EUROPEAN JOURNAL OF STEM EDUCATION

European Journal of STEM Education,
2026, 11(1), 8
eISSN: 2468-4368

lectito

Research paper

Assessing Pre-Service Science Teachers’ Academic Knowledge and Misconceptions about Evolution and Genetics Concepts

Sakyiwaa Boateng [1]*, Rosemary Naana Kumi-Manu [2]

[1] *Walter Sisulu University*, SOUTH AFRICA
[2] *University of Education,* GHANA

***Corresponding Author:** sboateng@wsu.ac.za

Citation: Boateng, S., & Kumi-Manu, R. N. (2026). Assessing pre-service science teachers’ academic knowledge and misconceptions about evolution and genetics concepts. *European Journal of STEM Education, 11*(1), 8. https://doi.org/10.20897/ejsteme/17966

Published: February 25, 2026

ABSTRACT

Evolution and genetics play a vital role in understanding biology and are widely recognised as unifying, interdisciplinary concepts in biological research. This study has a dual objective. It first assesses pre-service biology teachers’ (PSBTs) knowledge and misconceptions about evolution and genetics. Secondly, it sought to compare these findings across different levels of study and among participants by gender. A pragmatic, sequential, mixed-methods design was employed, involving 240 PSBTs in their 2nd, 3rd, and 4th years of pursuing a Bachelor of Education Science degree at one university in Ghana. The study collected data from the Test on Evolution and Genetics Concepts (TEGIC), semi-structured interviews, and document analysis. Descriptive, inferential, and descriptive-interpretive statistics were used to analyse the data. The results indicated no significant differences in academic success in evolution and genetics among PSBTs based on year of study and gender. Moreover, the findings revealed numerous misconceptions among the participants on these concepts. Therefore, the study has implications for stakeholders in biology education, suggesting the implementation of innovative teaching strategies, including technology integration, conceptual map development, simulations, differentiated instruction, and semantic feature analysis in the science classroom to enhance students' conceptual understanding of biology.

Keywords: academic achievement, biology, evolution, genetics, pre-service biology teachers

Evolution and Genetics are essential to understanding biology (Dobzhansky, 1973; Martincová et al., 2022). These concepts are widely acknowledged as a unifying, cross-disciplinary concept in biology research (Hanisch & Eirdosh, 2020). Understanding genetics enhances the comprehension of evolution, a complex and frequently misunderstood area of biology (Altunoğlu & Şeker, 2015). However, evolution and genetics are perceived as challenging in school science curricula (Borgerding et al., 2015; Hanisch & Eirdosh, 2020), despite being central science concepts essential to scientific literacy. Studies have shown that students and teachers have difficulty grasping these concepts (Glaze & Goldston, 2019; Ozgür, 2013). Numerous studies have shown that undergraduate students often lack sufficient knowledge and understanding of evolution and genetics (Buckberry & Burke da Silva, 2012; Karatas, 2020), despite generally being considered more knowledgeable than high school students and the general public (Gregory & Ellis, 2009; McFadden et al., 2007). This limited understanding of key concepts in evolution and genetics is frequently linked to misconceptions and a range of cognitive and religious influences (Adjapong, 2019; Grewe, 2025; Nelson-Ebimie et al., 2023; Rosengren et al., 2012).

Alternative conceptions that conflict with the accepted scientific understanding continue to pose challenges in science education (Elrod, 2008). Karatas (2020) explains that scientifically inaccurate ideas stored in long-term memory can shape how new information is perceived and interpreted, as these ideas serve as a framework for understanding and assigning meaning, even in emotionally charged contexts. Such flawed understandings often persist in biology from high school to university, compromising students' foundational grasp of key scientific principles. As highlighted by Chisango et al. (2023), evolution, in particular, is a topic where these deeply rooted misunderstandings are widespread, as evidenced by a substantial body of literature. These alternative views may originate within formal education settings or be reinforced through informal social interactions. These misconceptions, which can range in severity from simple misunderstandings to total rejection of theories (McComas, 2006; Sadler, 2005), are frequently complex and deeply held, acting as major roadblocks to students' comprehension of the precise scientific explanations of evolution and genetics that are provided in the classroom (Shrestha & Bhattarai, 2022; Can & Soylu, 2025). It is, therefore, not surprising to find a vast body of literature on alternative conceptions about evolution, genetics, and biology in general.

Although there is a substantial body of research exploring teachers' conceptual understanding and prior knowledge of evolution and genetics (Chisango et al., 2023; Karatas, 2020; Kirbaslar & Baris, 2016), limited attention has been given to how pre-service biology teachers (PSBTs) comprehend these topics. Research indicates that inaccurate conceptions can develop not only in early education but also persist into higher education, making it critical to investigate PSBTs' thinking about these subjects and how they may influence their future teaching. Uncovering PSBTs' prior conceptions and misunderstandings is necessary for informing targeted instructional strategies. However, there remains a notable gap in research regarding the nature and origins of PSBTs' difficulties in grasping core concepts in evolution and genetics (Carney, 2022; Karatas, 2020).

Against this background, this study fills the gap in the literature by assessing PSBTs' academic knowledge and misconceptions about evolution and genetics in a university of education in Ghana. The study used empirical evidence to advocate for effective instruction at all levels of the educational ladder to enhance students' academic achievement in biology and eliminate the element of misconceptions.

The study was guided by the following research questions:

1. Do the academic achievement scores obtained by pre-service biology teachers on evolution and genetics show any significant difference according to gender and year of study?
2. What misconceptions do pre-service biology teachers have about evolution and genetics?

THEORETICAL FRAMEWORK

The foundation of our theoretical framework is based on the Conceptual Change Theory (Posner et al., 1982) and the Social Constructivism theory of learning (Vygotsky, 1962). Conceptual Change Theory, posited by Posner et al. in 1982, is grounded in understanding how individuals restructure their conceptual knowledge, particularly in educational contexts. The theory proposes that effective learning occurs not merely through acquiring new information but significantly through transforming existing mental models and misconceptions. These processes involve radical accommodation, in which learners reject prior conceptions that contradict newly acquired scientific understandings, thereby reconstructing their cognitive frameworks. This foundational concept emphasises that learners must experience cognitive conflicts that motivate them to revise their misconceptions, leading to deeper conceptual insight (Addido et al., 2022; Demastes et al., 1995; Posner et al., 1982).

Posner et al. (1982) outline four key conditions necessary for conceptual change: (1) the learner must recognise that their existing conception is inadequate; (2) the alternative conception must be intelligible; (3) the alternative conception must be plausible; and (4) the alternative conception must be fruitful, contributing to a better understanding of phenomena. This model has been influential and applied across various domains of science education, demonstrating its versatility in addressing student misconceptions that often persist due to resistance to change stemming from prior knowledge (Addido et al., 2022; Chiu et al., 2016; Duit & Treagust, 2003).

In this study, Conceptual Change Theory as a lens acknowledges that identifying misconceptions is a critical first step but that effective learning involves engaging PSBTs in a deliberate process of cognitive conflict. In assessing PSBTs' knowledge, the study examines the correctness of their ideas and the robustness of their conceptual frameworks. Moreover, Conceptual Change Theory reminds us that emotional, motivational, and epistemological factors influence learners' willingness to revise their conceptions (Sinatra & Pintrich, 2003). In the case of evolution, for instance, acceptance of scientific explanations may be influenced by religious or ideological beliefs (Barnes et al., 2017), meaning that purely cognitive interventions might not always lead to conceptual change without addressing these broader factors.

Thus, by framing the study within Conceptual Change Theory, the research emphasises the need to diagnose, confront, and reconstruct PSBTs' misconceptions about evolution and genetics in a structured, supportive, and reflective learning environment. Hence, we concur with Ohlsson's (2009) assertion that students do not simply restructure existing ideas but rather generate novel ones as their prevailing framework for explaining facts while preserving previous concepts that may be dormant or disguised.

