

Effects of Audio-visual and Simulation-based Learning Strategies on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

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Certification

This is to certify that Isyaku MOHAMMED with Matriculation Number LCU/PG/002678 carried out this research work titled “Effect of Audio-visual and Simulation-based Learning Strategies on Achievement in Genetics among Pre-Service Biology Teachers in Ogun State, Nigeria” in the Department of Science Education, Faculty of Education, Lead City University, Ibadan, Oyo State, for the Award of Master of Science Education Degree MSc(Ed) in Biology Education and that this work has not been previously submitted to any Institution for the award of any Degree or Certificate.

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Dedication

This research work is dedicated to God Almighty for His gift of life and absolute guidance.

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Abstract

The effectiveness of traditional teaching methods in Genetics education has often been questioned, especially as Pre-service Biology teachers struggle to comprehend abstract and complex Genetic concepts. This study determined the Effects of Audio-visual and simulation-based strategies on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria. Four hypotheses were formulated and tested at 0.05 level of significance. A pretest–posttest quasi–experimental design was applied. A total of 90 Biology education students, comprising 45 male and 45 female participants, took part in this study. Genetics Achievement Test (KR-20 = 0.79) and Guides for Instruction in Teaching and Learning of Genetics were used as instruments for data collection. Analysis of Covariance (ANCOVA) was used for data analysis. There was no significant main effect of audio-visual strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 57)} = 1.449, p > 0.05$). There was no significant main effect of simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 59)} = 0.809, p > 0.05$). There was significant main effect of gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 101)} = 4.559, p < 0.05$). There was a significant interaction effect of audio-visual strategy, simulation-based learning strategy and gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(5; 84)} = 7.921, p < 0.05$). It was concluded that a blended approach, incorporating both audio-visual Strategy and Simulation-based learning strategy while addressing gender-specific learning preferences, enhanced achievement in Genetics among pre-service Biology teachers in Ogun State, Nigeria. Based on the findings, it was suggested that educators should implement a blended approach that combines both audio-visual strategy and simulation-based learning strategy, while considering gender-specific learning preferences.

Keywords: Audio-visual Strategy, Simulation-based Learning Strategy, Traditional Teaching Strategy, Academic Achievement in Genetics

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List of Acronyms

Abbreviation	Meaning
DNA	Deoxyribonucleic Acid
STEM	Science, Technology, Engineering and Mathematics
PBL	Problem-Based Learning
VR	Virtual Reality
AR	Augmented Reality
UDL	Universal Design for Learning
CFTR	Cystic Fibrosis Trans-membrane Conductance Regulator
GMOs	Genetically Modified Organisms
CTML	Cognitive Theory of Multimedia Learning
ICT	Information and Communication Technology
GPT	Genetics Performance Test
SS2	Senior Secondary Two
ANOVA	Analysis of Variance
KR – 20	Kuder – Richardson
ANCOVA	Analysis of Covariance
AVS	Audio-Visual Strategy
SBLS	Simulation Learning Strategy
TLS	Traditional Learning Strategy
GAT	Genetics Achievement Test

Chapter One

Introduction

1.1 Background to the Study

Academic Achievement represents students' learning outcomes, often measured through assessments that reflect and skill development. The role of academic achievement is particularly pronounced in the knowledge acquisition sciences, where conceptual understanding is essential for higher education and professional competencies. Research indicates that academic achievement is influenced by a range of variables including instructional strategies, classroom environment, and learner motivation^{1,2}. Studies showed that students exposed to innovative teaching strategies often demonstrate higher academic achievement, particularly when these methods emphasize active and experiential learning³. Moreover, educational psychology underscores that academic achievement is often a predictor of future success in professional and academic pursuits, especially in Science, Technology, Engineering, and Mathematics (STEM) fields⁴.

Academic achievement is a critical determinant of educational success, particularly in specialized fields such as Biology in tertiary institutions. In Ogun State, Nigeria, Biology serves as a foundation for preparing future Biology teachers who are instrumental in shaping the scientific literacy of secondary school students. The subject encompasses various sub-disciplines, including Genetics, which is pivotal for understanding fundamental biological concepts and advancing scientific knowledge.

