$, $p = .825$. However, in the area of balancing chemical equations, female participants ($M = 17.99$, $SD = 2.59$) performed significantly better than males ($M = 15.78$, $SD = 3.21$), $t(253) = 5.93$, $p = .001$. Consequently, there was no statistically significant gender differences found in preservice elementary teachers conceptual understanding of basic electronics and infectious and non-infectious diseases.. Subsequently, the study highlights persistent conceptual gaps in the preparation of preservice science teachers and recommends targeted instructional interventions to strengthen their content knowledge. Implications for science teacher education and curriculum development are discussed.

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Introduction

Science education plays a vital role in national development, equipping students with the knowledge and skills necessary for informed decision-making in both local and global contexts (Yenni et al., 2017). Introducing science at the early stages of education is essential for nurturing students' curiosity, fostering scientific literacy, and enhancing their ability to solve real-world problems. One practical approach to achieving these objectives is through the teaching of integrated science, which synthesises content from biology, chemistry, physics, and agricultural science to present topics holistically and thematically (Winarno et al., 2020).

Integrated science promotes not only a functional understanding of scientific principles and processes but also the development of responsible citizenship. By emphasising the interconnectedness of scientific concepts, it encourages inquiry-based and student-centred learning approaches (Kooiker-den Boer et al., 2025; Pascual & Noble, 2025). However, the effectiveness of integrated science instruction is closely tied to the conceptual clarity and pedagogical competence of teachers. Research has shown that students' comprehension of science is significantly influenced by their teachers' mastery of content and instructional methods (Anim-Eduful & Adu-Gyamfi, 2022a, 2022b).

In Ghana, recognising the centrality of science literacy, the Ministry of Education has mandated integrated science as a core subject from basic through secondary levels (MoE, 2010). The curriculum aims to cultivate scientific inquiry skills, positive attitudes toward science, and practical competencies. Despite these intentions, the effective delivery of integrated science is frequently hindered by several systemic challenges. These include insufficient teacher preparation (Laksono et al., 2025; Moody & Holtz, 2025; Isaeva et al., 2025; Verawati & Nisrina, 2025), lack of instructional materials (Diasse & Kawai, 2025; Kusmawan et al., 2025), limited content knowledge (Carrier et al., 2025; Lee & Kriewaldt, 2025; Yadav et al., 2025), and inadequate pedagogical practices (Dominguez et al., 2025; Isaeva et al., 2025; Masoumi & Noroozi, 2025; Quansah et al., 2019).

Among these instructional challenges, specific integrated science topics, such as basic electronics, chemical equations, and infectious and non-infectious diseases, have consistently posed particular difficulties for both teachers and learners (Mensah & Somuah, 2013; Sakpaku, 2016). WAEC Chief Examiners' Reports from 2013 to 2018 further underscore recurring misconceptions in these areas. This pattern raises key questions regarding the root causes of these difficulties, whether they stem from the abstract nature of content, ineffective teaching strategies, or fundamental gaps in teacher understanding.

While previous studies have primarily focused on the challenges faced by students and in-service teachers (Carrier et al., 2025; Lee & Kriewaldt, 2025; Yadav et al., 2025), there is a notable lack of research addressing the conceptual understanding of preservice elementary teachers. This omission is particularly concerning given that these future educators are instrumental in shaping foundational science learning outcomes. Despite ongoing educational reforms aimed at fostering inquiry and literacy from early grades, persistent issues suggest that preservice teachers may be inadequately prepared to deliver integrated science effectively.

The conceptual preparedness of preservice teachers, especially in core science topics, remains underexplored in the Ghanaian context. Compounding this gap is the insufficient attention to how gender may influence conceptual understanding, despite its relevance for equitable teacher training and support. Few studies have examined whether male and female preservice teachers differ in their grasp of science concepts, leaving a critical dimension of teacher development unaddressed.

Moreover, many existing investigations have not employed robust theoretical lenses such as constructivist learning theory or pedagogical content knowledge frameworks to diagnose why these difficulties persist. Such perspectives are essential for interpreting the nature of conceptual gaps and informing adequate teacher preparation. This study, therefore, aims to investigate the conceptual difficulties preservice elementary teachers face in learning integrated science concepts and to explore the extent to which these challenges vary by gender. Addressing these overlooked areas is essential for informing teacher education programs and supporting evidence-based reforms in science instruction at the foundational level in Ghana.

Purpose of the Study

This study sought to investigate the conceptual understanding of selected integrated science topics, namely basic electronics, chemical equations, and infectious and non-infectious diseases, among preservice elementary teachers enrolled in Colleges of Education. Recognising the foundational role of teachers' subject-matter knowledge in shaping effective science instruction, the study further examined potential gender-based differences in conceptual understanding. By identifying strengths and gaps in preservice teachers' comprehension of these conceptually demanding topics, the study aimed to inform science teacher education and curriculum development. Specifically, the study addressed the following research questions:

1. What is the level of preservice elementary teachers' conceptual understanding of basic electronics, chemical equations, and infectious and non-infectious diseases?
2. To what extent does conceptual understanding of these topics differ between male and female preservice teachers?

