Addressing conceptual difficulties in genetics through student-centered pedagogy: The case of thinking frames approach

American Journal of Education and Learning
Vol. 10, No. 2, 249-266, 2025
e-ISSN:2518-6647

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ABSTRACT

Genetics is a foundational concept in biology with far-reaching applications in health, agriculture, and forensic science. Despite its significance, students at the Senior High School level often struggle with conceptual understanding in genetics, resulting in poor academic performance. This study investigates the effectiveness of the Thinking Frames Approach (TFA), a student-centered instructional strategy grounded in constructivist theory, in addressing conceptual difficulties and improving performance in genetics. A quasi-experimental pretest-posttest non-equivalent control group design was employed, involving 200 SHS Biology students from two schools. The experimental group was taught using TFA, while the control group received conventional instruction. Data were collected using a validated Genetic Concept Test and analyzed using non-parametric statistical methods due to non-normal distribution. Results from the Wilcoxon Signed Rank Test revealed a statistically significant improvement in the experimental group's posttest scores ($p = .001$, $r = 0.87$), indicating the positive impact of TFA on student performance. Furthermore, the Mann-Whitney U Test showed no significant gender-based differences in posttest scores, suggesting that TFA fosters equitable learning outcomes. The findings underscore the pedagogical value of TFA in enhancing conceptual clarity and academic achievement in genetics, advocating its integration into biology instruction to promote inclusive and effective science education.

Keywords: *Academic performance, biology education, constructivist pedagogy, conventional method, gender differences, genetics, student-centered learning, thinking frames approach.*

DOI: 10.55284/ajel.v10i2.1604
Citation | Gyamfi, M., & Agyei, C. A. (2025). Addressing conceptual difficulties in genetics through student-centered pedagogy: The case of thinking frames approach. *American Journal of Education and Learning, 10*(2), 249–267.

Funding: This study received no specific financial support.
Institutional Review Board Statement: The study involved minimal risk and adhered to ethical guidelines for social science fieldwork. Formal approval from an Institutional Review Board was not required under the policies of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Ghana. Informed verbal consent was obtained from all participants, and all data were anonymized to ensure participant confidentiality.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study. Both authors have read and agreed to the published version of the manuscript.
History: Received: 23 July 2025/ Revised: 26 August 2025/ Accepted: 22 September 2025/ Published: 10 October 2025
Publisher: Online Science Publishing

Highlights of this paper

- This study demonstrates that the Thinking Frames Approach (TFA), rooted in constructivist pedagogy, significantly improves senior high school students' conceptual understanding and academic performance in genetics.
- Using a quasi-experimental design and non-parametric analysis, the research found a large effect size (r = 0.87) with no significant gender-based differences, highlighting TFA's potential for equitable science education.
- The findings advocate for integrating TFA into biology instruction to address persistent misconceptions and foster inclusive, student-centered learning environments.

1. INTRODUCTION

Genetics plays a crucial role in human health and reproduction, making it a core concept in biology that requires broad understanding (Ahmed, Opatola, Yahaya, & Sulaiman, 2018). Duncan, Freidenrich, Chinn, and Bausch (2009) describe genetics as the foundation of modern biology, highlighting its importance in achieving scientific literacy. Today, genetic knowledge is increasingly applied across diverse areas of society, including reproductive technologies, agriculture, healthcare, and forensic science, making the effective teaching and learning of genetics essential. Despite its significance, many students still struggle with the concepts of genetics taught in schools (Ahmed et al., 2018; Machová & Ehler, 2021). Research in the United Kingdom by Chu (2008) revealed persistent misconceptions and confusion about core genetic ideas, such as the structure and role of cells and their organelles, cell division (mitosis and meiosis), reproduction, probability, and mathematical reasoning. Similarly, Langheinrich and Bogner (2015) found that students' understanding of DNA structure is generally poor. Studies in Nigeria also show that learners face major challenges in genetics. For example, Ahmed et al. (2018) observed difficulties in students' conceptualization of DNA and RNA, while Ekong, Akpan, Anongo, and Okrikata (2015) reported that genetics-related questions often reduce overall biology performance. Kılıç, Taber, and Winterbottom (2016) further argued that these difficulties hinder students' ability to apply genetics in everyday contexts and to make informed decisions. Other studies confirm that many SHS Biology students experience similar conceptual barriers in genetics (Dzidzinyo, 2020; Hadiprayitno, Muhlis, & Kusmiyati, 2019). For instance, Dzidzinyo (2020) documented widespread misunderstandings of DNA, chromosomes, and genes among Ghanaian students. Beyond conceptual issues, gender remains a concern in science education, especially with the ongoing push to increase female participation in STEM-related careers. Historically, fields like medicine, engineering, and architecture were regarded as male-dominated, while careers such as nursing or catering were considered female-oriented (Tambaya, Alade, & Samaila, 2016). Evidence from Eseine (2021) suggests mixed findings regarding the influence of gender on academic achievement in genetics. Reports in Ghana indicate that students' difficulties in genetics persist year after year. The WAEC Chief Examiners' Report (2021) emphasizes students' continued weakness in answering genetics-related questions, despite consistent teaching. This raises important questions about the instructional methods being used. Whittle, Telford, and Benson (2018) argue that teaching approaches significantly shape conceptual understanding, and these can be broadly divided into teacher-centered and student-centered methods.