Biology in tertiary institutions aims to equip pre-service teachers with comprehensive knowledge of biological sciences and effective pedagogical strategies. Academic achievement in this field is influenced by several factors, including the quality of instruction, availability of resources, and students' intrinsic motivation. High academic

achievement not only enhances the competence of Biology Educators but also contributes to the development of critical thinking and problem-solving skills, which are essential for teaching complex topics such as Genetics. Academic Achievement in Biology, particularly in genetics, is pivotal for preparing competent Biology Educators in Ogun State. By addressing the challenges in Genetics and adopting innovative teaching strategies, colleges of education can bridge the gap between theoretical knowledge and practical application. This, in turn, will not only improve students' academic performance but also contribute to the advancement of Science Education in Nigeria^{3,4}.

Genetics, a foundational topic in Biology, presents complex concepts that are essential for students pursuing Biology at the colleges of Education in Ogun State, Nigeria. Understanding Genetics requires cognitive skills to grasp inheritance, Deoxyribonucleic acid (DNA) replication, gene expression, and mutation^{5,6}. Genetics, therefore, plays a crucial role in developing Biology teachers who will later transfer this knowledge to their students. However, Genetics concepts have traditionally been challenging for students, partly due to their abstract nature⁷. Researchers emphasize that instructional strategies enhancing visualization and interactivity can help pre-service Biology teachers comprehend Genetic principles effectively⁸.

In recent years, various instructional strategies have been introduced to improve students' academic achievement, including inquiry-based learning, project-based learning, and cooperative learning. Inquiry-based learning encourages students to explore scientific questions, fostering critical thinking and problem-solving skills⁹. Project-based learning involves students in real-world problems, leading to deeper understanding and long-term retention of knowledge¹⁰. Cooperative learning strategies have also proven effective by

encouraging peer interaction, which reinforces understanding¹¹. Despite these advances, research reveals mixed outcomes, as not all students benefit equally from these methods. Consequently, strategies like audio-visual aids and simulation are emerging as potentially effective approaches to address the gaps in traditional learning methods, especially in subjects like Genetics where visual and interactive content can aid comprehension¹².

To improve academic achievement in Genetics, innovative teaching strategies are essential. Simulation strategy, which involve creating virtual models of genetic processes, allow students to visualize and manipulate abstract concepts, leading to better understanding and retention. Similarly, audio-visual interventions, such as animated videos and interactive tutorials, can simplify complex topics and engage students more effectively¹². In the evolving landscape of education, innovative teaching strategies have emerged as essential tools to enhance learning outcomes and promote academic achievement. Among these strategies, audio-visual intervention stands out as a powerful strategy to bridging the gap between abstract concepts and learners' comprehension¹³. By integrating multimedia elements such as videos, animations, and interactive simulations, audio-visual intervention has the potential to revolutionize education, particularly in subjects that require visualization of complex processes, such as Biology.

Audio-visual intervention strategy leverage the combination of auditory and visual stimuli to create a dynamic learning environment. This strategy aligns with the principles of dual-coding theory, which suggests that individuals learn better when information is presented in both verbal and visual formats. By appealing to multiple senses, audio-visual materials enhance engagement, improve memory retention, and cater to diverse learning styles¹³. In subjects like Biology, where understanding complex

systems such as genetics, ecology, or cell Biology is crucial, audio-visual tools can simplify intricate processes. For instance, animated videos can illustrate the step-by-step mechanisms of DNA replication, while interactive simulations allow students to explore genetic inheritance patterns. This intervention not only make learning more enjoyable but also improve students' grasp of challenging concepts^{13, 14}.

Audio-visual intervention strategy offer several advantages that directly contribute to better academic performance: By providing clear and engaging representations of complex topics, audio-visual materials enable students to understand concepts that might otherwise seem abstract or confusing. Visual and auditory elements capture students' attention and maintain their interest throughout the lesson, reducing the likelihood of cognitive overload or distraction. The integration of visuals with narration reinforces learning, making it easier for students to recall information during assessments. Audio-visual tools cater to diverse learning needs, including those of students with disabilities, such as visual or hearing impairments, by providing alternative formats for content delivery¹³.