Literature Review

Conceptualizing Integrated Science

Integrated science is an interdisciplinary approach that combines elements of biology, chemistry, physics, and agricultural science to explore themes from multiple perspectives. Pascual and Noble (2025) describe integrated science as a program that provides students with hands-on experiences that build their understanding of the nature and structure of science. This understanding enables learners to make informed decisions in everyday life and contribute meaningfully to society. The integrated approach emphasises concepts, themes, and strategies to enhance student engagement and critical thinking.

Importance of Teacher Competence in Science Instruction

A recurring theme in the literature is the crucial role of teacher knowledge in influencing student understanding. Several studies have highlighted that learners' grasp of science concepts strongly correlates with teachers' mastery of both content and pedagogy (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021, 2022a). Teachers who lack content knowledge or use inappropriate instructional methods often contribute to students' poor comprehension of scientific concepts (Anim-Eduful & Adu-Gyamfi, 2022b; Nbina, 2012). Effective science teaching requires continuous teacher development and self-improvement to keep up with both subject knowledge and teaching methodologies (Adesoji & Omilani, 2012).

Science Education Policy and Curriculum Objectives in Ghana

According to Ghana's Ministry of Education (MOE, 2010), integrated science education at the basic and secondary school levels aims to foster scientific thinking, develop positive attitudes and values, and prepare learners to engage with scientific inquiry. The curriculum emphasises skills such as observation, analysis, experimentation, and innovation (Uzezi et al., 2017). It also prepares students for a scientifically and technologically driven society, encouraging collaboration and problem-solving (Somuah & Agyenim-Boateng, 2014). Integrated science is a core and compulsory subject introduced as early as primary four and taught through to the third year of Senior High School. The curriculum aims to produce scientifically literate citizens who are capable of contributing to national development and economic sustainability (MOE, 2010). Achieving these objectives requires that teachers possess both subject matter expertise and strong pedagogical skills.

Challenges in Teaching and Learning Integrated Science

Despite the curriculum's intent, multiple challenges hinder the effective teaching and learning of integrated science in Ghana. These include:

Inadequate Teacher Training and Support

The limited availability of continuous professional development opportunities for teachers significantly undermines the effectiveness of integrated science instruction. Many science educators lack access to in-service training, subject-specific workshops, and ongoing support mechanisms designed to update their pedagogical and content knowledge (Quansah et al., 2019). As a result, teachers often rely on outdated instructional practices and struggle to adapt to evolving curricular demands.

Professional development is essential for equipping teachers with innovative strategies, deepening their subject mastery, and enhancing their ability to facilitate inquiry-based learning. The absence of such opportunities contributes to instructional stagnation, reduces teacher confidence, and negatively affects classroom engagement. Furthermore, without regular training, teachers may be ill-prepared to address students' misconceptions or integrate interdisciplinary content effectively—core features of integrated science education. To improve science learning outcomes, educational policies must prioritise structured and sustained professional development programs that respond to both content and pedagogical needs across different teaching contexts.

Limited Instructional Resources

A critical impediment to effective integrated science instruction in many Ghanaian schools is the inadequate provision of instructional resources. Numerous studies report persistent shortages of essential teaching and learning materials, including textbooks, laboratory equipment, and basic science infrastructure (Anim-Eduful & Adu-Gyamfi, 2022a). The absence of these resources severely restricts the implementation of practical, inquiry-based learning, which is central to science education.

Without access to laboratories or scientific apparatus, teachers are often forced to rely on theoretical explanations, which limit students' ability to engage in hands-on experimentation and apply scientific principles to real-world situations. This undermines students' conceptual understanding and weakens their interest and motivation. Additionally, the lack of visual aids and instructional tools makes it difficult to address diverse learning needs within the classroom, thereby contributing to learning disparities. These resource constraints not only affect instructional quality but also hinder the realisation of curriculum objectives that emphasise scientific literacy, creativity, and problem-solving. Addressing these gaps requires targeted investment in educational infrastructure, especially in underserved and rural areas.

Pedagogical Gaps

Another significant barrier to effective teaching and learning of integrated science lies in the pedagogical approaches employed by teachers. In many classrooms, outdated and ineffective teaching strategies continue to dominate instruction, with a heavy reliance on rote memorisation, lecture-based delivery, and teacher-centred methods (Adu-Gyamfi et al., 2018). These approaches tend to prioritise content coverage over conceptual understanding, leaving little room for student inquiry, critical thinking, and active participation.

Rote learning, in particular, limits students to surface-level recall of information without fostering deeper engagement with scientific principles. This method often fails to nurture analytical and problem-solving skills, which are essential for success in science education. Lecture-dominated instruction also reduces opportunities for hands-on experimentation, group work, and interactive learning activities that are known to enhance student comprehension and retention. Furthermore, these traditional methods do not accommodate the diverse learning styles of students. While some learners may benefit from verbal explanations, others require visual aids, real-life examples, or experiential activities to grasp scientific concepts fully. The lack of variety in teaching strategies results in disengagement, especially among students who find abstract concepts difficult to visualise without a practical context.