Teacher-centered approaches refer to traditional systems that place a strong emphasis on the teacher as an educator. In other words, while students work to achieve the teacher's objectives, the teacher adopts a directive role, plans activities for them to complete to meet the goals, manages student interaction, and uses extrinsic motivators to encourage learning, such as grades and marks through assessments (Thomas, 2013). Students only contribute to the learning process when asked to ask or respond to questions (Mackatiani, Imbova, & Wambua, 2018). On the other hand, student-centered teaching methods put the student at the center stage of the lesson (Ampiah, 2004). The teacher only plays the role of a guide, coach, or facilitator. The teacher provides materials, gives directions, asks questions, and encourages students' discovery in the classroom (Fernando & Marikar, 2017). Student-centered approach puts the student at the center of the educational process. With each student contributing to the learning process, the student-centered teaching style fosters more harmony between the teacher and student (Mackatiani et al., 2018). Thus, students decide what they need to know and do to respond to a central question, but under the guidance of the teacher. Therefore, many curricula have recommended the utilization of student-centered teaching methods to increase students' achievements.

Given that a teacher's instructional approach has a significant impact on students' academic performance, the Ghanaian Senior High School Biology syllabus advises teachers to employ constructivist teaching methodologies to maximize conceptual understanding of biology concepts (CRDD, 2012). In order to address the problem of students' poor performance in biology, it is reasonable to consider successful constructivist teaching strategies used in other nations while instructing biology topics. Science education studies indicate that student performance improves when constructivist, student-centered teaching techniques are employed (Adak, 2017; Magak, 2016).

One of these student-centered approaches that has been found to improve students' performance is the Thinking Frames Approach (TFA).

The TFA is a multifaceted approach to conceptual change that stimulates students' interest and cognitive processes by presenting contradictory ideas, scaffolds the development of explanations by producing multiple written, visual, and verbal representations of explanations, supports co-construction of understanding through small group interactions and the teacher's careful questioning techniques, and provides opportunities for self-reflection and explanation evaluation (McLure, Newberry, & Gilbert, 2020).

There is, therefore, a compelling need to explore alternative and evidence-based instructional approaches, such as the Thinking Frames Approach, that can enhance conceptual clarity and improve student performance in genetics. Hence, the need for this study.

1.1. Purpose of the Study

The purpose of this study is to assess the effect of the thinking frames approach on senior high school students' performance in genetics.

1.2. Research Questions of the Study

The following research questions grounded the study.

1. What is the effect of the thinking frames approach on students' performance in genetics?
2. What difference exists between the academic performance of male and female biology students instructed with the thinking frames approach in genetics?

2. LITERATURE REVIEW

2.1. Conceptual Framework of the Study

The constructivism theory, which was used to drive the study, asserts that people build their own knowledge of the world as they engage in experiences and reflect on those experiences, which is fundamental to understanding how people perceive the world (Woolfolk, 2016). According to the constructivist theory of learning, students generate insight and significance derived from their encounters by working in groups or independently on a variety of learning tasks (Kazeni & Onwu, 2012). This theory served as the foundation for conceptualizing how the research variables interacted, as shown in Figure 1.

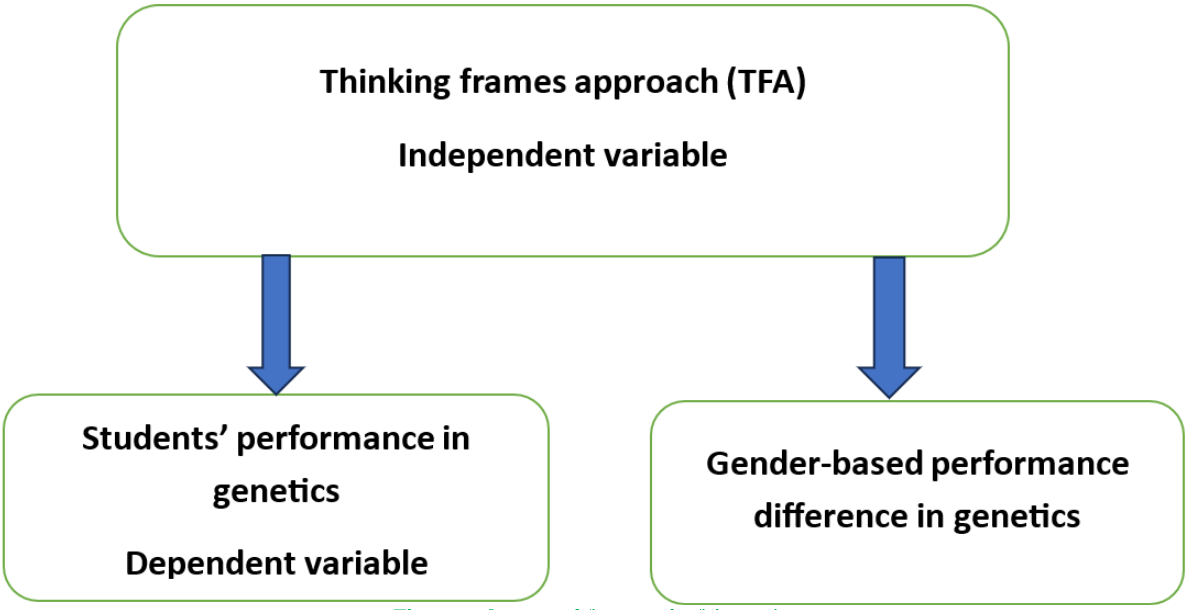

Figure 1. Conceptual framework of the study.