In Biology classrooms, audio-visual intervention have been particularly effective in addressing the challenges of teaching intricate and dynamic processes. For example: Virtual laboratory and simulations allow students to experiment with genetic crosses, observe ecosystem interactions, or manipulate variables in physiological systems without the constraints of traditional laboratories. Videos on topics such as Evolution, Climate change, or human anatomy provide vivid, real-world contexts for theoretical concepts. Online platforms offer step-by-step guides to topics like cell division, making them more accessible and interactive for learners^{12,15}.

Despite their benefits, the adoption of audio-visual strategy is not without challenges. Limited access to technological resources, lack of teacher training, and the high cost of quality audio-visual materials can hinder their implementation. To overcome these barriers, stakeholders in education must: Invest in affordable and user-friendly audio-visual tools. Provide professional development programmes to equip educators with the skills to effectively use these tools. Foster collaborations between educational institutions and technology developers to create curriculum-aligned resources. Audio-visual Intervention Strategies hold immense potential to transform teaching and learning by making education more engaging, accessible, and effective. By integrating these tools into the classroom, educators can enhance academic achievement, particularly in subjects like Biology, where visualization is key. As technology continues to advance, Audio-visual Interventions will undoubtedly play an increasingly vital role in shaping the future of education^{12,16}.

Audio-visual intervention leverages multimedia resources to enhance the learning experience, combining visual and auditory stimuli that help students understand and retain information¹³. Such interventions are particularly effective for abstract topics like Genetics, where visualization of cellular processes and Deoxyribonucleic acid (DNA) structures is essential¹⁴. Studies indicate that when complex topics are taught using videos, animations, and interactive media, students' comprehension and retention improve significantly¹⁵. In Biology, audio-visual aids can make abstract concepts concrete, providing an engaging and intuitive learning experience¹⁶. Thus, Audio-visual Intervention hold promise for pre-service Biology teachers, equipping them with foundational knowledge in Genetics through interactive, multisensory engagement.

In the quest to improve teaching and learning outcomes, simulation strategy has emerged as a transformative educational tool. This strategy involves creating realistic, interactive models of processes, systems, or phenomena to provide learners with hands-on experience in a controlled environment. Simulation-based strategy have been particularly impactful in science education, where understanding complex and dynamic processes often challenges students. By enabling learners to experiment and interact with simulated scenarios, this strategy fosters deeper comprehension and enhances academic achievement. Simulation strategy is instructional model that replicate real-world processes or systems using digital or physical models. These tools allow students to explore, experiment, and analyze phenomena that might otherwise be inaccessible due to limitations in resources, time, or safety. For example, in Biology, simulations can model cellular processes, genetic inheritance, or ecological systems, enabling students to visualize and manipulate variables in ways that traditional teaching methods cannot achieve^{17,18}.

Simulation-based strategy offer several advantages that contribute to academic success: Simulations engage students in active exploration, encouraging them to participate in their learning process rather than passively receiving information. By visualizing abstract concepts and experimenting with different scenarios, students develop a deeper understanding of subject matter. Simulations provide a risk-free environment for students to explore hazardous or delicate processes, such as chemical reactions or genetic modifications. Simulations help students build critical thinking, problem-solving, and decision-making skills by allowing them to test hypotheses and

evaluate outcomes. Virtual simulations reduce the need for expensive laboratory equipment or fieldwork, while offering similar, if not superior, learning experiences^{12,17}.

Despite the advantages, implementing Simulation-based strategy face several challenges: High-quality simulations often require advanced technology and significant financial investment. Educators need proper training to effectively integrate simulations into their teaching practices. Excessive dependence on simulations may reduce opportunities for hands-on experimentation in traditional laboratories. To address these issues, educational stakeholders should: provide affordable simulation tools and software. Train teachers in the effective use of simulation strategy. Integrate simulations-based with hands-on activities to balance virtual and physical learning experiences¹⁷.