On the other hand, Constructivist theory posits that the learner actively constructs knowledge (Vygotsky, 1962) and that the generation of information and the creation of meaning are rooted in personal or social experience. This implies that the constructivist theory emphasises that knowledge is not acquired passively but actively built by the individual (Treagust & Duit, 2009), and that cognitive function is adaptable, allowing the learner to create credible explanations of their experiences. Hence, constructivist teaching approaches consider the students' existing knowledge when they enter a learning environment (Hare & Graber, 2007). Nevertheless, caution should be exercised when implementing this approach, as students' efforts to understand unfamiliar material may lead to misconceptions if the class is poorly guided. This study utilises the constructivist approach to elucidate how PSBTs acquire knowledge of the concepts of evolution and genetics.

LITERATURE REVIEW

Teaching and learning of evolution and genetics

Teaching and learning genetics and evolution in Ghanaian schools remain significant concerns, mainly due to the complexity of the content, inadequate teacher preparation, and sociocultural factors (Cofie et al., 2021). Numerous studies conducted locally in Ghana and internationally have consistently shown that evolution and genetics are particularly challenging topics for teachers and students to grasp (Cofie et al., 2021; Deniz & Borgerding, 2018; Siani & Yarden, 2020; Wilmot, 2020). Several factors have been identified as contributing to these difficulties. These include the inherently complex nature of evolutionary concepts, limited content knowledge among teachers, the influence of strong fundamentalist religious beliefs held by both learners and educators, as well as the prevalence of essentialist and teleological thinking patterns that shape their understanding (Friedrichsen et al., 2018, p. 273; Kyriacou et al., 2015; Stern et al., 2018, pp. 4–5). Genetics is widely acknowledged as a conceptually challenging topic for students who consistently underperform on assessments in this area (WAEC, 2024). Similarly, evolution presents pedagogical difficulties rooted in both a lack of teacher content knowledge and deep-seated religious and cultural beliefs. In both topics, poor instructional approaches have been identified as central to learners' struggles. Research shows that genetics teaching in many classrooms continues to rely heavily on traditional methods that limit learner engagement and foster misconceptions (Ngwenya, 2020; Wilmot, 2020), a trend that is mirrored in how evolution is often taught in isolation, without connecting it meaningfully to broader scientific principles or evidence (Coleman et al., 2015; Ngwenya, 2020).

Teachers' pedagogical content knowledge (PCK) is critical in mediating how learners engage with genetics and evolution. In both cases, a teacher's depth of understanding directly influences the quality of lesson planning, delivery, and classroom activities (Hadiprayitno, 2019; Wilmot, 2020). However, many Ghanaian teachers lack both the content knowledge and pedagogical training required to teach these subjects effectively. For instance, evolution was only introduced into the national curriculum in 2008, meaning many teachers received no formal pre-service education on the topic (Holtman, 2010). This gap has forced them to teach unfamiliar content using untrained methodologies, often leading to fragmented or superficial instruction (Dempster & Hugo, 2006).

Compounding the issue, sociocultural factors deeply influence how both topics are received and understood. In evolution education, teachers' personal religious beliefs often conflict with scientific content, leading to biased or incomplete instruction. Some teachers hold fundamentalist Christian or Muslim views that hinder their acceptance and effective teaching of evolutionary theory (Naude, 2013). These beliefs may also discourage classroom dialogue on sensitive issues such as human origins or racialised interpretations of hominid evolution (Sutherland & L'Abbé, 2019). In genetics, while religious controversy is less prominent, the complexity of abstract concepts and their invisibility in everyday experience make them difficult to grasp without active, engaging teaching methods.

Prevalence of misconceptions about evolution and genetics among students

Misconceptions, also referred to as alternative conceptions, are deeply ingrained beliefs that learners hold prior to formal instruction and often conflict with accepted scientific knowledge (Chi, 2005; Duit & Treagust, 2003). In evolution and genetics, such misconceptions are widespread and persistent across educational levels, hindering meaningful learning and scientific reasoning (Matazu & Isma'il, 2024; Ojo, 2024).

Misconceptions often arise from a complex interplay of factors. External influences include the media, textbooks, and societal beliefs, which can present misleading or simplified narratives about evolution and genetics (Ferguson et al., 2022; Rice et al., 2015). For instance, many educational materials fail to adequately explain the mechanisms of evolution, leading students to cling to simplified or erroneous notions, such as the idea that humans evolved directly from monkeys or that evolution is a linear process aimed at perfection (Rice et al., 2015; Sanders & Makotsa, 2016). Furthermore, cultural beliefs, particularly those related to creationism, can strongly influence students' acceptance of evolutionary theory, leading to misconceptions that are resistant to corrections provided in formal education (Ramadani & Ibama, 2020).

Internally, students' pre-existing notions, often formed in early childhood, can shape their understanding of biological concepts. These intuitive beliefs may conflict with scientific explanations, making it difficult for students to shift their understanding (Coley & Tanner, 2015). For example, concepts such as adaptation may be misinterpreted through teleological reasoning, where students ascribe purpose to evolutionary changes rather than recognising them as outcomes of natural selection (Gresch, 2020; Nielson et al., 2025). As these misconceptions are often rooted in informal reasoning, they can persist even after formal instruction intended to clarify and correct them (Coley & Tanner, 2015).

Evolution-related misconceptions include the belief that evolution is goal-directed or that individual organisms evolve over their lifetimes, as well as confusion stemming from Lamarckian thinking and teleological reasoning (Bishop & Anderson, 1990; Gregory, 2009; Kampourakis & Zogza, 2009). Learners often misunderstand genetic mutation as purposeful and struggle with the population-level dynamics of natural selection (Southerland et al., 2001). Classroom language and textbooks often unintentionally reinforce these misconceptions (Sanders & Makotsa, 2016). A study by Yates and Marek (2015) revealed widespread misconceptions about biological evolution among pre-biology high school students, indicating a pervasive issue across K-12 education. Similarly, research involving Nigerian secondary school students indicated substantial gaps in understanding key concepts such as natural selection and genetic variation, further corroborating the prevalence of misconceptions within diverse educational contexts (Matazu & Isma'il, 2024).

In genetics, students frequently conflate genes with traits and misunderstand abstract processes like meiosis, gene expression, and genotype-phenotype relationships (Duncan & Tseng, 2011; Lewis & Wood-Robinson, 2000). They often view dominant alleles as "stronger" and misinterpret Punnett squares deterministically (Donovan & Venville, 2012).

Research conducted by Ojo (2024). showed that students exhibit significant misunderstandings in foundational genetics topics. Misconceptions about the principles governing heredity and genetic transmission underscore the need for more effective instructional approaches. Hence, Botes (2025) and Yaki (2022) advocated the use of virtual reality (VR) and an integrated STEM approach to biology learning to help students engage with the concept and understand it.

RESEARCH METHODOLOGY

Research design and participants

The study adopted a pragmatic, sequential, mixed-methods design (Dawadi et al., 2021), which is essential for exploring academic achievement and misconceptions about evolution and genetics among science students. This methodology integrates qualitative and quantitative approaches to provide a holistic understanding of these concepts' prevalence, nature, and influencing factors of misconceptions (Andrews et al., 2012). Data from both approaches corroborated findings and provided a comprehensive view through triangulation.

Sampling

The sample for the study was selected using purposive and convenience sampling for the quantitative study and an extreme case sampling strategy for the qualitative study (Onwuegbuzie & Collins, 2007). The participants (n=240) comprised a cohort of PSBTs majoring in Biology in the Bachelor of Science Education program at a university of Education in Ghana. The sample included 240 students in their second, third, and fourth years of study in the biology education department who had been taught the concept of Evolution and Genetics.