The conceptual framework for this study is built around the central premise that the Thinking Frames Approach (TFA) serves as the core instructional strategy designed to improve students' understanding of genetics. From this central intervention, the framework shows two primary outcome variables (dependent variables) that the study seeks to investigate. The first is students' academic performance in genetics, which reflects their conceptual understanding and achievement after being taught using TFA. This performance was quantitatively measured through pretests and posttests. The assumption is that the structured and guided nature of TFA enhances comprehension, retention, and application of genetics content. The second outcome focuses on gender-based differences in performance, aiming to explore whether male and female students benefit equally from the Thinking Frames Approach. This component is important for addressing issues of equity and inclusion in science education.

2.2. The Thinking Frames Approach

According to McLure et al. (2020), the TFA is a comprehensive approach to conceptual change that facilitates co-construction of understanding through small group interactions and the teacher's careful questioning techniques. It engages students' interest and cognition by presenting disparate events, scaffolds explanation development by producing multiple representations of explanations in verbal, pictorial, and written modes, and offers opportunities for self-reflection and explanation evaluation. TFA teachings are composed of the following elements:

1. *Setting the scene (PDEODE and group/whole-class discussion):* Students are divided into small groups and given a scenario that aims to refute other ideas about the subject. They discuss their predictions and the reasons behind them in small groups before presenting their ideas to the class. Following the teacher's demonstration (or description of a scenario's outcome), the students provide an explanation that aligns with their observations. The class is then given these updated explanations.
2. *Brainstorming*: Students are assisted in developing explanations by the teacher's thought-provoking questions, which connect explanations to observations and the ontological model.
3. *Written and visual explanations:* Students choose the keywords they want to use while writing explanations. Individual diagrammatic explanations are constructed by small groups. A detailed written description of the phenomenon is then created when understanding has been converted into a logical series of brief dot points (Treagust, Chittleborough, & Mamiala, 2018). It has been demonstrated that producing student-generated

multiple representations encourages students to participate more thoroughly in the construction of explanations and supports their adoption of higher levels of explanation, such as the more frequent use of causal statements and non-visible entities (Chang, Sung, & Chen, 2016; McLure et al., 2020). As students create multiple representations of what they understand, the teacher moves between groups and utilizes questioning to encourage further elaboration of ideas.

4. *Thinking Sequence and Paragraphing:* Students create dot points for "what happens" and "why" based on the visual depiction of concepts and important words. Students then write a paragraph explaining the phenomenon and responding to the initial questions using the keywords that were thus generated.
5. *Feedback from the teacher*: The instructor assesses the students' explanations, offers detailed, helpful criticism on how the students can enhance their explanations in studying.
6. *Progressive development of conceptual knowledge over time:* Each topic is covered by a set of TFA lessons that help students enhance their knowledge of various facets of the theoretical scientific model.

2.3. Students' Conceptual Difficulties in Genetics

Genetics is often seen as one of the toughest topics in secondary school biology. For many Senior High School (SHS) students, the subject feels abstract, layered with complex ideas, and demanding in its reasoning. Even after formal lessons, misunderstandings about genetics remain stubbornly common, showing up repeatedly in classrooms across the world (Chapman & Martin, 2021). These misconceptions don't just make it harder for students to grasp the content; they also limit their ability to connect genetic concepts to everyday life and real-world problems.

One of the most persistent sources of confusion is the idea of dominance and recessiveness. Many students come away thinking dominant traits are "stronger" or more common in a population, while recessive traits are "weaker" or less important (Lewis & Kattmann, 2004). The problem often starts with how these terms are introduced. Textbooks and teachers may unintentionally reinforce these ideas by not making it clear that dominance is simply about how two alleles interact, not about the importance, strength, or frequency of a trait.

Students also frequently struggle with understanding how traits are inherited. A common misconception is the belief that every trait comes from a single gene and neatly follows Mendel's rules. While that model is a useful starting point, it doesn't reflect the complexity of most traits, which can involve many genes (polygenic inheritance), show patterns like incomplete dominance or codominance, or be influenced by epigenetic factors (Gericke & Wahlberg, 2013). On top of that, students often confuse the terms "genotype" and "phenotype," using them interchangeably without recognizing that one describes the genetic code and the other the traits we can actually observe. These are two connected but distinct concepts.

2.4. Impact of Thinking Frames Approach in Science Classrooms

The Thinking Frames Approach (TFA) first gained widespread use in the United Kingdom through the *Learning to Learn* project, led by McClure, Newbery, and Bird (2008). In this initiative, schools integrated thinking frames across different subjects, including science, to encourage structured reasoning and independent thinking. The results were encouraging: students using TFA produced more coherent explanations, expanded their scientific vocabulary, and were better able to justify their ideas. Teachers noted that TFA worked well for learners of all abilities by providing a consistent structure for expressing understanding (Newberry, Gilbert, & Bird, 2007; Newberry, Gilbert, & McClure, 2011). A key insight from the project was that when teachers actively modeled the use of thinking frames, students not only mastered the method but also began applying it in different scientific contexts on their own.

Follow-up studies have reinforced these findings. Higgins and Baumfield (2004) observed substantial gains in students' ability to explain and reason scientifically when TFA was used in both primary and secondary science classrooms. They also found that the approach strengthened assessment for learning because students' thinking was visible, teachers could more easily identify misconceptions, give timely feedback, and adapt lessons to meet different needs.