Simulation-based learning is an instructional strategy that replicates real-life processes in controlled environments, allowing students to explore complex systems and scenarios¹⁷. In Genetics, simulations can enable students to experiment with gene expression and mutation processes, facilitating a hands-on experience in understanding abstract principles¹⁸. Simulations support experiential learning, fostering active engagement by allowing students to manipulate Genetic models and observe potential outcomes¹⁹. Research shows that simulation-based learning enhances problem-solving skills, critical thinking, and conceptual understanding, making it a suitable strategy for pre-service Biology teachers who need a robust understanding of Genetics to teach effectively²⁰.

Gender differences in academic achievement have been a focal point in educational research, with findings often suggesting that male and female students may respond differently to instructional strategies²¹. In science education, some studies reveal

that female students generally outperform male counterpart in comprehension and retention, whereas male students may excel in spatial and technical aspects²². This variation in achievement may be attributed to social, cognitive, and cultural factors highlighting the need for gender-sensitive teaching strategies²³. As pre-service teachers prepare for careers in education, examining gender as a moderating variable in Genetics achievement could help identify and address learning gaps, promoting equal access to effective instruction regardless of gender.

In co-educational classrooms, these disparities are sometimes perpetuated by teacher biases, peer dynamics, and curriculum design. For example, male students might receive more attention in science laboratories, while female students may be encouraged to focus on collaborative or nurturing roles. To create a more equitable education system, it is essential to address the root causes of gender disparities through: developing inclusive curricula that challenge stereotypes and encourage both genders to explore diverse fields of study; equipping educators with the skills to recognize and counteract gender biases in their teaching practices; promoting role models of both genders in non-traditional fields to inspire students to break stereotypes; providing mentorship programmes, scholarships, and safe spaces to empower underrepresented genders in specific academic disciplines²².

Gender continues to influence educational access, engagement, and outcomes, shaping the academic trajectories of learners in profound ways. While significant progress has been made in reducing disparities, achieving true gender equity requires sustained effort from all stakeholders, including policymakers, educators, and communities. By addressing systemic biases and fostering inclusive learning

environments, society can unlock the full potential of every individual, regardless of gender^{22,23}.

Despite the efficacy of Audio-visual and Simulation-based strategies in enhancing comprehension and retention, their application in Genetics for pre-service Biology teachers remains limited²⁴. Most existing research emphasizes general Biology without specific attention to Genetics or the unique needs of pre-service teachers²⁵. Additionally, while research has addressed the role of gender in academic achievement broadly, there is a need for further investigation into how gender moderates the effects of specific instructional strategies in science education, particularly in Nigerian tertiary institutions²⁶. Thus, this study aims to fill these gaps by determining the effects of audio-visual and simulation-based Strategies on achievement in Genetics among Pre-service Biology teachers, with gender as a moderating factor.

1.2 Statement of the Problem

The effectiveness of traditional teaching methods in Genetics has often been questioned, especially as pre-service Biology teachers struggle to comprehend abstract and complex Genetic concepts. Genetics, with its intricate processes involving Deoxyribonucleic acid (DNA), gene expression, and inheritance, requires a level of visualization and interactivity that conventional lecture-based methods may fail to provide. Consequently, many pre-service Biology teachers enter the teaching profession with insufficient understanding of Genetics, potentially impacting the quality of science education they can offer in their future classrooms. Emerging instructional strategies, such as audio-visual intervention and simulation-based learning, hold promise for

improving comprehension and retention in complex subjects. Despite these benefits, the application of these strategies remains understudied in Genetics course for pre-service Biology teachers, particularly in the Nigerian educational context. Given these challenges, this study aims to address the gap by determining the effects of audio-visual and simulation Strategies on achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria. By identifying the role of gender as a moderating factor, this study intends to provide insights into the optimal instructional strategies that could enhance Genetics course and equip future Biology teachers with a deeper, more applicable understanding of the subject.

