[JRET]

Eğitim ve Öğretim Araştırmaları Dergisi
Journal of Research in Education and Teaching
(ISSN: 2146-9199)
http://www.jret.org/
Geliş/ Received: 08.09.2025, Kabul/ Accepted: 19.12.2025, Yayın Tarihi (Published): 31.12.2025
Makalenin Türü / Article Type: Research / Araştırma

From Lecture To Inquiry: Transforming Genetics Instruction With The ISA Model [*]

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Abstract

This quasi-experimental study investigated the effect of the Immersion, Structuring, and Applying (ISA) instructional model on Senior High School students' genetics performance in Ghana. A total of 170 biology students were assigned to either an experimental group (taught with the ISA model) or a control group (taught traditionally). Results from pre- and post-tests showed that students in the ISA group significantly outperformed their counterparts, with a large effect size (Cliff's δ = –0.857). Gender-based analysis revealed no statistically significant difference in performance between male and female students within the ISA group. The findings suggest that the ISA model is an effective and equitable constructivist approach for improving genetics education, recommending its adoption to enhance learning outcomes in resource-constrained settings.
Keywords: Genetics education, students' performance, senior high school, Instructional approach.

Introduction

To teach is to impart knowledge, sound judgment, and mature wisdom to a learner through a learning process. The main goal of teaching is to develop students' performance, abilities, and conduct to have a better life (Dorgu, 2015). A solid teaching approach must be employed to accomplish this since teaching strategies have been shown to significantly influence student performance (Munna &

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Kalam, 2021). According to Van Geel et al. (2019), because of the uniqueness of each student and his or her environment, teachers should employ various teaching strategies to engage, encourage, and improve students' learning outcomes. Effective teaching strategies are tailored to the learners' requirements, as each learner understands and responds to events and experiences differently (Franklin & Harrington, 2019). Several approaches and strategies have been developed to guarantee that teachers give excellent education that allows students to comprehend topics quickly and meaningfully (Wilson & Conyers, 2020). Multiple ideologies underpin the beliefs that serve as the foundation for instructional approaches. Methods of teaching are divided into two types. These are the teacher-centred and student-centred strategies, which focus on the instructor and the learner, respectively. Teacher-centred strategies are founded on the idea of behavioural learning, which emphasises the necessity of providing appropriate stimuli that result in the expected and desired outcomes for learners (Agyei, 2022).

Teacher-centred approaches to teaching are traditional instructional methods in which the teacher is the exclusive authority and major source of knowledge in the classroom. In this model, the instructor determines the lesson's pace and organisation, while students are supposed to passively absorb the material presented (Massouleh & Jooneghani, 2012). This style frequently stresses direct instruction, lectures, and rote memorisation, with the teacher giving material and the students following along. The emphasis is mainly on transmitting factual knowledge from instructor to student, with evaluations often measuring retention of the given material (Darling-Hammond et al., 2020). Several studies suggest that a progression from a teacher-centred to a student-centred approach may be optimal for learning novel concepts in science, particularly at the senior high school (SHS) level (Dervić et al., 2018; Ubulom & Ogwunte, 2017; Emaliana, 2017) which positively improves students' performance.

Science education now focuses on lifelong learning by engaging students in practical applications and teamwork to tackle real-world sustainability issues. This approach encourages independent learning and the application of scientific concepts, moving away from traditional teacher-centred methods criticized for promoting rote memorisation (Darling-Hammond et al., 2020; Singha & Singha, 2024). The shift to constructivism in the late 1950s emphasized the learner's role in hypothesizing and reflecting on experiences, leading to improved performance in various science subjects, particularly biology (Matthews, 2024; Rannikmäe et al., 2020).

Moreover, research also indicates that differences exist between male and female students' performance in some fields of science (Sonnert & Fox, 2012). Efforts to identify effective and inclusive teaching methods in science, technology, engineering, and mathematics (STEM) education have led to the adoption of numerous student-centred approaches to teaching STEM topics (Aguillon et al., 2020). Although more girls are encouraged to pursue STEM courses, only a few have been successful (Cheryan et al., 2017). To solve this difficulty, educators have discovered innovative strategies to entice student engagement and improve performance for a successful STEM career using the constructivist approach (Taconis & Bekker, 2023).

One such model is the Immersion, Structuring, and Applying model (ISA). It consists of three phases (Immersion, Structuring, and Applying), each phase with two sub-phases that highlight specific roles for the teacher and the students (Singer & Moscovici, 2008). It begins with an Immersion phase, in which students immerse themselves in the topic, using their prior knowledge, gathering additional information, organising experiments, and detecting tentative patterns. The teacher's responsibility is to encourage students' interest, assist in formulating learning objectives, and scaffold research. The Immersion phase is divided into two interconnected subphases: Evoking and Exploring. Evoking sub-phase entails students applying prior knowledge to the problem, discussing and criticising ideas with classmates, and finding resources. Students explore in the next sub-phase by organising, carrying out, and assessing investigations while addressing an issue. Students learn how to pick relevant knowledge, correlate variables and experimental outcomes, recognise experiment constraints, and apply higher-order thinking abilities. They alternate between concrete and abstract experiences, allowing them to explain and generalise patterns while separating abstract information from concrete experimental/trial stages (Singer, 1995; Singer, 2007; Singer & Moscovici, 2008).

The Structuring Phase is a crucial stage in the learning process, where students interpret and adjust their experiential results. They explain their claims using examples and counter-examples and create new situations to challenge them. The teacher plays a facilitator role, helping students synthesise observations, summarise findings, and explore inferences during the Systematization sub-phase. The Conceptualization sub-phase helps students use new terminology, generalise conclusions, and expand their findings beyond specific problems. The Structuring phase teaches students to differentiate between opinion and fact, understand experiment limitations, and use appropriate language (Singer & Moscovici, 2008).