Instrumentation and procedure

The Test on Evolution and Genetics Concepts (TEGIC) was used to assess PSBTs' academic achievement in evolution and genetics. The TEGIC was constructed based on Haladyna's (2018) study, which provided guidelines for creating concept test items. The test questions were constructed based on the curriculum followed by the biology education department at the sampled university. The test questions were organised into three sections. Section A inquired about the demographic background of PSBTs. Section B of the test consisted of 20 multiple-choice questions on the concept of evolution. Finally, section C included 20 multiple-choice questions on genetics.

Three experts in biology education evaluated the 40-question concept items for clarity and coherence. The test was finalised by revising and modifying the wording of the questions. The test was then piloted with thirty (30) third- and fourth-year PSBTs (who were not part of the main study) to determine its reliability. Cronbach's alpha reliability coefficients were utilised to determine the test's reliability. A Cronbach's alpha of 0.75 was achieved, indicating that the test items were reliable. Test items were then administered to the participants (levels 200 (second years), 300 (third years), and 400 (fourth years) PSBTs).

PSBTs were then interviewed on evolution and genetics to understand the subject and thoroughly identify any probable misconceptions. The TEGIC test scores determined the sample for the interview. The researchers selected respondents from the following achievement range: (i) low achievers (n=9; for level 200, 300 and 400), (ii) middle achievers (n=9; for level 200, 300 and 400), and (iii) high achievers (n=9; for level 200, 300 and 400). All interviews were conducted face-to-face. Interviews were scheduled based on the PSBTs' own free time and set in a relaxed, comfortable environment, as suggested by Brinkmann and Kvale (2015).

The course structure and instruction

The Genetics and Evolution course for 2nd, 3rd and 4th-year PSBTs provides theoretical foundations in Mendelian genetics and evolutionary biology, enriched with simple, practical activities to strengthen students' understanding. Students are exposed to the fundamental mechanisms of inheritance, forms of genetics and phenotypic variation, and the forces influencing these variations over time. The course also covers prevailing theories and evidence of evolution, enabling students to analyse evolutionary sequences and their causes. Key topics include Mendel's principles, sex determination, linkage and crossing-over, chromosomal aberrations and mutations, variations, introductory applied genetics, the chemical basis of genetics (DNA replication, transcription, and protein synthesis), natural selection, theories of evolution, and speciation. Teaching is delivered through lectures and practical activities.

Data Analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS) (version 28) to conduct a one-factor ANOVA of the TEGIC test data. In addition, an independent-samples t-test was used to determine gender-related changes in PSBTs' understanding of the key concepts of evolution and genetics.

The interview data were captured in an Excel spreadsheet, following the 12 questions posed, and analysed using descriptive-interpretive analysis (Elliott & Timulak, 2021) to describe the interview data, which were commented on to suit the purpose of the study. Possible misconceptions were identified after analysing the PSBTs' responses to the interview questions. Responses were then classified as either correct or incorrect. Incorrect responses did not satisfy the expected response or contained inaccurate statements. The PSBTs' incorrect responses were then assessed to determine whether they represented alternative conceptions of factual scientific truth, which were considered misconceptions. Direct quotations were also provided to give an adequate definition and analysis of the findings, as Eldh et al. (2020) advised. Lastly, percentages were generated comparing PSBTs' misconceptions based on gender. The datasets were then triangulated by utilising two ways to examine the same phenomenon (PSBTs' understanding/knowledge of evolution and genetics concepts and their misconceptions), and we evaluated the results in line with previous research. Document analysis was conducted to determine the concepts of evolution and genetics taught at the institute.

Ethical considerations

One University is Ghana provided ethical approval for this study. Through an invitation letter and a direct explanation in the lecture room, the goal of this study and the procedures for data collection, analysis, and reporting were communicated to the PSBTs. Before they signed the consent form to participate in the study, the PSBTs were allowed to ask any questions they might have. We used pseudonyms for all participants to ensure the anonymity and confidentiality of our findings. Participants were informed that they could withdraw from the study without providing a reason and that all acquired data would be kept confidential and anonymous. All ethical concerns were addressed to ensure that no conflicts of interest compromised the validity (Atkins & Wallace, 2012) or credibility (Corbin & Strauss, 2008) of the study.

RESULTS

Quantitative results

In this study, the changes in PSBTs' misconceptions and academic achievement in genetics and evolution, based on gender and year of study, were examined.

Table 1 provides the PSBTs' profiles. There were a total of 240 PSBTs, comprising 196 males and 44 females. While all participating PSBTs were in their second, third, or fourth year of study toward a bachelor's degree in biology education, 80 out of the 240 PSBTs underwent a semester of school-based experience (teaching practice).

Table 1

Pre-service biology teachers' profiles

Level	Male	%	Female	%	Total	%
200	65	27	15	6.3	80	33.3
300	70	29	10	4.2	80	33.3
400	61	25	19	8.0	80	33.3
Total	196	81	44	19	240	100

The findings of the research questions are presented below.

RQ1: Do the academic achievement scores obtained by the pre-service biology teachers on the Test on Evolution and Genetics show any significant differences according to their gender and year of study?

In **Table 2**, the descriptive statistical distributions of PSBTs' academic achievement scores based on gender and year of study are shown. Level 200 (*M*=19.388; *SD*=6.523). Level 300 (*M*=17.978, *SD*=6.581). Level 400 (*M*=16.050, *SD*=5.405). For gender, level 200, male (*M*=19.939 *SD*= 6.497) female (*M*=16.667, *SD*=6.532). Level 300, male (*M*=17.629, *SD*= 6.350) female (*M*= 20.400, *SD*=9.766). Level 400, male (*M*=15.951, *SD*=5.255) female (*M*=16.368, *SD*=6.002). An independent t-test analysis was conducted to establish any significant difference between the mean scores of the male and female. The results are presented in **Table 3.**

Table 2

Descriptive statistics of TEGIC scores by gender and year of study

Level/Gender	N	Mean score	SD
Level 200	80	19.388	6.523
Level 300	80	17.975	6.581
Level 400	80	16.050	5.405
Level 200			
Female	15	16.667	6.532
Male	65	19.939	6.497
Level 300			
Female	10	20.400	9.766
Male	70	17.629	6.350
Level 400			
Female	19	16.368	6.002
Male	61	15.951	5.255

From **Table 3**, no significant difference in mean scores was observed (t(238) = 0.56, p = 0.58), despite males (M = 18.17, SD = 6.04) obtaining a higher mean score than females (M = 17.59, SD = 7.04). This finding demonstrates that there is no significant difference in conceptual understanding of evolution and genetics between males and females.

A one-way ANOVA performed on Tables 4 and 5 revealed a statistically significant difference in TEGIC scores between at least two groups (F (2, 237) = [5.675], p <.004). Tukey's HSD Test for multiple comparisons determined that the mean TEGIC score was significantly different between levels 200 and 400 (p = 0.003, 95% *CI* = [0.9918, 5.6873]). There were no statistically significant differences between levels 200 and 300 (p=0.332) or between levels 300 and 400 (p=0.131).

Consequently, the average academic success rates of PSBTs in genetics and evolution indicate that they have comparable levels of knowledge. No significant differences in academic success in evolution and genetics were observed among PSBTs by year of study or gender.

Table 3

Independent sample t-test analysis on gender

Gender	Variable	N	*M*	SD	t	df	Sig(tailed)
Male		196	18.17	6.04	0.56	238	0.58
Female		44	17.59	7.04			

A one-way ANOVA was performed to compare the performance of the three PSBT levels (200, 300, and 400) on TEGIC scores. ANOVA results are presented in **Tables 4 and 5**.