The overemphasis on teacher talk and passive note-taking also discourages student participation and curiosity. When learners are not encouraged to ask questions, test hypotheses, or explore concepts independently, their motivation and confidence in science diminish over time. As Adu-Gyamfi et al. (2018) highlight, such pedagogical gaps create a disconnect between students and the subject matter, leading to poor academic outcomes and negative attitudes toward science. To address these challenges, there is a growing call for more learner-centred, inquiry-based, and constructivist teaching strategies in integrated science classrooms. These methods promote active engagement, foster critical thinking, and make science more relatable and meaningful to students' lives.

Learner-related factors

In addition to teacher-related and systemic challenges, several learner-centred issues significantly affect students' performance in integrated science. Notably, poor student attitudes toward science, low intrinsic motivation, and limited interest in scientific subjects have been consistently identified as major contributors to underachievement in the subject. Adu-Gyamfi (2013; 2014) emphasises that students often perceive science as an abstract and challenging discipline, which leads to a lack of enthusiasm and reduced effort in engaging with scientific content. This perception is especially prevalent in environments where science is taught theoretically, with minimal practical or hands-on activities to stimulate curiosity.

Moreover, Adu-Gyamfi and Ampiah (2016) found that learners who view science as irrelevant to their daily lives are less likely to participate actively in lessons or invest effort in understanding core concepts. The lack of contextualization in teaching—where scientific principles are not clearly connected to real-world applications—can further alienate students and reinforce the notion that science is only for high-achieving or "gifted" learners.

Similarly, Anamuah-Mensah et al. (2017) observed that learners' disinterest is exacerbated when science instruction is dominated by rote memorisation, with few opportunities for inquiry-based or exploratory learning. When students are not allowed to ask questions, test ideas, or engage in experimentation, they may develop a passive learning attitude that undermines both motivation and performance. Ngman-wara (2015) also noted that student apathy in science is often a reflection of both poor foundational knowledge and a lack of early exposure to engaging science experiences during their formative years.

These findings underscore the importance of fostering positive attitudes toward science from an early stage, through engaging pedagogies, relatable content, and encouraging classroom environments. Improving learner engagement requires not only changes in teaching strategies but also deliberate efforts to make science education relevant, inclusive, and stimulating for all students.

Difficult Topics and Learning Barriers

Integrated science encompasses a wide range of interdisciplinary concepts, some of which are consistently reported as difficult to teach and learn. Topics such as basic electronics, electrical energy, acids, bases, and salts, as well as infectious and non-infectious diseases, pose significant challenges for Junior High School students in Ghana (Mensah & Somuah, 2013). These conceptual difficulties often stem from the abstract nature of the content, the absence of practical demonstrations, and learners' limited prior exposure to scientific terminology and processes.

Teachers also report difficulties in effectively delivering these topics, citing gaps in their own subject knowledge, lack of instructional materials, and insufficient training in concept-specific pedagogy (Sakpaku, 2016). These challenges are symptomatic of broader systemic issues, including rigid curriculum structures, inadequate teacher preparation, and limited access to continuous professional development (Anamuah-Mensah et al., 2017; Ngman-wara, 2015). Addressing these learning barriers requires targeted interventions, such as differentiated instructional strategies, curriculum refinement, and strengthened teacher capacity, particularly in content areas that are conceptually demanding yet foundational to scientific literacy.

In conclusion, the literature consistently shows that while Ghana's integrated science curriculum is ambitious and well-structured, its implementation is hampered by inadequate teacher preparation, limited resources, and complex subject matter. Addressing these challenges is crucial to enhancing science learning outcomes and achieving national goals of scientific literacy and economic growth.

Theoretical Framework

This study is theoretically grounded in Constructivist Learning Theory, with particular emphasis on Piaget's cognitive constructivism and Vygotsky's sociocultural theory. Constructivism posits that learners actively construct meaning by integrating new information with existing cognitive frameworks, thereby shaping their understanding through experiential engagement (Cong-Lem, 2025; Panhwar et al., 2025). Within the context of preservice elementary science education, conceptual difficulties often arise when instructional methodologies are misaligned with learners' prior knowledge and mental models.

Vygotsky's concept of the Zone of Proximal Development (ZPD) further substantiates the significance of scaffolded instruction and social interaction in facilitating conceptual development. Learning is most effective when students engage with more knowledgeable others, peers or instructors who provide the necessary support to bridge the gap between current capabilities and potential understanding (Buhamad, 2024; Hai & Khuong, 2025; Nurhasnah et al., 2024; Pavlik & Pavlik, 2024; Yildiz, 2025). These interactions enable learners to transition from a superficial familiarity with scientific content to a robust conceptual understanding.

Nonetheless, meaningful science learning is contingent upon learners' ability to connect new concepts with pre-existing knowledge structures. In the Ghanaian educational context, limited exposure to inquiry-based science pedagogy at the basic and secondary school levels presents a significant challenge (Asabere-Ameyaw et al., 2012). This lack of foundational experiences may impede preservice teachers' ability to assimilate and internalise abstract scientific concepts, rendering them cognitively inaccessible.