In the Applying phase, students create abstract patterns and apply them to related and unrelated circumstances. They tweak and adjust these patterns to make them broader and more functional. They apply these notions to new settings by resolving current difficulties and developing hypothetical or actual scenarios in the extended sub-phase. This technique produces a more generic pattern for recognising restricting components. Teachers assess students' comprehension of ideas and the inquiry process by using concrete examples from the same or related/unrelated domains to demonstrate relationships or raise complexity. They may also encourage students to evaluate areas of their daily lives for future learning in the evaluate sub-phase (Singer & Moscovici, 2008).

Unlike traditional teaching approaches, in which teachers offer content through lectures and students passively absorb information, the ISA model challenges students to actively participate in learning through inquiry, problem-solving, and collaboration. This active participation not only keeps students involved but also allows them to have a better comprehension of the subject. For example, when students are encouraged to investigate concepts through hands-on activities, experiments, or discussions, they are more likely to connect the information to past knowledge, resulting in a more meaningful learning experience (Chen et al., 2020). Building on prior knowledge is essential to the constructivist approach and has been related to higher academic achievement. Constructivism encourages higher levels of cognitive engagement by requiring students to think critically and apply concepts, which leads to improved learning results (Van Riesen et al., 2022). It also promotes comprehension over memorisation, which helps students retain and apply their knowledge. It allows students to build their understanding by creating mental models for new situations. This knowledge transmission is crucial for academic and professional success (Larison, 2022).

In Ghana, biology is a critically debated subject in education, integral to the senior high school curriculum, and vital for careers in medicine, agriculture, and environmental sciences (Amoah et al., 2023). While biology emphasises observation and investigation of natural processes, its teaching often lacks interaction, resulting in passive student participation (Mccomas et al., 2018). The subject includes complex topics like genetics, which poses significant challenges due to the difficulty in visualising concepts like DNA structure and gene inheritance (Gupta, 2019). Many students struggle with these topics, negatively affecting their performance, as noted in the West African Examination Council's [WAEC] reports. The absence of practical teaching methods exacerbates these challenges, highlighting the need for improved instructional approaches in genetics education (WAEC chief examiner’s report, 2018; 2019; 2021; 2022; 2023; 2024).

Furthermore, the Ghanaian Senior High School Biology syllabus; both old and new, suggests that teachers adopt constructivist teaching approaches to ensure that Biology ideas are fully understood. The biology syllabus explicitly promotes learner-centred, constructivist teaching approaches; such as inquiry, problem-based learning, and differentiated instruction, to ensure deep conceptual understanding, development of 21st-century competencies, and alignment with social, emotional, and Ghanaian values (Curriculum Research and Development Division [CRDD], 2010; National Council for Curriculum and Assessment [NaCCA], 2023).

As a result, it stands to reason that, to solve the issue of students' low performance in genetics, successful constructivist teaching methodologies that have been proven elsewhere should be used when teaching biology concepts. This will assist students in improving their academic performance in the subject. Science education studies have shown that student-centred constructivist teaching approaches significantly improve students' science performance (Bara & Xhomara, 2020; Precious & Feyisetan, 2020; Dada et al., 2023). As a result, this study aims to examine the effect of the ISA model in teaching genetic concepts in the Ghanaian senior high school biology class.

Problem Statement

Numerous factors, including cognitive challenges, a lack of laboratory resources, student motivation, instructor competency, instructional strategies, and curriculum design can all contribute to the poor performance of students in genetics (Chifwa, 2015). However, because teaching methods have a direct and adjustable influence on students' learning outcomes, this study focuses on the influence of the teaching approaches on students' performance. According to research, teaching strategies have a big impact on students' understanding and involvement, especially when it comes to difficult subjects like genetics (Van Geel et al., 2019). Compared to the other external elements mentioned above, teaching methods are easier to adapt and apply within the current educational systems (Davis, 2003).

The challenges of teaching and learning genetics in senior high schools have been well-documented globally, and Ghana is no exception (Asare, 2020). As a crucial component of the biology curriculum, genetics deals with complex concepts such as DNA structure, inheritance patterns, gene expression, and mutations. However, students in Ghana need help with these abstract concepts, as reflected in their poor performance in the WAEC biology exams, particularly in genetics (WAEC Chief Examiner's Report, 2019; 2020; 2021; 2022; 2023; 2024). More specifically, the Chief Examiners' Report for the (2019) WASSCE said that most applicants failed to fully articulate the distinctions between DNA and RNA. Similarly, the WAEC Chief Examiners Report (2021) found that the applicants' Biology coursework was poor, citing genetic diagrams as an example of incorrect construction. Candidates had trouble explaining recombinant DNA technology and its applications. Students typically do badly in genetics, which affects their overall biology performance. This issue is primarily attributed to the traditional methods of teaching, which rely heavily on rote memorisation and passive learning. Teachers often provide content through lectures without engaging students in the hands-on activities and inquiry-based learning necessary for a deep understanding of genetic concepts (Wilmot, 2020).

Despite the well-documented challenges in teaching genetics, the potential impact of constructivist approaches, particularly the Immersion, Structuring, and Applying (ISA) model, on students' knowledge and performance in genetics remains unclear. It appears this model, known for its success in enhancing learning outcomes in other scientific fields (Singer & Moscovici, 2008), has not been thoroughly explored in the context of genetics education in Ghanaian senior high schools.

Improving student genetics performance is crucial for academic achievement and creating a scientifically literate population capable of solving national and global health and environmental challenges (Vandiver et al., 2022). This will allow for evidence-based solutions to improve biology teaching in Ghana. In order to achieve this, this study intends to evaluate the effect of the ISA model on students' genetics performance at the senior high school level.

Research Questions

1. What is the difference in academic performance between students taught genetics using the ISA model and those taught with the traditional approach at the SHS level?

2. What is the difference in performance between boys and girls taught genetics using the ISA model at the Senior High School?