Table 4

Results of ANOVA of pre-service biology teachers' TEGIC test scores according to year of study

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	449.058[a]	2	224.529	5.675	.004
Intercept	76077.204	1	76077.204	1922.875	.000
GROUPS	449.058	2	224.529	5.675	.004
Error	9376.738	237	39.564		
Total	85903.000	240			
Corrected Total	9825.796	239			

Table 5

Results of ANOVA of pre-service biology teachers' TEGIC test scores according to year of study

(I) GROUPS	(J) GROUPS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper bound
Level 200	Level 300	1.4125	.99454	.332	-.9332	3.7582
	Level 400	3.3375*	.99454	.003	.9918	5.6832
Level 300	Level 200	-1.4125	.99454	.332	-3.7582	.9332
	Level 400	1.9250	.99454	.131	-.4207	4.2707
Level 400	Level 200	-3.3375*	.99454	.003	-5.6832	-.9918
	Level 300	-1.9250	.99454	.131	-4.2707	.4207

Qualitative results

What misconceptions do pre-service biology teachers have about Evolution and Genetics?

Table 6 shows the occurrence of misconceptions among PSBTs based on the six sub-concepts related to evolution and genetics. Table 6 is divided into two main categories: genetics and evolution. For each category, the sub-concepts are listed, and the number and percentage of individuals who have misconceptions about each sub-concept are presented according to gender and year of study. In general, there are variations in the prevalence of misconceptions across the different sub-concepts, study years, and genders.

Table 6

Pre-service biology teachers' misconceptions based on gender and year of study

	2nd Year					3rd Year					4th Year				
	Female		Male		T%	Female		Male		T%	Female		Male		%
Concepts & Sub-Concepts	n	%	n	%		n	%	n	%		n	%	n	%	
Genetics															
DNA replication	4	40	6	60	100	0	0	10	100	100	4	40	6	60	100
Blood group	2	20	7	70	90	5	50	5	50	100	6	60	4	40	100
Genetic crossing	3	30	7	70	100	8	80	2	20	100	1	10	9	90	100
Evolution															
Natural selection	7	70	3	30	100	1	10	7	70	80	5	50	5	50	100
Evolution of humans	6	60	0	0	60	2	20	7	70	90	6	60	3	60	90
Links between Genetic & Evolution	8	80	1	10	90	3	30	7	70	100	6	60	1	10	70
Total number of misconceptions	54					57					56				167

When the distribution of these misconceptions is analysed according to PSBTs year of study, 54 misconceptions were observed among PSBTs in their 2nd year of study, 57 misconceptions were observed for those in their 3rd year of study and 56 misconceptions for those in their 4th year of study. It was observed that 3rd-year PSBTs had the most misconceptions compared to the other groups. This could be because third-year students often face increased academic demands and a higher workload than earlier years. Juggling multiple courses and assignments can strain cognitive resources, making it challenging to retain information on topics such as genetics and evolution equally.

For genetics, the highest prevalence of misconceptions found in the sub-concept of DNA replication among the 2nd year PSBTs are the male with 6(60%) and the female with least percentage of 4(40%). In the 3rd year, misconception is prevalence in the male PSBTs more than the female with highest percentage of 10(100%) and the females with no misconception 0(0%). Among the 4th year PSBTs, misconception is again higher in males, with a percentage of 6(60%), than females with a percentage 4(40%). For blood groups as the second sub-concept under genetics the highest prevalence of misconceptions among 2nd year are the males with 7(70%) having misconceptions and 2(20%) constitute that of the females with the least misconceptions. In the 3rd year PSBTs, misconceptions are equal among the two genders with a percentage of 5(50%) for males and 5(50%) for females respectively. Then again, the 4th year PSBTs data, misconception is highest in the females with a percentage of 6(60%) than the males 4(40%). For genetic crossing among the 2nd year PSBTs' misconceptions is found highest in the males with a percentage of 7(70%) than the females with a percentage of 3(30%). Misconceptions on genetic crossing as a sub-concept under genetics among the 3rd year PSBTs are highest in females, with 8(80%), than in males, with 2(20%). In the 4th year, misconception is said to be highest among the males with 9(90%) and the females with 1(10%).

For evolution, the sub-concepts include natural selection, evolution of humans, and links between genetics and evolution. The highest prevalence of misconceptions in natural selection among the 2nd year PSBTs is found among females with the highest percentage of 7(70%) and males 3(30%). In 3rd year, misconceptions are highest in males than in females, with 7(70%) and 1(10%) respectively. Misconceptions are said to be equal in the 4th year among both genders, with 5(50%) and 5(50%) respectively. For the evolution of humans, the highest prevalence of misconceptions is found among the 2nd year females, where 6(60%) have misconceptions, compared to the males with no misconceptions. In the 3rd year, the highest prevalence of misconceptions is among the males with 7(70%) and the females 2(20%). In the 4th year, misconceptions are highest in the females with 6(60%) than the males 3(30%).

For links between genetics and evolution, the highest prevalence of misconceptions was found among 2nd year females, with a percentage of 8(80%) and among males, 1(10%). In the 3rd year, misconceptions are said to be highest among the males with 7(70%) than the females 3(30%). Lastly, misconceptions in the 4th year are highest in females with 6(60%), as compared to males with 1(10%).

A convergence of the findings appears that there are some gender and study year differences in the prevalence of misconceptions among PSBTs. However, it is important to note that the sample size is relatively small, and the results should be interpreted cautiously. In addition, when the results are analysed according to gender, 2nd, 3rd, and 4th-year females have a total of 30, 19, and 18 (46%) misconceptions, while 2nd, 3rd, and 4th-year males have a total of 24, 38, and 28 (54%) misconceptions, respectively.

Qualitative findings

The analysis of individual interviews provided more profound insight into PSBTs' misconceptions about evolution and genetics. Through careful coding and thematic analysis, several recurrent patterns of misconception emerged. These themes reflect specific scientific misconceptions and broader thinking patterns that influence learning in genetics and evolution. The participants were given pseudonyms as PSBTL201 to PSBTL425 (PSBTL2s in level 200), (PSBTL3s in level 300) and (PSBTL4s in level 400).

The following key themes were generated and are discussed below:

a) Misconceptions of evolutionary mechanisms.
b) Misconceptions about genetic inheritance.
c) Teleological and anthropocentric thinking.
d) The influence of prior knowledge and belief systems.

Each theme captures critical aspects of how PSBTs conceptualise core ideas in evolution and genetics, offering valuable insights into areas that require targeted instructional support to facilitate conceptual change.

Sub-theme 1: Misconceptions of evolutionary mechanisms

This theme highlights the prevalent misconceptions held by PSBTs about the mechanisms and principles underpinning evolutionary theory. The interviews revealed confusion between natural selection and adaptation, a limited understanding of the role of genetic variation, and a tendency to view evolution as a linear, progressive, and goal-directed process. Many PSBTs described evolution inaccurately as a process of increasing complexity or improvement of species over time. Evolution was often interpreted as a deliberate transformation, akin to metamorphosis, and not as a result of random genetic mutations, environmental pressures, and differential reproductive success. One PSBT has this to say: *Ah…well, to me, evolution is about changes that organisms undergo, beginning as a simple thing that gradually becomes more complex and may eventually evolve into somewhat more complex creatures* (PSBTL425).

PSBTL425 response reflects the common misconception that evolution is a unidirectional process aimed at complexity or improvement. This contradicts scientific understanding, which views evolution as non-linear and driven by environmental factors, not progression toward better organisms. One PSBTL410 shared his view: *Human evolution is linear, with a clear progression from simpler organisms to more complex ones and becoming more beautiful every generation.*

This comment indicates a belief that evolution has a predetermined goal or direction. The idea that humans are the *endpoint* of a linear chain oversimplifies the branching nature of evolutionary history and reflects a human-centred bias. PSBTL205 shared her sentiment: *Natural selection itself is complex. How come nature selects some organisms to survive while others do not? This means that natural selection will always lead to greater complexity…which means that natural selection is a random, deliberate, or purposeful process targeting unfortunate organisms.*

PSBTL205's narrative showcases multiple layers of misconception. She views natural selection as intentional or moralistic and incorrectly associates it with complexity as a guaranteed outcome. This anthropomorphises nature, treating it as an agent with intent rather than a mechanism based on environmental pressures and genetic variation.