Vygotsky's sociocultural theory also emphasises the crucial role of collaborative learning, peer dialogue, and instructional scaffolding in enhancing students' conceptual understanding. In the absence of such pedagogical supports, learners often resort to intuitive, experience-based reasoning, which may conflict with scientific explanations (Cong-Lem, 2025; Panhwar et al., 2025; Vygotsky, 1978). Accordingly, pedagogical approaches that incorporate peer-assisted learning, guided inquiry, and scaffolded tasks are essential to support preservice teachers in constructing scientifically accurate understandings.

Shulman's framework of Pedagogical Content Knowledge (PCK) which provides an integrated lens through which to examine the dual demands of content mastery and pedagogical proficiency, complemented the constructivist and sociocultural perspectives in this study. Effective science teaching requires not only a solid grasp of disciplinary content but also the ability to translate that knowledge into developmentally appropriate instructional strategies (Kong, 2025; Ward & Kim, 2024). Empirical evidence suggests that preservice teachers' difficulties in science stem from deficiencies in both domains, thereby affecting their future instructional effectiveness (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2021).

Thus, enhancing science education in basic schools requires more than the transmission of factual content; it demands a pedagogical focus on fostering conceptual understanding, critical thinking, and adaptive instructional strategies. The theoretical framework employed in this study comprising constructivist learning theory, sociocultural theory, and pedagogical content knowledge offers a robust and multidimensional foundation for investigating the conceptual difficulties preservice elementary teachers in Ghana face in learning school science concepts. Against this backdrop, the study explores how preservice teachers' cognitive structures, educational backgrounds, and instructional experiences shape their perceptions of the difficulty inherent in school science content.

Methodology

Research Design

This study employed a cross-sectional survey design (Cohen et al., 2010) to gather quantitative data on preservice elementary teachers' conceptual understanding of selected integrated science concepts. This design was appropriate for assessing the current state of knowledge among a defined population at a single point in time.

Sampling Procedure

The study was conducted in the Eastern Region of Ghana, which had seven Colleges of Education during the 2020/2021 academic year. Three colleges were randomly selected. Sophomore preservice teachers were chosen because they had already been introduced to the targeted concepts basic electronics, chemical equations, and infectious and non-infectious diseases—in their first year, thus possessing the foundational knowledge required to respond meaningfully to the instrument. Each College of Education had approximately 800 preservice teachers, totaling 3200 students across all levels. The accessible population consisted of 2,400 sophomore students, with 57.3% female and 42.7% male students. Using simple random sampling and Krejcie and Morgan's (1970) table, a sample of 255 preservice teachers was selected.

Instrument for Data Collection

Data were collected using a self-developed instrument, Achievement Test on Integrated Science Concepts (ATISC). The items on the instrument were developed from existing literature, standardised curriculum materials, and WAEC past items, and benchmarked against test items from the Institute for Teacher Education and Continuing Professional Development (ITECPD) at the University of Education, Winneba, to ensure content validity. The instrument comprised two sections. Section A collected demographic data (sex, age, programme), while Section B included 21 two-tier, four-option multiple-choice items assessing conceptual understanding. Eight items covered basic electronics, seven covered chemical equations, and six addressed infectious and non-infectious diseases. Respondents selected an answer (Tier 1) and provided a justification (Tier 2). Incorrect responses to either or both tiers indicated gaps in conceptual understanding.

Validity and Reliability

Face and content validity were ensured through expert reviews by experienced science tutors, WAEC examiners, and a university science education expert. A pilot test was conducted with 49 preservice teachers from a different college. Based on item difficulty indices, 11 items were removed due to redundancy or extreme difficulty. The final instrument included 21 items. The Kuder-Richardson 21 (KR-21) reliability coefficient for the test was *.79*, indicating acceptable internal consistency.

Ethical Considerations

This study adhered to established ethical standards in educational research to ensure the protection and dignity of all participants. Prior to data collection, permission was obtained from the relevant authorities at the participating Colleges of Education. Participants were fully informed about the purpose, procedures, and voluntary nature of the study.

Each respondent provided informed consent, and they were assured that their participation was entirely voluntary and that they could withdraw at any time without any penalty or consequence. To protect the privacy of respondents, confidentiality and anonymity were maintained throughout the study. No identifying information was collected, and responses were used solely for academic purposes. The study posed minimal risk to participants, as it involved only a diagnostic test on science concepts with no manipulation or sensitive questions. The data collected were securely stored and accessible only to the researcher. As the research involved no personal, clinical, or sensitive data, formal ethical clearance was not required, in line with institutional and national guidelines for low-risk educational studies.

Data Collection Procedure

An introductory letter from the Department of Science Education facilitated access to the selected colleges. The researchers met with integrated science tutors to confirm coverage of the relevant content. After informing participants of the study's purpose and securing their consent, the achievement test was administered under examination-like conditions. All 255 respondents completed and returned the instrument, with perfect response rate.

Data Analysis

Each item was scored on a two-point scale: two marks for correct answers with correct reasoning (Full Scientific Understanding), one mark for a correct answer or reason only (Partial Scientific Understanding), and zero for incorrect answers and reasoning (No Scientific Understanding) (Anim-Eduful & Adu-Gyamfi, 2021). The maximum score of the diagnostic test was 42.