Literature Review

Conceptual Framework

The conceptual framework for this study is rooted in the constructivist learning paradigm, which asserts that learners actively construct knowledge through experiences, interaction, and reflection. This framework has been operationalized in the present study through the application of the ISA model—Immersion, Structuring, and Applying—developed by Singer and Moscovici (2008). It is designed around the core phases of the Immersion, Structuring, and Applying (ISA) model and their expected influence on students' performance in genetics.

At the heart of the framework is the assumption that the ISA model, grounded in constructivist principles, creates more opportunities for active engagement, collaboration, and real-life application than traditional teacher-centred methods. By immersing learners in authentic problems, helping them structure and clarify concepts, and then applying knowledge in new contexts, the ISA model is expected to foster deeper understanding and improved performance.

In addition, gender functions as a moderating variable within this framework. Prior research in Ghana and elsewhere suggests that male and female students may experience and respond differently to teaching approaches due to socialization patterns, self-concept, and classroom dynamics (Eddy & Brownell, 2016; Wang & Degol, 2017). The framework therefore accounts for possible variations in how ISA influences performance and dispositions across genders.

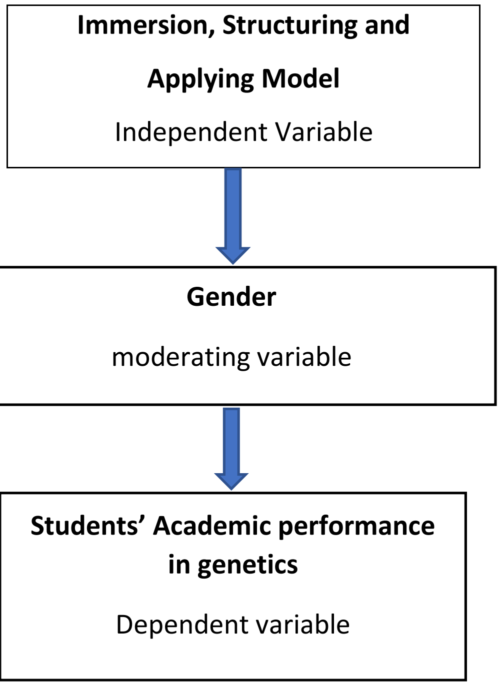
In the context of the ISA model, gender differences may manifest in students' levels of engagement, confidence in handling practical activities, or willingness to collaborate during group tasks. For example, some studies have shown that female students may exhibit stronger collaborative skills and prefer interactive learning settings, while male students may engage more competitively, potentially affecting their performance (Almasri, 2021; Dewi & Muhid, 2021). Similarly, differences in prior exposure to scientific concepts could influence how quickly each group adapts to the inquiry-based and application-focused elements of the ISA model.

By examining gender as a moderator, this study aims to determine whether the instructional benefits of the ISA model are consistent across male and female students or whether targeted adjustments may be necessary to ensure equitable learning outcomes. Understanding such differences is crucial for developing inclusive teaching strategies that cater to diverse learners in genetics education.

In summary, the conceptual framework positions the ISA model as an intervention expected to influence their cognitive (performance) outcomes, with gender acting as a potential moderator of this relationships. The conceptual framework is represented graphically below in figure 1.

Figure 1.

Conceptual Framework Of The Study



Empirical Review on the effect of the ISA model

Empirical studies demonstrate that constructivist-based instructional models, including the Immersion, Structuring and Applying (ISA) model, positively influence students' academic performance and attitudes in science education. While direct investigations of the ISA model in Ghana are limited, relevant models like inquiry-based, problem-based, and cooperative learning have been extensively researched. A notable study by Singer and Moscovici (2008) in the U.S. revealed that middle school students taught using the ISA model outperformed their peers receiving traditional instruction on post-tests and exhibited higher engagement, indicating that ISA promotes a deeper conceptual understanding through its hands-on, inquiry-driven approach.

Similarly, a study by Zudaire and Napal Fraile (2021) in Spain used an inquiry-structured ISA-like model to teach biological systems. Their results indicated improved student reasoning skills and conceptual retention, highlighting that, instructional models involving immersion and application enhance long-term understanding. Similarly, Renninger's (2024) study also shows that activity-based, learner-centred approaches significantly enhance student achievement compared to traditional lecture methods. Although not labelled as ISA, their models shared similar stages and demonstrated positive learning outcomes.

In Africa, empirical research on constructivist models has also shown improved learning outcomes. Manishimwe et al. (2023) conducted a quasi-experimental study in Rwanda using activity-based, learner-centred teaching approaches in biology. Their findings revealed significant gains in students' genetics achievement compared to those taught through lecture methods. This aligns with the core assumption of the ISA model that active involvement enhances comprehension of abstract scientific concepts.

A study by Ahiaba (2023) in Ghana investigated the effect of cooperative and inquiry-based methods on SHS students' performance in biology. The findings showed that students taught with learner-centred methods outperformed their peers taught with traditional approaches. In another Ghanaian study, Baah (2021) examined the effect of problem-based learning on SHS students' understanding of genetics. The results showed significant improvement in students' achievement.

Despite the documented success of constructivist approaches, empirical studies specifically examining the ISA model in African or Ghanaian contexts remain limited. Most studies in Ghana focus broadly on inquiry or cooperative learning, with few targeting the specific phases of the ISA model. Moreover, little empirical work has investigated how such models influence both performance and dispositions in genetics, a topic consistently reported as difficult for SHS students.

Gender Performance in Science

The relationship between gender and performance in science has been widely debated in educational research. Globally, meta-analyses suggest that gender differences in science achievement are relatively small, with performance outcomes being more influenced by contextual factors such as teaching methods, classroom climate, and socio-cultural expectations than by inherent ability (Hyde, 2014). In Ghana, stereotypes are reinforced by cultural expectations, which often discourage girls from pursuing science-related careers, thereby influencing their self-concept and engagement in science classrooms (Gyan & Mensah, 2025).