These findings indicate that PSBTs carry forward deep-rooted misconceptions about evolution, shaped by prior knowledge, societal beliefs, and insufficient instructional scaffolding, which can pose a challenge to effective science teaching.

Sub-theme 2: Misconceptions about genetic inheritance

This theme captures the inaccurate beliefs held by PSBTs about how genetic traits are passed from one generation to the next. These misconceptions involve confusion surrounding fundamental genetics concepts, including dominant and recessive traits, gene expression, the structure and function of chromosomes and chromatids, and the processes of mitosis and meiosis.

Throughout the individual interviews, several recurring misconceptions were identified. While such notions are widely reported in the literature, they remain challenging to correct. One prevalent issue was the conflation of closely related genetic terms, where PSBTs incorrectly assumed that terms like chromosome and chromatid, or centrosome and centriole, were interchangeable. Moreover, there was a tendency among PSBTs to perceive DNA replication and cell division processes as flawless, error-free mechanisms, which contradicts the scientific understanding of mutation and genetic variation. Another common misconception was the oversimplification of inheritance patterns, particularly about blood group inheritance, where PSBTs failed to recognise the co-dominant nature of the ABO blood group system and the polygenic control of some traits. PSBTL301 narrated: *Ah…to me, I think since mitosis and meiosis all have to do with the cell dividing, I think the cells do not make mistakes when they start dividing. In other words, the process occurs free of errors.*

This response reflects a misconception that cellular processes, particularly mitosis and meiosis, are perfectly regulated and error-free. The PSBTL301 fails to recognise the possibility of mutations or errors during DNA replication or cell division, which are critical for understanding genetic variation and some genetic disorders. Another PSBT413 shared: *To me, I do not actually find any difference between these terms. The chromosomes and chromatids are essentially the same thing, and centrosomes and centrioles are essentially the same thing, and all are found in the nucleus of the cell.*

This illustrates conceptual conflation, in which the PSBT fails to distinguish between structurally and functionally distinct cell components. This misunderstanding can confuse understanding key genetic processes like chromosome segregation during mitosis and meiosis.

PSBT419 concurred: *Blood type is determined solely by the mother or the father's blood type and not a combination of their blood.*

This response demonstrates a fundamental misunderstanding of Mendelian inheritance and co-dominance. The PSBT assumes a one-parent blood type determination, neglecting both parents' genetic contributions and the interaction between multiple alleles (A, B, O) in determining the child's blood group.

These findings highlight persistent and overlapping misconceptions about genetic inheritance among PSBTs. The confusion between related terms and biological processes indicates that many PSBTs may memorise definitions without fully understanding the concepts. This suggests a need for instructional strategies that emphasise conceptual clarity, visual models, and interactive simulations to reinforce understanding.

Sub-theme 3: Teleological and anthropocentric thinking

This theme captures participants' tendency to assign purpose, intent, or human-like reasoning to evolutionary and genetic processes. It suggests that organisms change because they *need to* or that evolution happens with a specific goal. Several PSBTs displayed teleological reasoning, revealing a fundamental misconception of evolutionary processes' non-directional and non-purposeful nature. These participants often explained evolutionary change as a conscious, need-driven process and some expressed beliefs that align genetic changes with human desires or needs. These misconceptions indicate that intuitive and belief-driven reasoning still strongly influences conceptual understanding despite formal instruction. This form of reasoning may stem from everyday language, cultural beliefs, or prior learning that frames biological change in human-like terms. PSBTL320 narrated: *Giraffes grew longer necks because they needed to reach the tall trees for food. If they did not stretch, they would die, so nature helped them to change and so evolved.*

PSBTL320's explanation implies that evolution is a purposeful response to a need, suggesting Lamarckian thinking (use and disuse), which has been long debunked. It reflects a common teleological misunderstanding and a failure to grasp natural selection as a non-conscious process driven by variation and differential survival. Another PSBT has this to say: *Humans are the most evolved because we are smarter and can control other animals. Evolution made us the best species* (PSBTL208).

PSBTL208 uses anthropocentric reasoning, viewing evolution as a ladder culminating in human superiority. This interpretation reflects a progressivist misconception, which inaccurately presents evolution as a linear journey towards perfection or intelligence. Another PSBT has this to say: *I understand from the lessons so far that animals change their genes over time when the environment becomes harsh to survive better* (PSBTL217).

This response shows a belief in intentional genetic change, implying that organisms can consciously modify their genes in response to environmental stressors. This reflects a misunderstanding of how random mutations and selection pressures work in evolution and blurs the line between individual adaptation and generational genetic change.

Sub-theme 4: Influence of prior knowledge and belief systems

This theme covers PSBTs' prior knowledge and belief systems that influence their scientific understanding. The data revealed that many PSBTs' understanding of evolution and genetics was significantly influenced by their personal belief systems, religious upbringing, and prior informal learning experiences. One PSBT lamented: *I believe that God specially created humans, so I find it hard to accept that we came from apes, as we have been taught and read from textbooks for the past years of my schooling. This information does not match what I have always been taught in church* (PSBTL224).

PSBT's response reflects an apparent religious conflict with the scientific theory of evolution. The PSBTs' belief in special creation overrides the scientific explanation, indicating a faith-based resistance to evolutionary concepts. The phrase *what I have always been taught and read from textbooks* suggests deep-rooted prior knowledge that may hinder the acceptance or integration of new scientific perspectives. Another PSBT lamented: *In high school, we were told that evolution is just a theory, not something proven, so I never really took it seriously* (PSBTL202).

This statement points to misinformation or oversimplified teaching during earlier educational experiences. In a scientific context, misunderstanding the term *theory* reflects a linguistic and conceptual misconception reinforced by prior schooling. Another PSBT alluded: *My parents always said that genetics means you look like your parents, so I did not think it involved DNA and all that complicated stuff we are learning at school* (PSBTL214).

PSBTL214's understanding of genetics is shaped by informal family knowledge, which lacks scientific depth. The simplification of genetics to mere physical resemblance demonstrates how everyday explanations can lead to conceptual misconception when not clarified or corrected in formal education.

DISCUSSIONS

The study aimed to assess PSBTs' academic knowledge and misconceptions about evolution and genetics, guided by two research questions. Regarding the first research question, the findings from Table 3 revealed no statistically significant difference in conceptual understanding between male and female PSBTs, as indicated by $t(238) = 0.56$, $p = 0.58$, despite males obtaining a slightly higher mean score. This suggests that gender does not play a significant role in shaping academic success in genetics and evolution. Similarly, while a one-way ANOVA (Tables 4 and 5) showed significant differences among year groups ($F(2,237) = 5.675$, $p < .004$), the post hoc Tukey's test revealed that only the difference between second-year (level 200) and final-year (level 400) students was statistically significant. No significant difference was found between levels 200 and 300 or between levels 300 and 400. These findings collectively suggest that while some gains are made as students advance through their studies, overall, PSBTs exhibit comparable levels of academic knowledge, highlighting persistent challenges in fully mastering these concepts, leading students to cling to simplified or erroneous notions, such as the idea that humans evolved directly from monkeys or that evolution is a linear process aimed at perfection (Rice et al., 2015; Sanders & Makotsa, 2016).

From the perspective of Conceptual Change Theory (Posner et al., 1982), these results suggest that despite increased exposure to coursework, PSBTs may not be experiencing the deep restructuring of knowledge necessary for genuine conceptual understanding. According to the theory, meaningful learning requires dissatisfaction with existing conceptions and adopting new, intelligible, plausible, and fruitful scientific concepts. The limited differences across levels imply that instructional strategies may not sufficiently promote dissatisfaction with misconceptions or support the robust cognitive conflict necessary for conceptual change.