Descriptive statistics (frequencies, percentages, means, and standard deviations) were used to analyse levels of conceptual understanding. To examine gender differences (Research Question 2), an independent samples *t*-test was conducted. Normality was confirmed (Kolmogorov-Smirnov = 0.200, $p > .05$), and Levene's test indicated homogeneity of variance ($p = .792$). Further multiple comparisons were made across the three science concepts using *t*-tests disaggregated by gender.

Results and Discussion

To address the research question concerning the level of conceptual understanding among preservice teachers in selected integrated science concepts, data were analysed using a three-level categorisation scheme. Table 1 presents the criteria used for interpreting the levels of conceptual understanding in basic electronics, balancing of chemical equations, and infectious and non-infectious diseases.

Table 1. Categorisation of Level of Conceptual Understanding

Level	Mean range	Interpretation
1	1.36-2.00	Full Scientific Understanding
2	0.68-1.35	Partial Scientific Understanding
3	0.00-0.67	No Scientific Understanding

Item 7 assessed knowledge of the primary component of sand. The results (M = 0.47, SD = 0.61) indicate that the majority of preservice teachers lacked scientific understanding of the fact that silicon is the most common constituent of sand. Specifically, 60.0% showed no understanding, 21.6% demonstrated partial understanding, and only 18.4% exhibited full scientific understanding. Item 8 evaluated understanding of why resistors are necessary for LED functionality. The mean score (M = 0.87, SD = 0.78) suggests partial scientific understanding. While 33.3% of respondents demonstrated full understanding, a notable 43.5% showed no understanding, and 23.2% indicated partial understanding.

In Item 9, which focused on identifying transistor types, preservice teachers again demonstrated partial understanding (M = 0.78, SD = 0.70). The distribution showed that 38.4% fully understood the concept, 23.1% had partial understanding, and an equal 38.4% had no understanding. Item 10 investigated the rationale for preferring LED bulbs over traditional lighting. Results (M = 0.98, SD = 0.79) reflected partial understanding, with 51.8% of respondents demonstrating partial understanding, 30.6% showing no understanding, and only 17.6% achieving full scientific understanding. This suggests limited comprehension of energy efficiency as a distinguishing feature of LED technology.

In Item 11, preservice teachers were assessed on the behavior of a P-N junction diode when not connected to a circuit. The mean score (M = 0.42, SD = 0.82) revealed low conceptual understanding. Only 6.7% demonstrated full understanding, while 16.1% had partial understanding and 77.3% showed no scientific understanding, indicating significant conceptual gaps. Item 12 examined the identification of the majority charge carrier in a P-type semiconductor. The results (M = 0.92, SD = 0.61) again suggest partial understanding. While 22.4% exhibited partial understanding and 7.1% had full scientific understanding, the majority (70.6%) demonstrated no understanding of the fact that "holes" are the majority carriers in P-type materials.

This section presents findings that address the research question: *What is the level of conceptual understanding of selected integrated science concepts among pre-service teachers?* Conceptual understanding was categorised using the criteria outlined in Table 1, and the results for individual test items are summarized in Table 2.

Table 2. Levels of Pre-service Teachers' Conceptual Understanding in Integrated Science

	Understanding level							
Item	**Full Scientific Understanding**		**Partial Scientific Understanding**		**No Scientific Understanding**		**M**	**SD**
	n	**%**	**n**	**%**	**n**	**%**		
Basic electronics								
7	47	18.4	55	21.6	153	60.0	0.47	0.61
8	85	33.3	59	23.1	111	43.5	0.87	0.78
9	98	38.4	59	23.1	98	38.4	0.78	0.70
10	45	17.6	132	51.8	78	30.6	0.98	0.79
11	17	6.7	41	16.1	197	77.3	0.42	0.82
12	18	7.1	57	22.4	93	70.6	0.92	0.61
13	19	7.5	88	34.5	148	58.0	0.45	0.58
14	25	9.8	67	26.3	163	63.9	0.43	0.63
Total mean							***.67***	***.69***
Balancing of equation								
15	13	5.1	36	14.1	206	80.6	0.38	0.79
16	29	11.4	74	29.0	152	59.6	0.47	0.61
17	7	2.7	54	21.2	194	76.1	0.23	0.46
18	18	7.1	102	40.0	135	52.9	0.59	0.70
19	22	8.6	44	17.3	189	74.1	0.25	0.43
20	17	6.7	39	15.3	199	78.0	0.23	0.46
21	7	2.7	21	8.0	227	89	0.24	0.66
Total mean							***.34***	***.59***
Infectious diseases								
22	95	37.3	107	42.0	53	20.8	1.28	0.85
23	59	23.1	104	40.8	92	36.1	1.23	0.90
24	58	22.7	130	51.0	67	26.3	1.14	0.80
25	46	18.0	60	23.5	149	58.4	0.47	0.61
26	59	23.1	125	49.0	71	27.8	1.06	0.82
27	98	38.4	79	31.0	78	30.6	0.98	0.75
Total mean							***1.03***	***.79***
Average mean							***.68***	***.69***

The data presented in Table 2 reveal significant gaps in the scientific understanding of pre-service teachers across key integrated science concepts, including basic electronics, chemical reactions, and infectious and non-infectious diseases. In basic electronics, a majority of pre-service teachers (58.0%) lacked scientific understanding of the behavior of a P-N junction when the P end is connected to the negative terminal and the N end to the positive terminal, indicating a fundamental misconception about its insulating behavior (M = 0.45, SD = 0.58). Similarly, regarding the concept of capacitors charging and discharging, only 9.8% demonstrated a full understanding, while 63.9% showed no comprehension (M = 0.43, SD = 0.63).