Research indicates that teaching approaches significantly interact with gender to influence performance. Active, learner-centred strategies such as cooperative learning, inquiry, and problem-based approaches have been shown to reduce gender disparities by providing inclusive and supportive environments (Annan et al., 2019; Russo-Tait, 2023). In Ghana, Ahiaba (2023), found that activity-based biology instruction not only improved overall performance but also enhanced female students' participation and confidence. This suggests that instructional models such as ISA, which emphasize immersion, structuring, and applying, may mitigate gender-related performance gaps while improving students' perceptions of genetics.

The role of gender in science performance must also be understood within the framework of socialization and classroom dynamics. Studies suggest that boys are often encouraged to take leadership roles in group work, participate more actively in class discussions, and take risks in answering questions, while girls may adopt more passive roles (Hyde & Deal, 2003). These patterns are visible in many Ghanaian classrooms, where teacher expectations and peer interactions subtly reinforce gendered participation. Without deliberate strategies to ensure equal participation, these dynamics can perpetuate differences in performance and attitudes between boys and girls.

Importantly, gender differences in science education are context-dependent rather than universal. For example, in some studies, girls outperform boys in biology due to their diligence and interest in health-related topics, while boys outperform in physics and chemistry (Kiernan et al., 2023). This suggests that gender effects are shaped not by inherent ability but by the alignment of teaching methods, curriculum relevance, and student dispositions. In genetics, where abstract reasoning and problem-solving are required, teaching methods that fail to contextualize content may disproportionately disadvantage female students, who already report lower confidence in tackling abstract science problems (Marsh et al., 2019).

In Ghana, promoting gender equity in science education is also tied to broader educational policy goals, including the push to increase female participation in STEM fields (Boateng, 2025). The integration of constructivist approaches like ISA into the SHS biology curriculum offers one pathway to achieve this goal by enhancing both performance and dispositions across genders. By situating genetics within real-life contexts and actively engaging students in collaborative learning, the ISA model has the potential to narrow gender differences while improving overall achievement.

In summary, gender, and performance are deeply interconnected in science education. While global evidence shows minimal inherent gender differences in science achievement, socio-cultural factors, and classroom practices significantly shape outcomes. In the Ghanaian SHS context, these influences are particularly pronounced in challenging topics such as genetics. The ISA model provides a promising framework for addressing these challenges by improving the cognitive outcomes (performance), while creating more equitable learning opportunities for male and female students alike.

Methodology

Research Design

A quasi-experimental pre-test, post-test, and non-equivalent control group design was used for this study. An experimental group and a control group were used in this design to assess how the Immersion, Structuring, and Applying (ISA) model affects senior high school students' performance in genetics. Students in the experimental group studied genetics using the ISA model, a constructivist teaching methodology that prioritizes practical experience, teamwork, and idea application. To compare the efficacy of the ISA model, the control group was instructed in genetics using the conventional lecture-based methods.

In order to assess the students' initial genetics knowledge, a pre-test was given prior to the intervention, and a post-test was given following the intervention to gauge any performance improvements. The efficacy of the ISA model was evaluated by contrasting each group's pre-test and post-test results. This design is beneficial in educational settings where random assignment may be impractical or unethical (Cook, 1979).

The use of intact classes, meaning that the students were not randomly assigned to the experimental or control group. This approach is practical and often necessary in educational research, where students are already organised into specific classes or schools (Creswell & Creswell, 2017). However, because intact classes nested within schools formed the units of analysis, students' scores may not be completely independent. Cluster effects (school/class-level differences) can inflate Type I error if unaddressed. Although the present study primarily used non–parametric tests due to non-normality, clustering effects were accounted for by reporting effect sizes and using robust non-parametric tests. Future studies should consider cluster-robust standard errors or mixed-effects modelling to formally adjust for non-independence.

The target population for this study consisted of all senior high school students participating in biology classes in the Sekyere central district of Ghana's Ashanti region, and the accessible population was all Form three (3) students enrolled in biology classes in SHSs in the district. The study focused on this group of students because they had the prerequisite knowledge needed to be engaged in genetics classes in order to assess the influence of the Immersion, Structuring, and Applying (ISA) model on students' genetics performance with the ultimate goal of enhancing educational results in this tough topic.

Research Sample and Participants

A multi-stage sampling procedure was utilised in this study. In the first stage, two (2) senior high schools from the district were selected using simple random sampling. One (1) school was randomly assigned as the experimental group, while the other served as the control group. In the next stage, a purposive sampling strategy was employed to select four (4) intact classes of biology students (comprising of one general science and one home science (clothing) classes), two from each school. The use of intact classes was necessary to preserve existing school structures and avoid disrupting the normal instructional process. However, this approach introduces the possibility of selection bias, as the groups may differ in ways beyond the intervention. To mitigate this, a pre-test was conducted, and the results showed no statistically significant difference in baseline performance between the groups, suggesting a comparable starting point. Nevertheless, the limitation of using intact classes is acknowledged and should be considered when interpreting the findings.

The unit of analysis was 170 biology students. The experimental group comprised 84 students (26 males and 58 females), while the control group comprised 86 students (14 males and 72 females). This breakdown highlights the gender imbalance within the groups, particularly in the control group where female students were disproportionately represented. While this reflects the actual enrolment patterns in the participating schools, it is important to acknowledge that such imbalances may influence subgroup analyses, particularly those based on gender.

Research Instruments

The research instruments used are a standardised test known as the Genetic Concepts Test (GCT). The researcher developed the GCT, which consisted of five (5) essay-type questions covering genetics topics like heredity, DNA structure, and replication in their syllabus. This was used to evaluate the performance of SHS Biology students before and after the intervention. The students' responses to the test items were graded polytomously.

Data Collection

The study included the gathering of quantitative data in two stages. These are the pre-intervention and post-intervention stages.

Pre-intervention Stage

During the initial data collection phase, formal authorization was obtained from relevant educational authorities. Students participated in a pre-test without disclosing their names, using assigned identity numbers instead to maintain confidentiality. Conducted during regular school hours, the pre-test aimed to evaluate students' baseline characteristics prior to any intervention, allowing 40 minutes for completion.