1.3 Aim and Objectives of the Study

The aim of this study is to determine the effects of audio-visual and simulation-based strategies on achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.

The objectives were to:

- i. determine the main effect of audio-visual intervention strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria;
- ii. determine the main effect of simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria;
- iii. examine the main effect of gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria; and

- iv. examine the interaction effect of audio-visual intervention strategy, simulation-based learning strategy and gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.

1.4 Hypotheses

The following null hypotheses would be tested at 0.05 level of significance:

- H₀₁:** There will be no significant main effect of audio-visual intervention strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.
- H₀₂:** There will be no significant main effect of simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.
- H₀₃:** There will be no significant main effect of gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.
- H₀₄:** There will be no significant interaction effect of audio-visual intervention strategy, simulation-based learning strategy and gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.

1.5 Significance of the Study

This study, determined the effects of audio-visual and simulation-based strategies on Achievement in Genetics among Pre-service Biology teachers, holds considerable significance for various educational stakeholders, including students, teachers, curriculum planners, educational policymakers, and researchers. Each group stands to

benefit in unique ways from the insights and findings of this research, particularly in understanding and addressing the learning needs in complex topics like Genetics.

For students, particularly those who will eventually learn from pre-service teachers currently studying Genetics; this research has the potential to transform the quality of their learning experience. A strong understanding of Genetics among Biology teachers translates into a more comprehensive and engaging educational experience for students in secondary schools. The findings could help foster more interactive and understanding Biology lessons, where students are better able to grasp genetic concepts, increasing interest and proficiency in the topic. Given that Genetics is foundational to multiple disciplines in the biological sciences; this improved learning experience could inspire students to pursue careers in fields like biotechnology, medicine, and Genetic research, contributing to the development of Science, Technology, Engineering, and Mathematics (STEM) fields within Nigeria and beyond.

This study's insights would be valuable to present and future Biology teachers, including pre-service teachers who are still under preparation. By highlighting effective instructional strategies like audio-visual and simulation-based strategies, the research provides teachers with alternative tools to enhance students' comprehension and retention of complex Genetic concepts. Teachers could use the findings to develop more engaging lessons that cater to diverse learning preferences, addressing both visual and kinesthetic learners through the combination of visual aids and interactive simulations. Additionally, knowledge of how gender may moderate the effectiveness of these strategies enables teachers to tailor their instruction to address the unique needs of male and female students, ensuring that all learners have equal opportunities for success.

For curriculum planners, this study offers empirical evidence that could guide the development and structuring of Biology curricula, particularly in Colleges of Education. By demonstrating the efficacy of audio-visual and simulation-based strategies, this research supports the integration of these approaches into the Genetics curriculum for pre-service Biology teachers. Curriculum planners could develop specific modules or instructional units incorporating these strategies, allowing pre-service teachers to experience and practice using these tools during their preparation. This hands-on experience would prepare them to apply similar strategies effectively in their classrooms. Furthermore, the insights on gender as a moderating factor could guide curriculum planners in designing gender-sensitive instructional materials, ensuring that the curriculum is inclusive and responsive to different learning needs.

Educational policymakers can leverage the findings of this study to shape policies that encourage or mandate the use of innovative instructional strategies, such as audio-visual aids and simulation, particularly in Science, Technology, Engineering, and Mathematics (STEM) education. By providing evidence-based recommendations, this research could support policy initiatives aimed at enhancing the quality of science education in Nigerian schools and Colleges. Policymakers might consider funding or incentivizing the development of resources, preparation programmes, and infrastructure needed to implement these strategies effectively. Additionally, the gender-focused insights from this study could encourage policies promoting gender-sensitive instructional strategies in teacher preparation programmes, thus fostering a more inclusive educational environment that addresses the diverse needs of male and female students.