In the area of chemical reactions, knowledge gaps were also widespread. For example, only 5.1% of pre-service teachers correctly identified the balanced reaction between Fe^{2+} and O^{2-} to produce FeO, while 80.6% showed no understanding (M = 0.38, SD = 0.79). A similar pattern appeared with acid-base reactions, where 59.0% failed to recognize the correct stoichiometry between hydrochloric acid and sodium hydroxide (M = 0.47, SD = 0.61). The concept of double displacement reactions was particularly difficult, with just 2.7% properly identifying a reaction between barium chloride and sodium tetraoxosulphate(VI) (M = 0.23, SD = 0.46). Additionally, only 7.1% of participants accurately identified the products when evaluating the reaction between calcium hydroxide and ammonium chloride (M = 0.59, SD = 0.70). Low levels of understanding were also noted in recognizing hydrogen gas as a product of the reaction between hydrochloric acid and zinc metal (M = 0.25, SD = 0.43), as well as the products of the reaction between aluminum trioxonitrate(V) and sodium hydroxide (M = 0.23, SD = 0.46). Regarding the products formed in the reaction between aluminum metal and copper(II) chloride, only 2.7% of participants demonstrated complete understanding (M = 0.24, SD = 0.66).

In the domain of disease**,** responses showed slightly higher but still limited levels of understanding. While 37.3% fully understood that lifestyle is not a mode of transmission for infectious diseases (M = 1.3, SD = 0.85), 20.8% showed no understanding. Regarding disease classification, only 23.1% accurately recognised the distinction between pathogenic and non-pathogenic diseases (M = 1.2, SD = 0.90). Understanding of nutritional deficiency diseases was similarly weak; only 22.7% correctly identified vitamin B1 (thiamine) deficiency as the cause of beriberi (M = 1.1, SD = 0.80). Moreover, 58.4% of respondents failed to identify cancer, leukaemia, hypertension, and arteriosclerosis as non-pathogenic conditions (M = 0.50, SD = 0.61).

Regarding infectious diseases, just under half (49.0%) of pre-service teachers demonstrated partial understanding of malaria as a parasitic infection caused by *Plasmodium spp.* (M = 1.1, SD = 0.82). In contrast, a comparatively higher percentage (38.4%) fully understood that typhoid prevention involves safe sewage disposal, regular vaccination, and pasteurisation of milk (M = 1.0, SD = 0.75), although 30.6% still lacked scientific comprehension. Overall, the mean performance score was 0.68, indicating a generally partial level of scientific understanding across the items assessed. Scores ranged from 1 to 37 out of a possible 42, highlighting significant variability in comprehension levels. Collectively, the data demonstrate that pre-service teachers possess a limited and inconsistent understanding of fundamental integrated science concepts. These gaps, if not addressed through targeted pedagogical interventions and strengthened content training, may negatively impact future classroom instruction and student learning outcomes.

The overall average score across the three domains was M = 0.68 (SD = 0.69), indicating a partial understanding of science. Most pre-service teachers struggled significantly with balancing chemical equations and basic electronics, while performing somewhat better on topics related to infectious and non-infectious diseases. These findings highlight notable conceptual gaps, especially in fundamental science areas like chemical reactions and electronic principles. This points to a need for curriculum reinforcement and the development of improved teaching strategies in teacher education programs.

Further analyses compared conceptual understanding across gender. These comparisons aimed to determine whether male and female pre-service teachers differed significantly in their understanding of integrated science concepts across the three key areas. The results of the independent-samples *t*-test analysis are presented in Tables 3 and 4. Table 3 presents a comparison between the overall conceptual understanding of integrated science concepts among male and female preservice teachers.

Table 3. Independent-Samples *t*-test Results for Male and Female Preservice Teachers' Overall Conceptual Understanding of Integrated Science

Gender	**N**	**M**	**SD**	**t**	**df**	**p**
Male	87	14.84	6.45	2.21	253	*.825*
Female	168	14.68	6.23			

As shown in Table 3, there was no statistically significant difference in the overall conceptual understanding of integrated science between male (M = 14.84, SD = 6.45) and female (M = 14.68, SD = 6.23) preservice teachers, $t(253) = 2.21$, $p = .825$. This indicates that both male and female preservice teachers exhibited similar levels of conceptual understanding across the integrated science domains. Table 4 provides a gender-based comparison of preservice teachers' conceptual understanding across three specific integrated science domains.