Intervention Stage

The instructional approaches (ISA model and conventional method) were deployed at this stage, which serves as the study's independent variables.

The researcher taught the subject matter to the students (participants) in order to account for teacher differences. The intervention stage, which lasted for a period of four (4) weeks, involved teaching the same topics (genetics) and using different treatment activities (ISA instructional model and Traditional instructional approach) to all the intact classes Table 1 provides a summary of the various contents that were covered during the research.

Table 1

Content Of Genetics Taught To Students

Period	**Content Taught**
Week 1	Heredity

Week 2	Nucleic Acids
Week 3	DNA Structure
Week 4	DNA Replication

Intervention Activities

Both intact classes in the experimental group were exposed to ISA model's teaching and learning approach during the teaching and learning of genetic concepts. Table 2 gives a description of how the ISA model was implemented.

Table 2

Stages Of The ISA Model For Intervention Implementation

PHASE	**ISA STRATEGIES**		**ACTIVITY**
	Teacher	**Student**	
Immersion	Anticipation	Evoking	Stimulating curiosity through real-life problems, questions, or demonstrations. Activating prior knowledge. Introducing context through stories, images, or videos.
	Problem Construction	Exploring	Eliciting students' initial ideas, questions, or experiences related to the topic.
Structuring	Systematization	Synthesizing	Guiding students to identify patterns, relationships, and concepts from their observations. Concept mapping or guided group discussions.
	Conceptualization	Explaining	Formally constructing knowledge; teacher introduces core ideas based on student exploration. Use of charts, models, or concept summaries.
Applying	Transfer	Extending	Students apply learned concepts to new contexts, solve problems, or design tasks. Case studies,

			simulations, or practical exercises.
	Reinforcement	Evaluating	Assessment of conceptual understanding and application skills through quizzes, presentations, or reflective journals.

The implementation of the ISA instructional model in this study followed a structured, phased approach consisting of Immersion, Structuring, and Applying, each designed to support students' cognitive engagement in learning genetics. This model was applied over a series of carefully planned lessons with activities aligned to each phase.

Post-intervention Stage

Following the intervention stage, students were given a two-day revision break to review their notes before taking the post-test (GCT). Students were allowed forty (40) minutes to complete the test items.

Analysis of Data

The data analysis for this study involved purely quantitative analysis to comprehensively evaluate the effectiveness of the ISA model on students' performance in genetics.

Validity and Reliability

To establish the validity of the research instrument, the GCT questions were sent to experts in Biology and Science Education to assess the suitability of each item on the instruments; this is also known as face validity. Cohen et al. (2002) define face validity as a kind of content validity. Five experts were then asked to evaluate the GCT questions to determine their correctness and capacity to assess students' performance in the genetic topics covered in the study. Following the professional evaluations, the experts rated the content of the instrument to be valid using Lawshe's (1975) content validity ratio (CVR).

The Content Validity Index (CVI) was computed for every item on the instrument in order to determine the CVR. The CVI is calculated by dividing the number of experts who ranked the items as vital by the total number of experts who evaluated the items (Ayre & Scally, 2014). The CVI for the entire instrument is computed once the CVI for each item has been determined. This represents the average of every single CVI (Almanasreh et al., 2019). The CVR of the GCT was then determined by dividing the overall CVI by the total number of items.

The Five specialists in Biology and Science Education evaluated the relevance, clarity, and representativeness of each item. Experts used a rubric to rate:

1. Alignment with curriculum objectives
2. Cognitive demand
3. Clarity of wording
4. Appropriateness for SHS learners

Table 3, presents the Content Validity Ratio and Content Index for the GCT.

Table 3

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
6	X	X	X	X	X	5	1.00
CVR							**0.96**

O=non-essential

X= essential

CVI = Content Validity Index =

CVR = Content Validity Ratio =

N = total number of experts

= Number of experts indicating items as essential.

Almanasreh et al. (2019) stated that CVR ranges from -1 to 1, with high values signifying expert agreement over the significance of an item in the instrument. Consequently, the CVR value for GCT was 0.96, as shown in Table 4, indicating a viable instrument.

Pilot-Study of the Instruments

The GCT was initially tested in a pilot study involving 32 third-year biology students to evaluate the reliability of its scores. The study included pre-test and post-test assessments before and after implementing the ISA model. Internal consistency was measured using inter-rater reliability, specifically Cohen's Kappa, which assesses agreement among multiple evaluators. Kappa values classify agreement levels, with higher values (0.81-1.00) indicating stronger reliability among raters, thus confirming the test's reliability across different assessors (Gwet, 2014).

Scoring Procedures and Rater Training

Because the GCT contained open-ended responses, a detailed scoring rubric was developed with multiple score categories for each item. To enhance scoring consistency:

1. Two independent raters were trained using sample scripts.
2. Training included calibration sessions, comparison of scoring decisions, and discussion of discrepancies.
3. Raters were blinded to whether scripts were from the experimental or control group.
4. Sample anchor responses were generated and used for standardisation.

Table 5 below indicates the descriptive statistics for both raters' scores

Table 4

Descriptive Statistics on the Raters' Scores

Raters	N	Minimum Statistic	Maximum Statistic	Mean	Std. Deviation
First Rater scores (Pre-test)	32	0	8	3.69	0.42
First Rater scores (Post-test)	32	1	8	3.81	0.38
Second Rater scores (Pre-test)	32	11	20	15.91	0.42
Second Rater scores (Post-test)	32	10	20	16	0.42

Table 4 presents the descriptive statistics obtained from the two independent raters during the pilot study, which was conducted to evaluate the reliability of the scoring procedure for the GCT instrument. The scores from both raters show minimal variability, with standard deviations ranging between 0.38 and 0.42, indicating a high degree of consistency in how the scoring rubric was applied. The First Rater recorded mean scores of 3.69 on the pre-test and 3.81 on the post-test, while the Second Rater recorded slightly higher means of 15.91 and 16.00 for the pre-test and post-test, respectively. These slight increases from pre-test to post-test suggest marginal improvement in student responses following the intervention of the ISA model. The narrow spread of scores and similar rating patterns between the two raters demonstrate that the scoring rubric was clearly understood and applied consistently, confirming strong inter-rater reliability and supporting the use of the instrument in the main study.