TFA has also proven valuable for more complex topics. Duit and Treagust (2012) used it to develop systems thinking in environmental science lessons covering biodiversity, pollution, and climate change. Students who used cause–effect and systems-thinking frames gained a deeper grasp of how environmental systems interact and could explain interdependencies with greater clarity. This resonates with Andrade, Cook, and Page (2016) work, which shows that metacognitive strategies like TFA help students reflect on and regulate their thinking, especially in tasks requiring explanation, evaluation, and argumentation.

More recently, Karamustafaoğlu and Kandaz (2022) investigated Turkish science teachers' views on using visual thinking tools such as TFA. Teachers appreciated the way it simplified challenging ideas, encouraged lively class discussions, and supported all learners, particularly those starting with limited background knowledge. Similarly, Treagust et al. (2018) explored the use of TFA in teaching cell biology and reported significant gains in conceptual understanding and retention. Students were able to build their knowledge step-by-step, linking abstract concepts to real-world examples. In the case of genetics education, the study found a statistically significant boost in performance after TFA was introduced, with a Wilcoxon Signed Rank Test showing $p = .001$ and $r = 0.87$. These results align with recent literature emphasizing the benefits of structured thinking tools for improving science learning (McLure et al., 2020; Ng & Chan, 2021).

Other research further supports this integration. Tang (2016) highlights how generative learning strategies such as drawing, summarizing, and explaining concepts within TFA promote deeper thinking and long-lasting learning. Alvermann and Moore (2022) also argue that graphic organizers and visual scaffolds, like thinking frames, are powerful tools for developing scientific literacy, enabling students to move beyond simple description toward more analytical, explanatory, and argumentative writing skills essential for success in modern science education.

2.5. Gender Differences in Science Achievement: A Focus on Biology and Genetics

Gender differences in science education, especially in student achievement and engagement, have been a long-standing focus of educational research. While some studies show that the gender gap in science performance has narrowed over time (Etobro & Fabinu, 2017), others point out that certain disparities persist, particularly in specific science domains at the secondary school level (Fikadu & Shimeles, 2019). Biology is often described as a "female-friendly" subject, but a closer look reveals a more complex picture. In subfields like genetics, which demand abstract thinking, symbolic reasoning, and model-based problem-solving, performance patterns are not always consistent with the broader trend.

Large-scale international assessments such as TIMSS and PISA have shown that boys often outperform girls in physics and chemistry, while girls tend to match or slightly exceed boys' performance in biology-related assessments (Mullis, Martin, & Foy, 2020; OECD, 2019). However, this advantage does not necessarily extend to all areas of biology. Genetics, for instance, presents unique conceptual challenges that can interact with gender-linked learning approaches. Research suggests that female students are often strong in rote memorization, attention to detail, and reading comprehension skills that serve them well in descriptive aspects of biology (Brotman & Moore, 2008). By contrast, tasks in genetics often require abstract reasoning, symbolic manipulation, and diagrammatic interpretation, areas where male students are sometimes found to excel (Wilgenbusch & Finson, 2000). This difference may help explain why gaps emerge in topics such as Mendelian inheritance, constructing Punnett squares, and calculating allele frequencies.

Gericke and Wahlberg (2013) studying Swedish upper secondary students, found that boys were generally more confident and accurate in solving genetics problems involving symbolic representations and probability. Girls, while showing strong descriptive understanding, were less assured when dealing with abstract model manipulation. This finding mirrors Zohar and Sela (2003) observation that gender-related gaps often reflect differences in cognitive orientation rather than innate ability; boys tend toward systematic, rule-based reasoning, and girls lean toward contextual or narrative explanations.

In African contexts, socio-cultural norms and classroom dynamics can amplify these disparities. Adesoji and Raimi (2020) in a study of Nigerian senior secondary students, reported that boys outperformed girls on multi-step genetics problems, especially those requiring translation from genotype to phenotype. They linked these differences to gender-biased teacher-student interactions, societal expectations, and unequal access to enrichment opportunities such as science clubs and competitions.

Yet, the research is not all one-sided. Multiple studies show that when teaching methods are equitable and engaging, such as using thinking frames, inquiry-based learning, and collaborative approaches gender gaps in performance often shrink. For instance, McLure et al. (2020) found that the Thinking Frames Approach (TFA) boosted achievement for both male and female students in biology, chemistry, and physics, with notable gains in confidence when tackling abstract concepts. Similarly, Etobro and Fabinu (2017) and Achor (2024) have shown that well-structured scaffolding can provide both boys and girls with the tools they need to approach complex science problems more effectively.

3. METHODOLOGY

The research design employed for this study was the quasi-experimental pretest/posttest non-equivalent control group design. The choice of this design is based on the fact that this study aimed to make causal inferences by comparing pretest and posttest scores to determine the effect of the Thinking Frames Approach (TFA) and the conventional teaching method on the academic performances of SHS Biology students (Cohen, Manion, & Morrison, 2018).

The sample size for this study comprised 200 SHS 3 Biology students from six intact classes selected randomly from two participating schools. That is, three intact classes from each school were sampled. In effect, there were a total of 114 males, while 86 were females. The two sampled schools were Amaniampong Senior High School and St. Joseph Seminary Senior High School in the Ashanti Region of Ghana. The distribution of participants according to school and gender is tabulated in Table 1.

Table 1. Participants' distribution according to school and gender.