The second research question uncovered various misconceptions about evolution and genetics, which were further illuminated through thematic analysis. Four main themes were identified: misconceptions of evolutionary mechanisms, misconceptions about genetic inheritance, teleological and anthropocentric thinking, and the influence of prior knowledge and belief systems. These findings align with constructivist learning theory, which posits that learners construct new knowledge based on prior experiences and ideas. As Coley and Tanner (2015) emphasise, pre-existing intuitive beliefs often conflict with scientific explanations, making conceptual change particularly difficult.

For instance, many PSBTs exhibited misconceptions regarding evolutionary mechanisms, viewing evolution as a goal-directed process to produce more complex organisms. This finding is consistent with previous studies (Ferguson et al., 2022; Rice et al., 2015; Sanders & Makotsa, 2016) documenting widespread misunderstanding of evolution as linear progression rather than an adaptive response to environmental pressures. Similarly, misconceptions about genetic inheritance, such as the belief that acquired traits can be inherited, reflect deep-seated intuitive reasoning and reveal how students struggle to differentiate between phenotypic changes and genetic changes. The prevalence of teleological and anthropocentric thinking among PSBTs further underscores the challenge of overcoming intuitive but scientifically inaccurate explanations. As Gresch (2020) and Nielson et al. (2025) argue, students often attribute purpose or intention to evolutionary changes, which hinders their ability to grasp natural selection and random genetic mutation. Moreover, external influences, including religious beliefs and media portrayals, play a significant role in shaping misconceptions, as Ramadani and Ibama (2020) and Cofie et al. (2021) noted.

These findings highlight critical implications for teacher education programs. To foster genuine conceptual change, educators must design learning experiences that directly confront misconceptions, create cognitive dissonance, and support students in constructing scientifically accurate understandings. Strategies grounded in both conceptual change theory and constructivist principles, such as inquiry-based learning, concept mapping, and reflective discussion, could prove effective in addressing persistent misconceptions about evolution and genetics among pre-service biology teachers.

CONCLUSION AND RECOMMENDATIONS

This study examined the academic achievement of PSBTs by year of study and gender, and their misconceptions about evolution and genetics to measure conceptual change in this demographic. The literature establishes that learning is a process of conceptual change in which the student proactively revises and reorganises their pre-existing knowledge. However, teachers need to help their students recognise their preconceptions and offer them opportunities and motivation to modify them. In biology education, students' prior knowledge can help promote conceptual change. The misconception arises from confusion between the informal and scientific uses of scientific terms and concepts. Therefore, this study found no statistical difference in PSBTs' year of study or academic achievement. The study further established that there were no gender differences in the academic achievement of PSBTs. However, the study found differences in PSBTs' misconceptions according to gender.

A limitation of this study is that, although it involved 240 participants, they were all drawn from a single institution. This restricts the generalisability of the findings. Including participants from multiple universities would offer a broader, more representative understanding of misconceptions across diverse educational settings in Ghana and, potentially, across Africa.

Nonetheless, the outcomes of this study carry significant implications for science educators in classroom contexts. Firstly, the findings reveal that PSBTs' understanding of evolution and genetics is influenced by their academic level and gender, often resulting in conceptual inaccuracies. Teacher educators can leverage this insight to design targeted instructional interventions for specific evolution and genetics topics that students commonly struggle with. Biology teachers need to begin by identifying learners' pre-existing notions and misunderstandings before applying learner-centred teaching strategies to foster conceptual clarity and deeper engagement. Moreover, biology textbooks should undergo a thorough review and approval process by higher education institutions prior to being recommended for student use. Finally, researchers can further explore how students' comprehension of evolution and genetics develops, particularly how certain teaching materials or instructional gaps contribute to persistent errors in understanding.

In general, we advocate expanding the scope of evolution and genetics beyond the boundaries of biology so that teachers/lecturers in science-related disciplines can better interpret the broader cross-disciplinary implications of contemporary science discourse.

Acknowledgement

The authors would like to express their sincere gratitude to all the student teachers who volunteered for this study. We also acknowledge the constructive feedback from the critical reviewers, which guided us in improving this manuscript.

Funding

This study did not receive any funding from any institution to conduct this study.

Ethical statement

The study received ethical approval from the Research Ethics One University of Education in Ghana. Prior to data collection, formal permission was obtained from the relevant school authorities. Informed consent was obtained from all participating students. Participation in the study was entirely voluntary, and confidentiality and anonymity were assured. All data collected was used solely for research purposes.

Competing interests

No conflicts of interest, whether financial, personal or professional, related to this manuscript.

Author contributions

SB was responsible for conceptualising the research, designing the instruments, and writing the initial draft. RNKM was responsible for data collection, drafting the initial proposal for approval, and analysing data. All authors read, revised and approved the final version of the article.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AI disclosure

The authors used Grammarly, an AI tool, to enhance sentence structure and improve the manuscript's readability. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

Biographical sketch

Dr Sakyiwaa Boateng is a Senior Lecturer in Sciences Education at the Department of Mathematics, Science and Technology Education within the Faculty of Education at Walter Sisulu University, Mthatha, South Africa. She specialised in Physics Education. Her research interests include enhancing learner performance in science and teacher professional development, particularly examining the affective aspects that teachers consider essential for making teaching a worthwhile profession. She is also looking to break down the disjunction between science and culture and to focus on 21st-century teaching, science education, and teacher training. Her current research focuses on Mathematics and Science anxiety, and she is investigating interventions to build resilience in mathematics and science among pre-service science teachers and high school science learners.

Dr Rosemary Naana Kumi-Manu is a science educationist with a good track record in science educational research. She holds a PhD in science education from the University of Education, Winneba. Currently, she is a lecturer in the Department of Biology Education of the University of Education, Winneba. Her research interest revolves around motivation in science education, biology teacher education, and teacher training. She is committed to creating a positive and inclusive learning environment that supports students of all abilities. She is very passionate about science teacher professional development and teacher mentoring at all levels of education. Her current research focuses on science teachers' perception of mental health among senior high school students.

Disclaimer/Publisher's Note

The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and do not necessarily reflect the views of Lectito Publications and/or the editor(s). Lectito Publications and/or the editor(s) disclaim responsibility for any injury to persons or property resulting from any ideas, methods, instructions, or products referred to in the content.

REFERENCES

Addido, J., Burrows, A., & Slater, T. (2022). Addressing pre-service teachers' misconceptions and promoting conceptual understanding through the conceptual change model. *Problems of Education in the 21st Century, 80*(4), 499–515. https://doi.org/10.33225/pec/22.80.499

Adjapong, E. S. (2019). Towards a Practice of Emancipation in Urban Schools: A Look at Student Experiences Through the Science Genius Battles Program. *Journal of Ethnic and Cultural Studies*, *6*(1), 15–27. https://doi.org/10.29333/ejecs/136

Altunoğlu, B. D., & Şeker, M. (2015). The understanding of genetics concepts and learning approach of pre-service science teachers. *Journal of Educational and Social Research*, *5*(1 S1), 61. https://doi.org/10.5901/jesr.2015.v5n1s1p61.

Andrews, T., Price, R., Mead, L., McElhinny, T., Thanukos, A., Perez, K., … & Lemons, P. (2012). Biology undergraduates' misconceptions about genetic drift. *Cbe—life Sciences Education, 11*(3), 248-259. https://doi.org/10.1187/cbe.11-12-0107

Atkins, L., & Wallace, S. (2012). *Research methods in education: Qualitative research in education*, 29-46. https://doi.org/10.4135/9781473957602.

Barnes, M. E., Elser, J., & Brownell, S. E. (2017). Impact of a short evolution module on students' perceived conflict between religion and evolution. *American Biology Teacher*, *79*(2), 104-111. https://doi.org/10.1525/abt.2017.79.2.104

Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching, 27(*5), 415–427. https://doi.org/10.1002/tea. 3660270503

Botes, W. (2025). Pre-service science teachers' reflections on using virtual reality open educational resources in life science education. *European Journal of STEM Education, 10*(1), 17. https://doi.org/10.20897/ejsteme/17192.