Inter-rater Reliability of the GCT

The inter-rater reliability of the GCT was examined using Cohen's Kappa's agreement metric. The results are presented in the table below.

Table 5

Inter-rater Reliability Of GCT Pre-test

	Value	Asymptotic Standard Error [a]	Approximate T[b]	Approximate Significance
Measure of Kappa Agreement	0.70	0.09	9.72	.001
No of Valid Cases	32			

Table 5 indicates, the value of Kappa's measure of agreement for the pre-test is 0.70, which is a substantial agreement, as per Gwet (2014). Therefore, the GCT-pre-test was deemed reliable to be used.

Following the reliability of the Pre-test the Post-test was also tested using the Kappa's agreement reliability. Its findings are also presented in Table 6 below.

Table 6

Inter-rater Reliability Of GCT Post-test

	Value	Asymptotic Standard Error [a]	Approximate T[b]	Approximate Significance
Measure of Kappa Agreement	0.82	0.07	12.89	.001
No of Valid Cases	32			

Table 6 indicates, the value of Kappa's measure of agreement for the post-test is 0.82, which is a strong agreement, as per Gwet (2014). Therefore, the GCT-post-test was also deemed reliable to be used.

Results

Data Suitability

To make sure the data was appropriate, normality tests were conducted before the study's results were analysed. This section presents the findings. To decide whether to apply parametric or non-parametric tests, the study's student results were put through a normality test. Using the numerical method, normality checks were performed. The Shapiro-Wilk and Kolmogorov-Smirnov tests were thus conducted quantitatively. According to the "null hypothesis that the data sets are normally distributed", normality tests were conducted (Khatun, 2021). This means that when the p-value from the Kolmogorov-Smirnov or the Shapiro-Wilk tests is more than 0.05, the null hypotheses are not rejected; hence, the data is normal. The outcomes of the normalcy tests are shown in Table 7**.**

Table 7

Results Of Normality Tests For Students' Scores

Groups	**Kolmogorov-Smirnov[a]**			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Pre-test of Control Group	.139	84	.001*	.944	84	.001*
Post-test of Control Group	.107		.018*	.966		.024*
Pre-test of Experimental Group	.214		.001*	.916		.001*
Post-test of Experimental Group	.118		.006*	.964		.019*

a. Lilliefors Significance Correction

***Significant since p < 0.05**

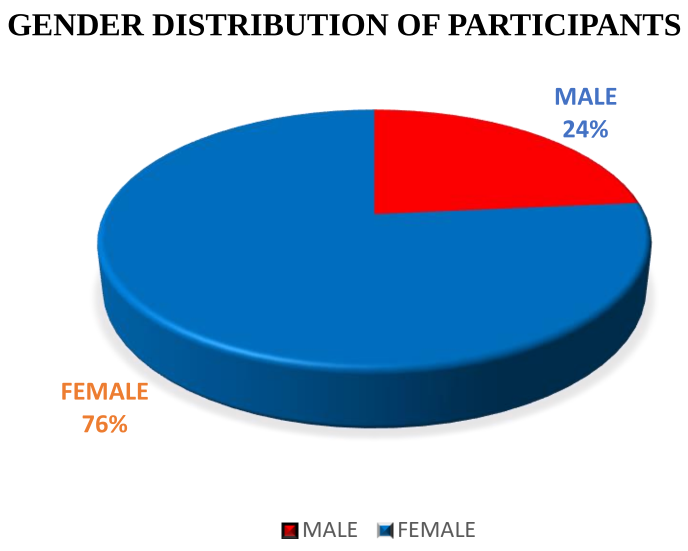
The results of the Kolmogorov-Smirnov and Shapiro-Wilk tests indicate that the students' pre-test and post-test scores for both the control and experimental groups are not normally distributed, as all significance values (p-values) are less than 0.05; thus, we reject the null hypothesis that states that the data is normal. This violation of the assumption of normality justifies the use of non-parametric statistical tests for further analysis. The Shapiro-Wilk test, which is more appropriate for smaller sample sizes, confirmed the non-normality across all test groups (Khatun, 2021). Therefore, statistical analyses such as the Wilcoxon Signed Rank Test and Mann-Whitney U Test were appropriately used in this study.

Demographics of Respondents

The study included 2 public senior high schools within the district, comprising 170 biology students who were selected. The Figure 2 below indicates the distribution of their gender.

Figure 2

Gender distribution of participants



The pie chart in Figure 2 shows that most of the students who took part in the study were female, 130, representing 76% of the total sample size, while only 40 were male, also representing 24%. This means that more girls than boys participated in the research. This difference depicts the natural settings of biology classes, dominated by female students, especially in Ghana (Annan et al., 2019).

Descriptive Statistics on the Scores of Participants

Table 8

Descriptive Statistics on the Scores of Participants

Groups	Mean	Std. Deviation	Medians	IQR
Pre-test of Control Group	3.58	2.46	4	4

Post-test of Control Group	12.12	2	12	3
Pre-test of Experimental Group	3.12	2.41	2	4
Post-test of Experimental Group	16.43	2.1	16	3

Table 8 provides the descriptive statistics for the pre-test and post-test performance of students in the control and experimental (ISA) groups. The pre-test results reveal that both groups started at comparable levels, with the control group reporting a mean score of 3.58 (median = 4, IQR = 4) and the experimental group reporting a mean of 3.12 (median = 2, IQR = 4). This similarity in baseline performance suggests that any differences observed in the post-test can more confidently be attributed to the intervention rather than initial disparities between groups. After the intervention, however, notable differences emerged. The control group achieved a post-test mean of 12.12 (median = 12, IQR = 3), while the experimental group demonstrated a substantially higher mean of 16.43 (median = 16, IQR = 3). Although both groups improved, the experimental group's improvement was considerably larger, indicating that the ISA instructional model had a strong positive impact on student achievement. The similarity in post-test IQR values suggests that the observed improvements were consistent across students, rather than being driven by a few high-performing individuals.