For researchers, this study contributes to the growing body of literature on instructional strategies and their impact on academic achievement, especially in science education. It fills an existing gap in the research on the role of audio-visual and simulation-based strategies in Genetics for pre-service teachers, with a specific focus on gender as a moderating variable. The study's findings can serve as a foundation for future research exploring similar interventions in other areas of science education or investigating other factors influencing the effectiveness of these strategies. Researchers interested in educational psychology, instructional design, or gender studies may find the results valuable for developing further studies on how instructional strategies could be optimized to improve learning outcomes in various educational contexts.

This study has the potential to impact various education stakeholders meaningfully. For students, it promises an enhanced and engaging learning experience in Genetics, with the potential to inspire future careers in Science, Technology, Engineering, and Mathematics (STEM) fields. For teachers, the research provides valuable instructional tools, empowering them to foster a more effective and inclusive classroom environment. Curriculum planners can use the findings to develop innovative, gender-sensitive curricula, while educational policymakers may rely on the evidence to shape policies that promote quality science education and inclusivity. Finally, researchers could build upon this study's findings, using them as a basis for further research in instructional strategies, science education, and gender inclusivity in learning. By addressing these diverse needs, this study aims to advance the overall quality of Biology and strengthen the foundation of science education in Nigeria.

1.6 Scope of the Study

This study focused on the effects of audio-visual and simulation-based strategies on pre-service Biology teachers' academic achievement in Genetics, specifically in Ogun State, Nigeria.

1.8 Limitation of the Study

The following limitations were observed throughout the course of conducting this study:

Technological Access: Limited access to or familiarity with technological tools among pre-service teachers hindered their participation and performance in the study.

Short Duration: The short period of the intervention limited the study's capacity to measure long-term retention and deeper learning impacts.

Assessment Limitations: Relying on achievement tests did not fully capture more complex learning outcomes, such as critical thinking and problem-solving skills.

1.8 Operational Definitions of Terms

Academic Achievement: Refers to the level of knowledge and skills that pre-service Biology teachers demonstrate in Genetics, measured through pre-tests, post-tests, assignments, and observational assessments.

Genetics: In this study, Genetics covers core topics in the Biology curriculum for pre-service teachers, focusing on concepts that are often challenging to comprehend without interactive or visual learning aids.

Pre-service Biology Teachers: These are students enrolled in teacher preparation programmes, specifically in University of Ibadan (Affiliated), Lagos State University

(Affiliated) and Open University of Nigeria (NOUN), Abeokuta in Ogun State, who are studying Biology as their major subject.

Audio-visual Aids: In this study, audio-visual aids are used to enhance pre-service teachers' understanding of complex Genetic concepts by offering visual representations that make abstract processes easier to grasp.

Simulation-based Strategy: This strategy is used in the study to foster deeper engagement and understanding of Genetics through hands-on, interactive experiences.

Gender: In this study, gender serves as a moderating variable, meaning that the impact of audio-visual and simulation strategies on academic achievement in Genetics may vary based on the participants' gender.

Traditional Learning Strategy: In this study, traditional strategy serve as a comparison to determine the relative effectiveness of audio-visual and simulation-based strategies in enhancing Genetics comprehension among pre-service Biology teachers.

Instructional Strategies: In this study, the main instructional strategies determined are audio-visual and simulation-based, each intended to improve pre-service teachers' understanding and retention of Genetic concepts.

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Chapter Two Literature Review

This chapter reviews the related literature and it is arranged under the subsequent subheadings:

2.1 Conceptual Review

2.1.1 Academic Achievement

2.1.2 Biology

2.1.3 Genetics

2.1.4 Teaching Strategies

2.1.2.1 Audio-visual Intervention Strategy

2.1.2.2 Simulation-based Strategy

2.1.3.3 Traditional Teaching Strategy

2.1.5 Gender

2.2 Theoretical Framework

2.2.3 Multimedia Learning Theory

2.3 Review of Empirical Studies

2.3.1 Audio-visual Strategy and Academic Achievement in Genetics

2.3.2 Simulation-based Strategy and Academic Achievement in Genetics

2.3.3 Gender and Academic Achievement in Genetics

2.4 Conceptual Model

2.5 Summary of Literature Reviewed

2.1 Conceptual Review

2.1.1 Academic Achievement

Academic Achievement is a multifaceted concept that encompasses a learner's level of proficiency, knowledge, and skills in a particular subject area, typically evaluated through various assessments, tests, and assignments. In education, academic achievement is a critical indicator of both individual student progress and the effectiveness of educational programs. It serves as a benchmark to assess learners' ability to comprehend, apply, and analyze subject-specific content and is influenced by a variety of cognitive, emotional, and social factors^{1,2}. Academic achievement, particularly in science and technical subjects, has become a focal point in educational research due to its implications for student success and broader societal development.