School	Number of male participants	Number of female biology participants	Total number of participants
Amaniampong Senior High School	47	35	114 Males
St. Joseph Seminary Senior High School	67	51	86 Females
Total	**114**	**86**	**200**

3.1. Research Instruments

This research employed one research instrument, namely, the Genetic Concept Test (GCT). The GCT comprised five (5) essay-type questions. The use of essay formats was based on the assertion of Oduro-Okyireh and

Annor (2018), who argue that essay test items reflect student knowledge of a subject much better than multiple-choice questions, and therefore are the best format for testing higher-order behaviors and mental processes such as analysis and evaluation.

3.2. Validity of the Instruments

Biology tutors and seasoned researchers were given the achievement test to provide their opinions and suggestions regarding the item suitability for evaluating the constructs that the instruments were designed to examine. This was carried out in order to assess the instruments' validity. Five experts were invited to assess the instruments, and during the assessment of the instruments by the experts, they were asked to rate the achievement test and interview guide based on their relevance, appropriateness of items, factual inaccuracies, grammatical errors, and whether the content aligns with the syllabus. Therefore, items were rated as essential or non-essential. Afterwards, Lawshe (1975) content validity ratio (CVR) was used to determine the content validity of the GCT and interview guide. To determine the CVR, the Content Validity Index (CVI) was calculated for each item on the instrument. The CVRs of the GCT and interview guide were then determined by dividing the overall CVI by the total number of item. Table 2 presents the Content Validity Ratio and Content Index for GCT.

Table 2. Content validity index and content validity ratio of GCT.

Item	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5	Agreement	CVI
1	X	X	X	X	X	5	1.00
2	X	X	X	X	X	5	1.00
3	X	X	X	X	X	5	1.00
4	X	X	X	X	X	5	1.00
5	X	X	0	X	X	4	0.80
CVR							**0.96**

According to Almanasreh, Moles, and Chen (2019) CVR varies between 1 and −1, where high values of CVR indicate the agreement of experts on the relevance of an item in the instrument. Therefore, as seen from Table 2, the CVR value for GCT was 0.96, which indicates a valid instrument.

3.3. Reliability of Research Instrument

The GCT was pilot-tested using a sample size of 41 students who did not participate in the main study. Since the pilot study's responses were essay-style, two raters were tasked with evaluating the completed items to assess the reliability of the research tools. Thus, using the inter-rater reliability method and Cohen's kappa (Cohen and Cohen, 1983), the scores from the two raters were used to ascertain the internal consistency of the item scores. Table 3 displays the findings of the kappa measure of agreement between the two raters.

Table 3. Inter-rater reliability of genetic concept test.

		Value	Approximate significance
Measure of agreement	Kappa	0.751	0.001
N of valid cases		41	

The Kappa measure of agreement for the scores of the two raters on the GCT was 0.751, which Kottner et al. (2011) interprets as substantial agreement. This suggests that the GCT was a trustworthy tool for the primary investigation.

3.4. Data Collection Procedure

As previously mentioned, the data collection process enabled the researcher to gather quantitative data. Three steps comprised the data collection process.

3.5. Pre-Intervention Stage

The headteachers of the schools chosen for the study were formally asked for their consent. These schools' biology teachers were duly informed as well. Teachers, administrators, and students from the sampled schools were assured of the confidentiality of the student data and the study's findings, as well as the study's significance and implications. Following the approval of various authorities, three intact SHS 3 biology classes from each school were chosen using simple random sampling, and they were divided into experimental and control groups.

The sampled schools were then visited to begin the pretest. To ensure that students were prepared for the pretest, students were informed one week prior to the conduction of the pretest. The purpose of the pretest was to ensure that all participants performed approximately equally before the intervention. The researcher distributed the pretest with the help of the sampled schools' biology tutors. The pretest was administered, and students in both groups had 45 minutes to complete the questions.

3.6. Intervention Stage

The second stage, which is the intervention stage, commenced after the successful completion of the pretest. To account for teacher differences, the researcher taught the subject matter to both groups during this stage. Throughout the intervention, both the experimental and control groups received the same content; however, the experimental group was instructed using the Thinking Frames Approach, while the control group was taught using traditional methods. A summary of the various content covered during the research, along with the treatment activities for the experimental and control groups, are illustrated in Table 4 and 5, respectively.

Table 4. Content of genetics taught to participants (Students).

Specific objectives	Content
The student will be able to:	
1. Explain and define some terms used in genetics with examples	Definition of terms with examples
2. Explain the basis of heredity and the concept of inheritance.	Heredity and Inheritance
3. Explain how hybrids are formed and Gene interacts	Hybrid formation and gene interaction
4. Explain variation, causes of variation consequences of variation and DNA recombinant.	Variation, causes of variation, consequences of variation and DNA recombinant.

3.7. Intervention Activities

Since the various groups were exposed to different treatments (teaching methods), treatment activities therefore differed across the two groups, such as the Thinking Frame Approach and the Conventional group. Tables 5 and 6 highlight the treatment activities for all groups.

Table 5. Intervention activities for thinking frames approach.

TFA steps	Teacher and students activities
1. Setting the Scene (PDEODE) group/whole-class discussion	a) The teacher challenges alternate conceptions with a hands-on example in a real-world setting. b) To describe what transpired during the demonstration, students collaborate in groups and apply the Predict, Discuss, Describe, Observe, Discuss, and Explain (PDE) framework. Based on the observations, groups employ argumentation to generate a verbal response to a higher-level thinking question, which is then presented to the class. The teacher leads students to think about the scientific model by asking questions.
2. Brainstorming	Students collect terms and expressions that they think will help them answer the issue.
3. See/Visualise	Students use labeled diagrams or visual timelines to create and convey their spoken representations.
4.Think/Sequence	Students create dot points for "what happens" and "why," building on the visual depiction of concepts and important terms. Students then write a paragraph explaining the phenomena and responding to the first questions using the main ideas that were thus generated.
5. Evaluation	The teacher assesses students' work based on how well they used scientific language and how well their explanations addressed cause and effect.