The Effect of the ISA Model on Student's Performance in Genetics

To evaluate the impact of the ISA model on students' performance in genetics, pre-test and post-test scores of the experimental group were analysed using the Wilcoxon signed-rank test due to violation of normality assumptions. This non-parametric test is suitable for related samples with non-normal distribution of differences, as confirmed by the Shapiro–Wilk test results. Results are shown in Table 9.

Table 9

Wilcoxon signed rank test results on the effect of the ISA model

Groups	N	Test Statistic	Mean	z	*r*	*p*
Pretest	84	3570	3.1	7.98	0.87	.001*
Posttest			16.4			

***Significant since p < 0.05**

The Wilcoxon Signed Rank Test assessed the effectiveness of the ISA instructional model by comparing students' pre-test and post-test scores in the experimental group. The test shown in Table 9 indicates a statistically significant increase in scores after the intervention, with a Z-value of 7.98 and a p-value of .001. The pre-test mean was 3.1, while the post-test mean improved dramatically to 16.4. The effect size (r = 0.87) is considered very large, suggesting that the ISA model had a strong and meaningful impact on improving students' performance in genetics (Fritz et al., 2011).

The difference in academic performance between students taught genetics using the ISA model and those taught with the traditional approach in genetics

In determining the difference between the control and experimental groups, a Quade ANCOVA was run on their post-test scores considering their pre-test scores also. This non-parametric test was selected because the data violated the assumption of normality required for an ANCOVA, as indicated by the Shapiro–Wilk test results. The results are presented in Tables 10 below.

Table 10

Quade ANCOVA Results Comparing ISA and CONTROL Groups on Posttest Scores Across Pretest Levels, with Cliff's δ

Pretest Level	n_1 (ISA)	n_2 (CONTROL)	Adjusted Mean Difference (Posttest)	SE	95% CI	Statistic	p-value	Cliff's δ
0	32	35	-5.01	0.42	[-6.15, -3.86]	11.84	.001	-0.857
1	41	42	-4.84	0.32	[-5.70, -3.99]	15.15	.001	-0.857
4	53	60	-3.70	0.37	[-4.68, -2.71]	9.91	.001	-0.857
5	48	46	-3.89	0.51	[-5.25, -2.52]	7.58	.001	-0.857
8	21	18	-3.94	0.63	[-5.75, -2.12]	6.25	.001	-0.857

Table 10 presents the results of the Quade nonparametric ANCOVA, which examined post-test differences between the ISA and control groups while controlling for pre-test scores. Across all pre-test levels (0, 1, 4, 5, and 8), the adjusted mean differences consistently favoured the ISA group, with values ranging from –3.70 to –5.01. These negative adjusted differences indicate that, when pre-test scores were statistically controlled, students in the ISA group performed significantly better on the post-test than those in the control group. All confidence intervals excluded zero, and all p-values were .001, demonstrating that the differences between groups were statistically significant at every level of pre-test performance. Furthermore, the effect size, represented by Cliff's delta (δ = –0.857), indicates a very large and practically meaningful effect. This value suggests that there is an 85.7% probability that a randomly selected student from the ISA group would outperform a student from the control group on the post-test. The consistency of the effect across all pre-test strata, combined with the large magnitude of the effect size, indicates that the ISA instructional model had a robust and substantial impact on students' learning outcomes.

The effect of the ISA model between the performance of boys and girls in genetics

In determining the difference between male and female students in the experimental group, the Mann-Whitney U test was run on their pre-test first to establish if there was any significant variation prior to the interventions, followed by the post-test results. The results are presented in Tables 11 and 12 below.

Table 11

Mann-Whitney U Test On The Pre-test Of Both Gender

Groups	**N**	***U***	**Mean rank**	**Z**	***r***	***p***
Female	58	587	39.62	-1.64	-0.18	.102*
Male	26		48.92			

Table 11 compares pre-test scores between male and female students from the experimental group. The Mann-Whitney U Test revealed no statistically significant difference (*p* = .102) between the genders. Female students had a mean rank of 39.62, and males had a mean rank of 48.92. This suggests that gender did not play a role in students' baseline understanding of genetics before the intervention, indicating a level playing field for analysing post-intervention effects across genders.

Table 12

Mann-Whitney U Test On The Post-test Of Both Gender

Groups	N	*U*	Mean rank	Z	*r*	*p*
Female	58	570	39.33	-1.8	-0.2	.072*
Male	26		49.58			

As indicated in Table 12 above, the post-test results by gender also showed no statistically significant difference (p = .072), even though males had a slightly higher mean rank (49.58) compared to females (39.33). Though the Z-score was -1.8, and a small effect size (r = -0.2). This indicates that both male and female students benefited equally from the ISA model, further confirming that the intervention was gender-neutral in its effectiveness.

However, it should be noted that the gender analysis was based on an unequal sample distribution (58 females vs. 26 males). This imbalance may reduce the statistical power of the Mann–Whitney U test and limit the generalisability of the gender-related findings.

Discussion and Conclusions

What is the difference in academic performance between students taught genetics using the ISA model and those taught with the traditional approach at the SHS level?

The gains observed in this study also address one of the limitations associated with traditional teacher-centred methods highlighted in the literature review (Renninger, 2024). Osborne and Dillon (2008) noted that such approaches often promote rote memorisation without equipping learners with higher-order cognitive skills. By contrast, the ISA model's application-focused design appears to have strengthened students' academic gains, which is critical for success in both academic and real-world contexts. In Ghanaian contexts, Baah (2021) reported similar results, noting that biology students exposed to interactive, real-life examples demonstrated significantly higher achievement scores than those taught through lectures alone. The present study mirrors this trend, as the ISA model's active learning phases encouraged student engagement, peer discussion, and problem-solving, which are largely absent in traditional methods. These interactive elements likely contributed to the experimental group's higher scores.