Borgerding, L. A., Klein, V. A., Ghosh, R., & Eibel, A. (2015). Student teachers' approaches to teaching biological evolution. *Journal of Science Teacher Education*, *26*(4), 371-392. https://doi.org/10.1007/ s10972-015-9428-1.

Brinkman, S., Kvale, S. (2015). *InterViews: Learning the craft of qualitative research interviewing* (3rd ed.). Sage.

Buckberry, S., & Burke da Silva, K. (2012). Evolution: Improving the understanding of undergraduate biology students with an active pedagogical approach. *Evolution: Education and Outreach*, *5*(2), 266-273. https://doi.org/10.1007/s12052-012-0416-z.

Can, H. B., & Soylu, H. C. (2025). Examining the 5th grade science textbook learning units in the context of values: Türkiye century education model. *Asia Pacific Journal of Education and Society, 13*(2), Article 5. https://doi.org/10.20897/apjes/17468

Carney, R. (2022). *Identifying misconceptions about evolution relative to science curriculum exposure at the secondary level.* Graduate Research Papers. 2456. https://scholarworks.uni.edu/grp/2456

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences*, *14*(2), 161–199. https://doi.org/10.1207/ s15327809jls1402_1

Chisango, T., Maunganidze, L., Maseko, M., Muchena, B., Ncube, S., Hombarume, L., & Matanga, A. A. (2023). Racial misconceptions of the theory of evolution predict opposition to the theory and science in general among a sample of Zimbabwean university students. *Heliyon*. https://doi.org/ 10.1016/j.heliyon.2023.e16783.

Chiu, M., Lin, J., Yen, M., Liang, J., & Guo, C. (2016). Examining the factors that influence students' science learning processes and their learning outcomes: 30 years of conceptual change research. *Eurasia Journal of Mathematics Science and Technology Education, 12*(9). https://doi.org/10.12973/ eurasia.2016.000600a

Cofie, R., Sarfo, J. O., & Doe, P. F. (2021). Teaching and learning of genetics using concept maps: An Experimental study among midwifery students in Ghana. *European Journal of Contemporary Education*, *10*(1), 29-34. https://doi.org/10.13187/ejced.2021.1.29

Coleman, J., Stears, M., & Dempster, E. (2015). Student teachers' understanding and acceptance of evolution and the nature of science. *South African Journal of Education*, *35*(2), 1-9. https://doi.org/ 10.15700/saje.v35n2a1079

Coley, J. and Tanner, K. (2015). Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. *CBE—Life Sciences Education, 14(*1), ar8. https://doi.org/10.1187/cbe.14-06-0094

Corbin, J., & Strauss, A. (2008). *Basics of Qualitative Research. Techniques and procedures for developing grounded theory*, (3rd ed.). Sage

Dawadi, S., Shrestha, S., & Giri, R. A. (2021). Mixed-methods research: A discussion on its types, challenges, and criticisms. *Journal of Practical Studies in Education*, *2*(2), 25–36. https://doi.org/ 10.46809/jpse.v2i2.20

Demastes, S. S., Good, R., & Peebles, P. (1995). Students' conceptual ecologies and the process of conceptual change in evolution. *Science Education*, *79*(6), 637–666. https://doi.org/10.1002/ sce.3730790605

Dempster, E. R., & Hugo, W. (2006). Introducing the concept of evolution into South African schools: science education. *South African Journal of Science*, *102*(3), 106–112. https://hdl.handle.net/ 10520/EJC96530

Deniz, H., & Adibelli S. E. (2016). Exploring the factors related to acceptance of evolutionary theory among turkish preservice biology teachers and the relationship between acceptance and teaching preference. *Electronic Journal of Science Education*, 20 (4).

Dobzhansky, T. (1973). Is genetic diversity compatible with human equality? *Social Biology, 20(*3), 280-288. https://doi.org/10.1080/19485565.1973.9988055

Donovan, J., & Venville, G. (2012). Exploring the influence of the mass media on primary students' conceptual understanding of genetics. *Education 3-13, 40*(1), 75-95. https://doi.org/10.1080/ 03004279.2012.635058.

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*(6), 671-688. https://doi.org/10.1080/ 09500690305016

Duncan, R. G., & Tseng, K. A. (2011). Designing project-based instruction to foster generative and mechanistic understandings in genetics. *Science Education, 95*(1), 21–56. https://doi.org/ 10.1002/sce.20407

Eldh, A. C., Årestedt, L., & Berterö, C. (2020). Quotations in qualitative studies: Reflections on constituents, custom, and purpose. *International Journal of Qualitative Methods*, *19*. https://doi.org/10.1177/ 1609406920969268

Elliott, R., & Timulak, L. (2021). *Essentials of descriptive-interpretive qualitative research: A generic approach*. American Psychological Association. https://doi.org/10.1037/0000224-000

Elrod, S. (2008) 'Genetics concept inventory (GenCI) development. Paper presented at Conceptual Assessment in Biology Conference II, Asilomar, California. http://bioliteracy.net/ CABS.htm

Ferguson, D., Abele, J., Palmer, S., Willis, J., McDonald, C., Messer, C., … & Jensen, J. (2022). Popular media and the bombardment of evolution misconceptions. *Evolution Education and Outreach, 15*(1). https://doi.org/ 10.1186/s12052-022-00179-x

Ferrari, M., & Chi, M. T. (1998). The nature of naive explanations of natural selection. *International journal of science education*, *20*(10), 1231-1256. https://doi.org/10.1080/0950069980201005

Friedrichsen, P. J., Brown, L. G., & Schul, J. (2018). Project teach evolution: preparing biology pre-service teachers to teach evolution in Missouri, USA. In *Evolution education around the globe* (pp. 41-58). Springer, Cham. https://doi.org/10.1007/978-3-319-90939-4_3

Glaze, A., & Goldston, J. (2019). Acceptance, understanding & experience: Exploring obstacles to evolution education among advanced placement teachers. *The American Biology Teacher*, *81*(2), 71-76. https://doi.org/ 10.1525/abt.2019.81.2.71

Gregory, T. R., & Ellis, C. A. (2009). Conceptions of evolution among science graduate students. *BioScience*, *59*(9), 792-799. https://doi.org/10.1525/bio.2009.59.9.11

Gresch, H. (2020). Teleological explanations in evolution classes: video-based analyses of teaching and learning processes across a seventh-grade teaching unit. *Evolution Education and Outreach, 13(*1). https://doi.org/ 10.1186/s12052-020-00125-9

Grewe, F. (2025). The need for diffraction in STEM-fields: An ethical feminist consideration of the concept of gender scripting. *Feminist Encounters: A Journal of Critical Studies in Culture and Politics, 9*(2), Article 28. https://doi.org/10.20897/femenc/16786

Hadiprayitno, G., Muhlis, M., & Kusmiyati, K. (2019). Problems in learning biology for senior high schools in Lombok Island. *Journal of Physics: Conference Series, 1241*(1), 012054. https://doi.org/ 10.1088/1742-6596/1241/1/012054

Haladyna, T. M. (2018). Developing Test Items for Course Examinations. IDEA Paper# 70. *IDEA Center, Inc.*

Hanisch, S., & Eirdosh, D. (2020). Educational potential of teaching evolution as an interdisciplinary science. *Evolution: Education and outreach*, *13*(1), 1-26. https://doi.org/10.1186/s12052-020-00138-4

Hare, M. K., & Graber, K. C. (2007). Investigating knowledge acquisition and developing misconceptions of high school students enrolled in an invasion games unit. *The High School Journal, 90*(4), 1-14. https://doi.org/ 10.1353/hsj.2007.0015

Holtman, L. (2010). The teaching of Evolution in South African schools: challenges and opportunities. *Biology International*, *47*(1), 102-108.