Source: Mclure (2020).

Teaching method introduced to the control group was mainly teacher-centered, specifically, lecture, as presented in Table 6.

Table 6. Intervention activities for conventional group.

Stage	Activities
Stage 1 Introduction	The teacher presented the lesson to the students.
Stage 2 Development	The teacher explained key points and wrote notes for students to copy.
Stage 3 Application	The teacher gave students in-class examples and questions to solve.
Stage 4 Evaluation	Using both formative and summative assessment techniques to determine the achievement of lesson objectives.

3.8. Post-Intervention Stage

Following the intervention phase, a posttest was administered, and students in the experimental and control groups had sixty minutes to complete it..

3.9. Data Analyses Procedure

This study adopted a quasi-experimental design with a quantitative approach; therefore, data were analyzed quantitatively. To process, manipulate, and analyze the scores from the pre-intervention test and post-intervention test, descriptive and inferential statistical techniques were employed via Statistical Package for Social Sciences (SPSS) version 27.

3.10. Research Question 1

What is the effect of the thinking frames approach on students' performance in genetics?

Research question one was answered using the Wilcoxon signed-rank test to analyze the effect of TFA on SHS biology students' performance in genetics. The Wilcoxon signed-rank test was performed because the data was not normally distributed.

3.11. Research Question 2

What difference exists between the academic performance of male and female biology students instructed with the thinking frames approach in genetics?

Research question 2 was analyzed using the Mann-Whitney U test to evaluate the difference in academic performance between males and females instructed using TFA. The Mann-Whitney U test was performed because the data was not normally distributed.

4. RESULTS

4.1. Demographic Characteristics

The gender distribution within both the experimental and control groups is a critical component of the study's analysis; it provides insights into the demographic composition of each group and sets the stage for a more nuanced interpretation of academic performance outcomes. Figure 2 depicts the distribution of gender.

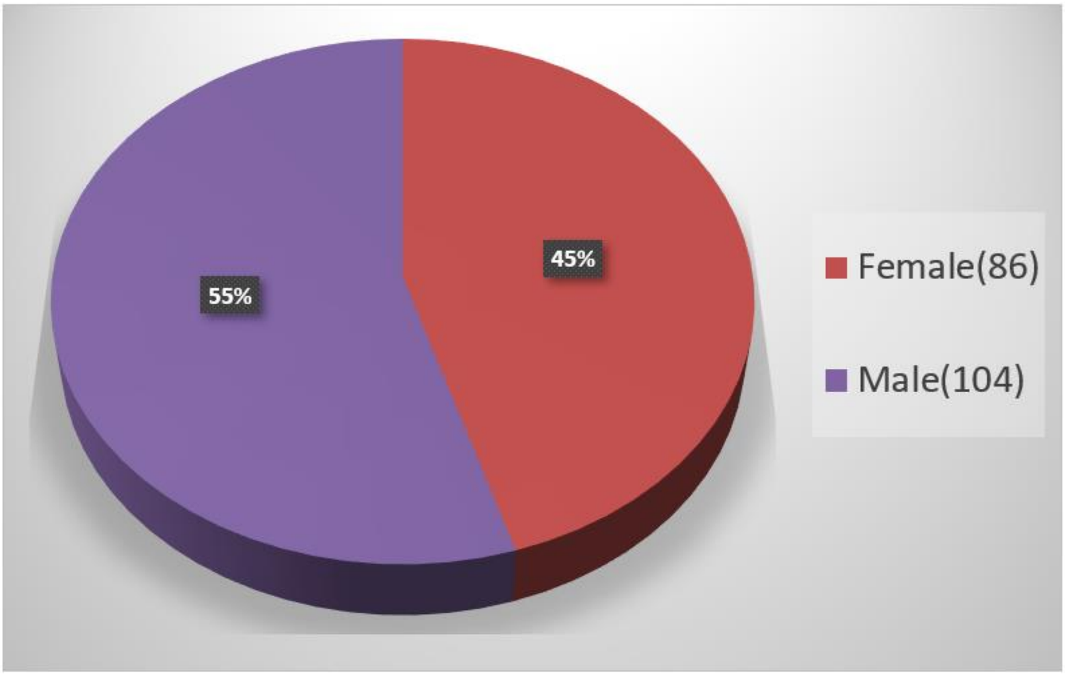

Figure 2. Gender distribution of participants.

Figure 2 presents the gender distribution of the participants in the study. Out of the total sample of 200, 43% (86) of the participants were females, while 57% (114) were males. This distribution indicates a higher representation of male students compared to their female counterparts in the study sample.

4.2. Data Suitability

Prior to analysing the study's outcomes, normality tests were performed to ensure that the data was suitable. The findings are presented in the following subsection: The scores from the students in this study were subjected to a normality test to determine whether parametric or non-parametric tests should be used. Normality checks were carried out utilizing the numerical approach. Thus, mathematically, the Kolmogorov-Smirnov and Shapiro-Wilk tests were performed. Normality tests were performed under the null hypothesis that the data sets are normally distributed (Pallant, 2011). This indicates that the null hypotheses are rejected when the Kolmogorov-Smirnov test yields a p-value larger than 0.05. Table 7 presents the results of the normality tests.