Table 4. Independent-Samples *t*-test Results for Conceptual Understanding by Gender Across Three Integrated Science Concepts

Concept Area	**Gender**	**N**	**M**	**SD**	**t**	**df**	**p**
Basic electronics	Male	87	17.77	2.62	1.02	253	.310
	Female	168	18.15	2.98			
Balancing of chemical equations	Male	87	15.78	3.21	5.93	253	*.001**
	Female	168	17.99	2.59			
Infectious and non-infectious diseases	Male	87	11.95	1.93	1.38	253	.168
	Female	168	12.30	1.90			

p < *.05*

The findings in Table 4 indicate no significant gender differences in conceptual understanding of basic electronics and infectious and non-infectious diseases, with *p*-values of .310 and .168 respectively. However, a statistically significant difference was found in balancing chemical equations, with female preservice teachers (M = 17.99, SD = 2.59) outperforming their male counterparts (M = 15.78, SD = 3.21), $t(253) = 5.93$, $p = .001$. This suggests that female preservice teachers have a relatively better understanding of this chemistry-related concept.

Overall, preservice teachers demonstrated no scientific understanding (M = 0.68, SD = 0.69) across the three domains, indicating general conceptual difficulties in integrated science. While participants exhibited partial understanding (M = 1.03, SD = 0.79) of concepts related to infectious and non-infectious diseases, they showed no scientific understanding of basic electronics (M = 0.67, SD = 0.69) and balancing chemical equations (M = 0.34, SD = 0.59).

Discussion

The findings from these six items in the basic electronics section reveal a generally low to moderate level of conceptual understanding among preservice teachers. Most participants struggled with fundamental semiconductor and circuit-related concepts, with many demonstrating either no understanding or only partial understanding. These results are consistent with previous studies (Adu-Gyamfi et al., 2024,2025; Anim-Eduful & Adu-Gyamfi, 2021), which have highlighted persistent conceptual difficulties in science education at the teacher preparation level.

The low mean scores and high percentages of incorrect responses suggest a need for more robust instructional strategies in teacher education programs. Conceptual teaching approaches—such as inquiry-based learning, conceptual change strategies, and the use of analogies—may better support preservice teachers in developing accurate mental models of abstract scientific concepts, including those in electronics.

Students' difficulties in integrated science concepts may be attributed to the abstract nature of these concepts (Baah-Yanney et al., 2025) and the pedagogical limitations in instructional delivery (Adu-Gyamfi et al., 2024; Assifuah & Anim-Eduful, 2025; Kocijanic, 2018; Metioui & Trudel, 2012; Twissel, 2018; Hanson, 2017). For example, basic electronics and chemical equations require symbolic and abstract reasoning that many preservice teachers struggle with, possibly due to inadequate prior knowledge, reliance on rote instruction, or limited self-directed study.

Furthermore, a robust understanding of science concepts among preservice teachers is essential for effective science instruction (Anim-Eduful & Adoboah Forson, 2025) and the development of scientific literacy at the elementary education level. As this study investigated the conceptual understanding of integrated science, specifically basic electronics, balancing chemical equations, and infectious and non-infectious diseases among preservice elementary teachers in selected Colleges of Education in Ghana, the findings revealed significant learning gaps in foundational science concepts, particularly in basic electronics and chemical equations, where most participants demonstrated a limited understanding of of science concepts.

Although no statistically significant gender difference was found in overall performance, a notable exception was observed in the area of balancing chemical equations, where female preservice teachers outperformed their male counterparts. These findings highlight the persistence of misconceptions in science education and suggest that such gaps remain largely unaddressed in preservice teacher training programmes.

The implications are critical; preservice teachers who do not understand core science concepts may struggle to teach them effectively at the basic school level. This aligns with findings by Anim-Eduful and Adu-Gyamfi (2021), who observed that students' understanding often reflects their teachers' conceptual grasp. Moreover, the continuity of these difficulties from basic school through college indicates systemic conceptual challenges in the teaching and learning of integrated science (Adu-Gyamfi et al., 2023; Baah-Yanney et al., 2025; Halim et al., 2014; Santyasa et al., 2018).

Conclusion

This study investigated preservice elementary teachers' conceptual understanding of three core integrated science topics: basic electronics, balancing chemical equations, and infectious and non-infectious diseases. The findings revealed that participants generally exhibited low conceptual understanding, particularly in basic electronics and chemical equations, with most demonstrating no scientific understanding. A partial understanding was observed in the areas of infectious and non-infectious diseases.

A gender-based analysis revealed no statistically significant difference in overall conceptual understanding, nor in the domains of basic electronics and disease-related concepts. However, a significant gender difference emerged in balancing chemical equations, where female preservice teachers outperformed their male counterparts.

These findings highlight the importance of enhancing content-focused teaching in teacher education programs, especially in difficult areas of integrated science. Filling these gaps is essential for training effective science educators who can provide inquiry-based, conceptually solid instruction at the elementary and secondary levels.

The findings indicate that conceptual difficulties within integrated science are pervasive, affecting not only students but also those training to become educators. Consequently, the ongoing learning challenges observed at the basic school level may stem from deficiencies in educator knowledge. To mitigate these issues, targeted interventions in preservice teacher education are necessary, focusing on enhancing conceptual understanding in physics and chemistry components of the curriculum.