Kampourakis, K., & Zogza, V. (2009). Preliminary evolutionary explanations: A basic framework for conceptual change and explanatory coherence in evolution. *Science & Education*, *18*, 1313-1340. https://doi.org/10.1007/s11191-008-9171-5

Karataş, A. (2020). Preservice science teachers' misconceptions about evolution. *Journal of Education and Training Studies*, *8*(2), 38-46. https://doi.org/10.11114/jets.v8i2.4690

Kırbaşlar, F. G., & Barış, Ç. Ç. (2016). The Investigation of pre-service science teachers' opinions on some of the biology and biotechnology concepts. *Journal of Educational and Social Research*, *6*(1), 9-9. https://doi.org/10.5901/jesr.2016.v6n1p9

Kyriacou, X., Beer, J. d., & Ramnarain, U. (2015). Evolutionary ideas held by experienced South African biology teachers. *African Journal of Research in Mathematics, Science and Technology Education, 19*(2), 118-130. https://doi.org/10.1080/10288457.2015.1014231

Lewis, J., & Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance—do students see any relationship? *International Journal of Science Education, 22,* 177-195. http://dx.doi.org/10.1080/09500690210126793

Martincová, R., Fančovičová, J., Iľko, I., & Peterková, V. (2022). The impact of evolutionary education on knowledge and understanding of evolution. *European Journal of Educational Research, 11* (2), 1063-1073. https://doi.org/10.12973/eu-jer.11.2.1063

Matazu, S. and Isma'il, A. (2024). Misconceptions about evolution in biology among secondary school students in Nigeria. *IJELS, 2*(7), 789-806. https://doi.org/10.59890/ijels.v2i7.1642

McComas, W. F. (2006). Science teaching beyond the classroom. *The Science Teacher*, *73*(1), 26. https://www.jstor.org/stable/24139113

MacFadden, B. J., Dunckel, B. A., Ellis, S., Dierking, L. D., Abraham-Silver, L., Kisiel, J., … & Koke, J. (2007). Natural history museum visitors' understanding of evolution. *BioScience, 57*(10), 875-882. https://doi.org/10.1641/b571010.

Naude, F. (2013). *Barriers in the teaching and learning of evolutionary biology amongst Christian teachers and learners*. University of Johannesburg (South Africa).

Nelson-Ebimie, D. M., Adolphus, T., Omeodu, D. M., & Naade, N. B. (2023). Identification of Biology Students' Misconceptions in Genetics Among Secondary School Students in Nembe Local Government Area in Bayelsa State. *Rivers State University Journal of Education*, *26*(1), 11-19. . Retrieved from: https://www.rsujoe.com.ng/index.php/joe/article/view/150

Ngwenya, P. (2020). *Life Sciences Teachers' Views on Teaching Socio-Scientific Issues in Genetics Using an Inquiry Approach*. University of Johannesburg (South Africa).

Nielson, C., Pitt, E., Fux, M., Nesnera, K. d., Betz, N., Leffers, J. S., … & Coley, J. D. (2025). Spontaneous anthropocentric language use in university students' explanations of biological concepts varies by topic and predicts misconception agreement. *CBE—Life Sciences Education, 24*(1). https://doi.org/10.1187/cbe.24-07-0198.

Ohlsson, S. (2009). Resubsumption: a possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20-40. https://doi.org/10.1080/00461520802616267

Ojo, A. (2024). Examination of secondary school students' conceptual understanding, perceptions, and misconceptions about genetics concepts. *Pedagogical Research, 9*(1), em0185. https://doi.org/10.29333/pr/14095

Onwuegbuzie, A. J., & Collins, K. M. (2007). A typology of mixed methods sampling designs in social science research. *Qualitative Report*, *12*(2), 281–316. https://doi.org/10.46743/2160-3715/2007.1638

Ozgur, S. (2013). The Persistence of Misconceptions about the human blood circulatory system among students in different grade levels. *International Journal of Environmental and Science Education*, *8*(2), 255-268. https://doi.org/10.12973/ijese.2013.206a

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: toward a theory of conceptual change. *Science Education, 66*(2), 211-227. https://doi.org/10.1002/sce.3730660207

Ramadani, S. & Ibama, L. (2020). Factors affecting student acceptance of evolution theory based on gender and educational background: a case study in Universitas Islam Madura, Indonesia. *Jurnal Pena Sains, 7*(1), 46-53. https://doi.org/10.21107/jps.v7i1.6846.

Rice, J., Clough, M., Olson, J., Adams, D., & Colbert, J. (2015). University faculty and their knowledge & acceptance of biological evolution. *Evolution Education and Outreach, 8*(1). https://doi.org/10.1186/s12052-015-0036-5

Rosengren, K. S., Brem, S. K., Evans, E. M., & Sinatra, G. M. (Eds.). (2012). *Evolution challenges: Integrating research and practice in teaching and learning about evolution*. Oxford University Press.

Rutledge, M. L., & Mitchell, M. A. (2002). High school biology teachers' knowledge structure, acceptance & teaching of evolution. The *American Biology Teacher, 64*(1), 21-28. https://doi.org/10.1662/0002-7685(2002)064[0021:hsbtks]2.0.co;2

Sadler, T. D. (2005). Evolutionary theory as a guide to socioscientific decision-making. *Journal of Biological Education*, *39*(2), 68-72. https://doi.org/10.1080/00219266.2005.9655964

Sanders, M., & Makotsa, D. (2016). The possible influence of curriculum statements and textbooks on misconceptions: the case of evolution. *Education as Change, 20*(1). https://doi.org/10.17159/1947-9417/2015/555

Shrestha, P., & Bhattarai, P. C. (2022). Application of case study methodology in the exploration of inclusion in education. *American Journal of Qualitative Research, 6*(1), 73-84. https://doi.org/10.29333/ajqr/11461

Siani, M., & Yarden, A. (2021). "I think that teachers do not teach evolution because it is complicated": difficulties in teaching and learning evolution in Israel. *International Journal of Science and Mathematics Education, 20(*3), 481–501. https://doi.org/10.1007/s10763-021-10179-w

Sinatra, G. M., & Pintrich, P. R. (Eds.). (2003). *Intentional conceptual change.* Routledge.

Southerland, S., Abrams, E., Cummins, C. L., & Anzelmo, J. (2001). Understanding students' explanations of biological phenomena: Conceptual frameworks or p-prims? *Science Education, 85(*4), 328–348. https://doi.org/10.1002/sce.1013

Sutherland, C. & L'Abbé, E. N. (2019). Human evolution in the South African school curriculum. *South African Journal of Science, 115*(7/8). https://doi.org/10.17159/sajs.2019/5672

Stern, F., Kampourakis, K., Huneault, C., Silveira, P., & Müller, A. (2018). Undergraduate biology students' teleological and essentialist misconceptions. *Education Sciences, 8*(3), 135. https://doi.org/10.3390/educsci8030135.

Treagust, D. F., & Duit, R. (2009). Multiple perspectives of conceptual change in science and the challenges ahead. *Journal of Science and Mathematics Education in Southeast Asia*, *32*(2), 89-104.

Vygotsky, L.S. (1962). *Thought and language.* MIT Press (original work published in 1934).

Wilmot, D. (2020). *Assessing biology teachers' PCK for teaching genetics at the senior high school level in Ghana* (Doctoral dissertation, University of Cape Coast).

WAEC (2024). Chief Examiners Report. https://waecgh.org/chief-examiners-report/

Yaki, A. A. (2022). Fostering Critical Thinking Skills Using Integrated STEM Approach among Secondary School Biology Students. *European Journal of STEM Education, 7*(1), 06. https://doi.org/10.20897/ejsteme/12481.

Yates, T. & Marek, E. (2015). A study identifyhttps://waecgh.org/chief-examiners-report/ing biological evolution-related misconceptions held by pre-biology high school students. *Creative Education, 06*(08), 811–834. https://doi.org/10.4236/ce.2015.68085