Table 7. Results of normality on students' scores.

Groups	Kolmogorov Smirnov			Shapiro-Wilk		
	Statistic	**Df**	**Sig.**	**Statistic**	**Df**	**Sig.**
Pretest of experimental group	0.124	96	0.001*	0.934	96	0.001*
Posttest of experimental group	0.168	96	0.001*	0.912	96	0.001*
Pretest of control group	0.096	96	0.030*	0.972	96	0.035*
Posttest of control group	0.135	96	0.001*	0.956	96	0.003*

Note: a. Lilliefors significance correction.
*Significant since p < 0.05.

Table 7 presents the results of normality tests (Kolmogorov-Smirnov and Shapiro-Wilk) conducted to assess whether students' pretest and posttest scores were normally distributed for both the experimental and control groups. Across all groups, the significance values (p-values) for both tests were less than .05. The experimental group's pretest and posttest scores had Shapiro-Wilk p-values of .001, and the control group's posttest score had a Shapiro-Wilk p-value of .003. Since all p-values are below the threshold of .05, the assumption of normal distribution is violated. This justified the use of non-parametric statistical tests such as the Wilcoxon Signed Rank Test and the Mann-Whitney U Test for further analysis in the study.

4.3. Results for Research Question 1

What is the effect of the thinking frames approach on students' performance in genetics?

The impact of the thinking frames approach on student performance was objectively assessed. This was accomplished by conducting a Wilcoxon signed-rank test on students' pretest and posttest results in the experimental group. The Wilcoxon signed-rank test was performed because the data was not normally distributed. Table 8 displays the Wilcoxon signed-rank test on pretest and posttest scores.

Table 8. Wilcoxon sign rank test results on the effect of TFA on students' performance in genetics.

Groups	N	Test Statistic	Mean	z	r	*p*
Pretest	104	5460	9.2	8.86	0.87	0.001*
Posttest			35.9			

Note: *Significant since p < 0.05.

4.4. The Effect of Thinking Frames Approach on Students' Performance in Genetics

A Wilcoxon Signed Rank Test yielded a statistically significant result, z = 8.86, $p < 0.001$, with a large effect size (r = 0.87). The increase in mean ranks from the pretest (9.2) to the posttest (35.9) demonstrates a substantial improvement in performance.

4.5. Results for Research Question 2

What difference exists between the academic performance of male and female biology students instructed with the thinking frames approach in genetics?

The difference in student performance between males and females was determined by performing a Mann-Whitney U test on both students' pretest and posttest scores to provide rationale for the intervention. The Mann-

Whitney U test was performed because the data was not normally distributed. Table 9 shows the Mann-Whitney U test of the students' pretest results prior to the intervention.

Table 9. Mann Whitney U test results on the pretest of male and female biology students taught genetics using the thinking frames approach.

Groups	N	U	Mean rank	z	*p*
Female	47	1165.50	48.8	-1.14	0.254
Male	57		55.55		

4.6. Difference Between the Academic Performance of Males and Females' Biology Students Instructed with the Thinking Frames Approach in Genetics

A Mann-Whitney U test revealed no significant difference in the pretest scores of male students (mean rank = 55.55, n = 57) and female students (mean rank = 48.8, n = 47), z = -1.14, $p = 0.254$.

The posttest result of male and female students taught genetics using the thinking frame approach is presented on Table 10.

Table 10. Mann Whitney U test results on the posttest of male and female biology students taught genetics using thinking frame approach.

Groups	N	*U*	Mean rank	z	*p*
Female	47	1226.5	50.1	-0.76	0.446
Male	57		54.48		

A Mann-Whitney U test revealed no significant difference in the posttest scores of male students (mean rank = 54.48, n = 57) and female students (mean rank = 50.1, n = 47), z = -0.76, $p = 0.446$.

5. DISCUSSION

5.1. Discussion of Findings for Research Question 1

5.1.1. The Impact of Thinking Frames Approach on Students' Academic Performance in Genetics

The Thinking Frames Approach (TFA) first gained widespread use in the United Kingdom through the Learning to Learn project, led by McClure et al. (2008). In this initiative, schools embedded thinking frames across different subjects, including science, to help students develop structured reasoning and independent thought. The results were encouraging: students produced more coherent explanations, expanded their scientific vocabulary, and were better able to justify their ideas. Teachers also observed that TFA supported inclusive teaching, giving learners of all abilities a consistent framework for expressing their understanding (Newberry et al., 2007; Newberry et al., 2011). A key takeaway was that when teachers actively modelled how to use thinking frames, students internalised the process and applied it across different scientific topics. Later studies have reinforced these findings. For example, Higgins and Baumfield (2004) reported significant gains in students' ability to explain and reason scientifically when TFA was used in both primary and secondary science classes. They also found that TFA strengthened assessment for learning, as the visible structure of students' thinking made it easier for teachers to identify misconceptions, give timely feedback, and tailor lessons to different needs.

The benefits of TFA have also been demonstrated in more complex areas of science learning. Duit and Treagust (2012) used it to develop systems thinking in environmental science lessons on biodiversity, pollution, and climate change. Students who worked with cause–effect and systems-thinking frameworks gained a deeper understanding of how environmental systems interact and could explain interdependencies more clearly. This aligns with Andrade et al. (2016) findings that metacognitive tools like TFA help students reflect on and regulate their thinking, particularly in tasks involving explanation, evaluation, and argumentation.