The performance gap between the groups also supports the findings of Freeman et al. (2014), who argued that practical, inquiry-orientated activities not only improve students' understanding of science concepts but also enhance retention and application skills. In the current study, the ISA model's

"Immersion" and "Application" phases gave students direct opportunities to apply genetic principles in contextualised situations, deepening their grasp of complex concepts such as dihybrid crosses, genetic variation, and inheritance patterns. By contrast, the control group primarily engaged in note-taking and listening to teacher explanations, consistent with Renninger's (2024) critique that teacher-centred methods foster passive learning and limit opportunities for higher-order thinking.

Moreover, Renninger (2024) further highlighted that contextualising learning to students' lived experiences enhances both motivation and achievement. In this study, the ISA model incorporated examples from Ghanaian cultural and environmental contexts, such as local agricultural practices and hereditary traits common in the population, which may have made the subject matter more relatable and memorable for the experimental group. This kind of contextualisation is often missing from traditional lecture formats, which can appear abstract and disconnected from students' realities.

The findings also align with Zudaire & Napal Fraile (2021) conclusion that cooperative and collaborative learning environments create conditions for students to learn from one another, fostering peer support and reinforcing understanding through discussion and shared problem-solving. These dynamics were present in the ISA model but largely absent in the control group, further explaining the observed performance differences. Overall, the statistically significant advantage of the ISA model over the traditional approach reinforces the reviewed literature's claim that active, learner-centred, and contextually relevant teaching methods are more effective for developing both conceptual understanding and practical application skills in science subjects. The results of this study therefore provide strong empirical support for adopting the ISA model in senior high school genetics instruction as a means of improving students' learning outcomes beyond what is achievable through conventional methods.

What is the difference in performance between boys and girls taught genetics using the ISA model at the Senior High School?

The results are consistent with studies where both male and female biology students benefited equally from inquiry-based and cooperative learning activities (Annan et al., 2019; Russo-Tait, 2023). In the current study, the ISA model's structuring phase ensured that all students, regardless of gender, actively participated in the learning process, collaborated with peers, and applied concepts in real-life scenarios. Such equitable engagement is likely to have contributed to the lack of performance disparity.

From a constructivist perspective, learning occurs most effectively when students are actively involved in constructing their own knowledge through meaningful interaction with content, peers, and teachers (Vygotsky, 1978). The ISA model's design, which incorporates immersion, structured guidance, and application, appears to have provided balanced opportunities for male and female students to engage with the material in ways that matched their abilities and interests. This supports Russo-Tait's (2023) argument that well-designed, collaborative science instruction can bridge traditional participation gaps between genders.

While some earlier studies have reported gender differences in science achievement due to factors such as prior exposure, confidence, and societal expectations (Sibisi et al., 2025), the absence of such differences in the present study may be attributed to the ISA model's emphasis on cooperative group work, peer discussion, and hands-on learning tasks. Though the effect size for the gender comparison in this study was small, further reinforcing the conclusion that the ISA model worked equally well for male and female students (Fritz et al., 2011). This has practical implications for science teaching in Ghanaian senior high schools, suggesting that adopting student-centred, contextually relevant instructional models like the ISA can promote gender equity in learning outcomes for complex subjects such as genetics.

In summary, the findings demonstrate that the ISA model not only improved overall academic performance but also supported equitable learning gains across genders. This supports the reviewed literature's assertion that when pedagogy is active, engaging, and inclusive, traditional gender gaps in science achievement can be minimised or eliminated (Russo-Tait, 2023).

Conclusions

The study findings reveal a strong association between the ISA instructional model and improved student performance in genetics. Despite the lack of random assignment, notable differences between experimental and control groups imply that the ISA's phases—Immersion, Structuring, and Application—support students' conceptual understanding and retention. Caution is advised as mediating factors like engagement and self-efficacy weren't measured, meaning conclusions about causality are not definitive. Additionally, the ISA model benefited students across genders, though unequal representation may have impacted gender power comparisons. Future research should use balanced samples and advanced modelling to provide clearer insights on gender effects and classroom dynamics.

Beyond its empirical findings, this study offers several practical implications for improving genetics instruction in resource-constrained senior high school settings. First, teacher-training modules should be developed to support educators in designing and implementing ISA-based lessons. Providing sample ISA lesson templates, step-by-step facilitation guides, and rubrics for inquiry activities can increase teachers' confidence and pedagogical readiness. Second, low-cost activity examples, such as household-material DNA models, paper-based simulations, and structured think-pair-share tasks, can help schools adopt the ISA approach without requiring advanced laboratory resources.

In conclusion, while additional research is needed to establish causal pathways and examine long-term impacts, the evidence presented in this study demonstrates that the ISA instructional model is a promising, inclusive, and contextually adaptable strategy for strengthening genetics education in senior high schools.

Research and Publication Ethics

In this study, all rules specified in the "Directive on Scientific Research and Publication Ethics of Higher Education Institutions" were followed. None of the actions specified under the second section of the Directive, "Actions Contrary to Scientific Research and Publication Ethics", have been carried out.)

Ethics committee permission information

Name of the committee that conducted the ethical assessment: Committee on Human Research Publication and Ethics-KNUST, Ghana.
Date of the ethical assessment decision: September 5, 2025.
Ethics assessment document number: CHRPE/AP/929/25

Disclosure Statements

1. Isaac Kwame Boafo served as the principal investigator and was responsible for the design, data collection, analysis, and drafting of the manuscript. Richmond Mensah and Maxwell Gyamfi assisted in the data collection and analysis. The study was supervised by Dr. Charles Amoah Agyei, who provided overall academic guidance and review support.
2. Authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgment

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The study was self-funded by the authors.

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