Implications

The findings of this study carry significant implications for researchers, policymakers, and educational practitioners involved in science teacher preparation. For researchers, the study underscores the need for ongoing investigation into the cognitive and pedagogical challenges that preservice teachers face in mastering integrated science concepts. There is a critical need to explore innovative instructional models and assessment tools that can better identify and address conceptual gaps. Longitudinal and intervention-based studies would provide deeper insights into the efficacy of specific teaching strategies in fostering durable conceptual change among preservice teachers.

For policymakers, the results call for a re-evaluation of the science curriculum and instructional standards within Colleges of Education. Policies should support the integration of constructivist-based pedagogies, adequate instructional resources, and ongoing professional development for science teacher educators. Furthermore, teacher education programs should include structured opportunities for preservice teachers to engage with science content in contextually meaningful and pedagogically sound ways.

For practitioners, especially science teacher educators, the study emphasises the importance of delivering instruction that prioritises conceptual clarity and actively addresses misconceptions. Educators must adopt teaching methods that are interactive, inquiry-driven, and grounded in real-world contexts to make science accessible and engaging. Building preservice teachers' confidence and competence in science is not only critical for their professional success but also foundational for inspiring scientific curiosity and literacy among the young learners they will eventually teach. Collectively, these implications underscore the urgency of strengthening science teacher education to ensure a robust pipeline of educators capable of delivering high-quality science instruction at the elementary level.

Recommendations

Based on the findings of this study, several recommendations are proposed to address the conceptual challenges faced by preservice elementary teachers in learning integrated science concepts:

Firstly, content pedagogy within Colleges of Education should be strengthened by placing greater emphasis on concept-focused instruction and practical demonstrations. This approach is essential for developing deeper scientific understanding of complex topics such as basic electronics and chemical equations.

Secondly, the adoption of conceptual teaching strategies is critical. Constructivist approaches including inquiry-based learning, conceptual mapping, analogical reasoning, and real-life applications should be integrated into instruction. It is essential to contextualize science teaching within real-world scenarios that are familiar and relevant to preservice teachers. These methods facilitate conceptual change by helping learners connect abstract ideas, particularly in chemistry, to familiar experiences. An adoption of conceptual change instructional strategies explicitly addresses and restructure learners' misconceptions. Such approaches foster deeper, more meaningful learning by challenging existing mental models and guiding learners toward scientifically accurate conceptions.

In addition, targeted interventions should be implemented for persistently difficult concepts. Workshops and remediation programs focusing on topics such as basic electronics and chemical equation balancing can employ hands-on activities and simulations to minimize abstraction and enhance engagement. Furthermore, the integration of digital technologies in science instruction should be prioritised. Tools such as virtual laboratories, interactive simulations, and online learning platforms can render complex scientific ideas more concrete and accessible, particularly in resource-limited settings.

Moreover, early diagnostic assessments should be employed to identify preservice teachers' conceptual gaps at the onset of their training. Tailored instructional support should then be provided to address these gaps before teaching practice begins. Also, gender-responsive teaching should be strengthened. Although gender disparities were minimal, the observed difference in understanding chemical equations indicates a need for inclusive strategies that support diverse learning preferences and ensure equitable science learning opportunities for both male and female trainees.

Subsequently, ongoing professional development for in-service teachers must be institutionalised. Continuous training ensures that science teachers at the basic school level maintain updated content knowledge and pedagogical competence aligned with current scientific standards.

Finally, qualitative investigations into the root causes of conceptual difficulties should be undertaken to yield more profound insights. At the same time, longitudinal studies could assess the long-term impact of improved teacher preparation on learner outcomes in science education. These recommendations collectively underscore the need for systemic reform in science teacher education to ensure that preservice teachers are well-equipped to foster scientific literacy at the foundational level. Collectively, these recommendations aim to improve the quality of preservice science teacher education and, by extension, the effectiveness of science instruction in Ghana's basic schools.

Suggestions

While this study provided valuable insights into preservice elementary teachers' conceptual understanding of selected science concepts, it did not include any intervention strategies to address the identified learning challenges. As such, future research should consider implementing and evaluating the effectiveness of participatory teaching and learning methods. Approaches such as inquiry-based learning, collaborative concept mapping, and flipped classroom models hold promise for enhancing preservice teachers' conceptual development and should be systematically explored in subsequent studies.

Additionally, this study focused on a limited range of science concepts. Future investigations would benefit from a broader conceptual scope, encompassing additional critical areas of integrated science such as energy transformations, genetics, and environmental science. Expanding the range of concepts examined would provide a more holistic understanding of the conceptual gaps that preservice teachers face and offer more profound insight into the areas that require pedagogical reinforcement.

Ethical Considerations

This study did not require formal ethical approval, as comprehensive information regarding the purpose, procedures, and intended use of the data was transparently communicated to both participants and relevant school authorities. Informed consent was obtained from all participants, and participation in the study was entirely voluntary.

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Conflict of Interest

The authors declare that there are no conflicts of interest associated with this study.

Availability of Data and Materials

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