In a recent classroom-based study, Karamustafaoğlu and Kandaz (2022) explored Turkish science teachers' views on TFA and found that they valued it for simplifying difficult concepts, sparking classroom discussions, and supporting all learners, especially those with little prior knowledge. Likewise, Treagust et al. (2018) applied TFA in teaching cell biology and recorded significant improvements in conceptual understanding and retention. Students were able to build knowledge step-by-step, linking abstract concepts to real-world examples. In genetics education specifically, the study showed a statistically significant improvement in student performance after using TFA, supported by a Wilcoxon Signed Rank Test result ($p = .001$, $r = 0.87$). These findings align with recent work emphasizing that structured thinking tools can substantially enhance learning outcomes in science (McLure et al., 2020; Ng & Chan, 2021).

5.2. Discussion of Findings for Research Question 2

5.2.1. Difference in Academic Performance of Male and Female Biology Students Instructed with the Thinking Frames Approach in Genetics

Research suggests that female students often demonstrate strengths in rote memorization, attention to detail, and reading comprehension skills that serve them well in descriptive areas of biology (Brotman & Moore, 2008). Genetics, however, places greater emphasis on abstract conceptualisation, symbolic reasoning, and the interpretation of diagrams skills that studies indicate male students are more likely to excel in Wilgenbusch and Finson (2000). This difference in cognitive strengths may help explain why performance gaps sometimes emerge in areas such as Mendelian inheritance, Punnett square construction, and allele frequency calculations.

A study by Gericke and Wahlberg (2013) with Swedish upper secondary students, it was found that boys were generally more confident and accurate when solving genetics problems involving symbolic representations and probabilistic reasoning. Girls, while showing strong descriptive understanding, were less confident when tackling tasks that required manipulating abstract models. This finding is consistent with Zohar and Sela (2003)'s observation that gender gaps in science often stem from differences in cognitive orientation rather than innate ability, with boys tending toward systematic, rule-based reasoning and girls favoring contextual or narrative approaches.

In African contexts, socio-cultural expectations and classroom dynamics can amplify these differences. For example, Adesoji and Raimi (2020) reported that Nigerian male students outperformed their female peers in genetics tasks, particularly those involving multi-step reasoning and translating genotypes into phenotypes. They attributed this to gender-biased classroom interactions, societal norms, and unequal access to enrichment opportunities such as science clubs and competitions.

However, evidence also shows that these gaps are not fixed. Studies highlight that when learning environments are equitable and teaching approaches are inclusive, using tools like thinking frames, inquiry-based learning, and collaborative activities, gender differences in performance tend to narrow (Achor, 2024; Etobro & Fabinu, 2017). For instance, Mclure (2020) found that the Thinking Frames Approach (TFA) significantly improved the performance of both male and female students in biology, chemistry, and physics. Interestingly, the gains were strong across genders, suggesting that structured scaffolds can give all learners, regardless of gender, the confidence and skills to engage with abstract scientific concepts.

6. CONCLUSION AND PRACTICAL RECOMMENDATIONS

This study offers strong evidence that the Thinking Frames Approach (TFA) can significantly enhance senior high school students' understanding and performance in genetics. By providing structured cognitive scaffolds rooted in constructivist principles, TFA not only helps students grasp complex ideas but also corrects persistent misconceptions and fosters deeper scientific reasoning. The clear gains observed, alongside the finding that these benefits applied equally to male and female students, highlight TFA's potential as an inclusive and transformative teaching strategy.

For these benefits to translate into lasting change, policymakers and curriculum developers need to go beyond general calls for "student-centered" learning and take concrete steps to embed TFA into mainstream science education. This could involve:

- Embedding Thinking Frames sequences into the national biology curriculum, complete with sample lesson plans, visual scaffolds, and PDEODE-based activities that align with syllabus goals.
- Offering targeted in-service training to equip biology teachers with the skills to design and implement TFA effectively. Workshops could focus on building frames, facilitating meaningful discussions, and assessing student explanations.
- Revising national examinations to include open-ended questions that reward reasoning, explanation, and conceptual clarity skills that TFA is designed to nurture.
- Establishing systems to track TFA's impact through performance data and teacher feedback, ensuring that the approach is applied consistently and refined over time.

As Ghana's education system seeks to innovate and raise achievement in science, the Thinking Frames Approach presents a practical, evidence-based path forward. By weaving it into both policy and classroom practice, we can move towards a future where genetics and science as a whole are taught in ways that empower all learners to think critically, reason scientifically, and participate confidently in problem-solving for the world they live in.

7. IMPLICATIONS OF THE STUDY

1. The significant improvement in student performance through TFA underscores the need for educational stakeholders to rethink conventional teaching practices. Incorporating structured, student-centered methods like TFA can foster deeper conceptual engagement and reduce reliance on rote memorization, especially for abstract topics like genetics.
2. The absence of significant gender differences in post-intervention scores suggests that TFA creates an equitable learning environment. This has powerful implications for closing persistent gender gaps in science achievement, making TFA a promising tool for inclusive pedagogy across diverse classrooms.
3. Curriculum developers should consider embedding Thinking Frames activities into existing syllabi. This could standardize the use of conceptual scaffolds across schools and better align instructional strategies with the goals of constructivist science education, as recommended in Ghana's SHS Biology syllabus.

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