Academic achievement is a foundational concept in education, representing the outcomes of learning processes and the ability of individuals to meet specific educational objectives. It is typically assessed through metrics such as grades, standardized test scores, and the completion of academic programs. Academic achievement reflects the knowledge and skills students acquire over time and their ability to apply these in various contexts. Beyond grades and tests, it often includes accomplishments in extracurricular activities, research, and community service, which demonstrate a well-rounded ability to succeed in diverse educational settings¹.

The factors influencing academic achievement are diverse and complex, ranging from individual characteristics to systemic issues. At the individual level, factors like intelligence, motivation, and learning styles play critical roles. For instance, students with high levels of intrinsic motivation often perform better as they find joy and purpose in

learning. External factors, such as the quality of teaching, access to educational resources, and classroom environment, also significantly impact outcomes. Socioeconomic status is another critical determinant, as students from more privileged backgrounds often have access to better schools, learning materials, and support systems².

Parental involvement and support also play a pivotal role in fostering academic achievement. Parents, who actively participate in their children's education, such as by helping with homework or attending school meetings, can enhance their child's performance. This involvement creates a supportive environment that values education and encourages children to set and achieve goals. Moreover, cultural attitudes toward education can shape a student's aspirations and determination. In many cases, societies that place a high emphasis on education tend to produce higher levels of academic achievement^{2,3}.

In the broader context, academic achievement has significant implications for individuals and society. For individuals, it serves as a stepping stone to higher education and career opportunities, contributing to personal development and economic mobility. On a societal level, higher levels of academic achievement are associated with economic growth, innovation, and improved social outcomes. Educated populations tend to have better health, lower crime rates, and increased civic engagement, highlighting the far-reaching impact of education on societal well-being³.

Ultimately, academic achievement is more than just a measure of intelligence or aptitude; it encompasses persistence, discipline, and the ability to overcome challenges. It reflects a student's commitment to learning and their capacity to adapt and excel in dynamic environments. As education systems evolve to address global challenges,

academic achievement remains a critical benchmark for success, guiding policies and practices aimed at nurturing the potential of individuals and communities alike^{1,3}.

A significant body of research indicates that academic achievement goes beyond rote memorization and is closely tied to critical thinking, problem-solving, and the application of knowledge in practical settings^{3,4}. For instance, in science education, students are expected to achieve a level of understanding that allows them not only to recall scientific facts but also to apply them in experimental and real-world contexts. This view is supported by recent studies that highlight the importance of experiential and interactive learning in promoting higher academic achievement in complex subjects like Biology and Genetics^{5,6}.

In the context of pre-service Biology teachers, academic achievement in specific areas such as Genetics is particularly crucial. Genetics is a complex subject that requires a deep understanding of abstract concepts, and pre-service teachers' proficiency in this area can significantly impact their future effectiveness as educators⁷. Academic achievement in Genetics involves mastery of topics such as DNA structure, gene expression, and heredity, which are essential for teaching Biology effectively. Studies suggest that pre-service teachers' academic achievement in subjects like Genetics strongly correlates with their confidence and capability in teaching these subjects, thereby directly influencing students' learning outcomes⁸.

The concept of academic achievement is also influenced by various instructional strategies employed in teaching. Research highlights that traditional lecture-based methods may be insufficient for complex subjects, leading to superficial understanding and low academic achievement⁹. Conversely, innovative teaching strategies such as

audio-visual aids and simulations have been shown to significantly improve students' comprehension and retention of complex topics¹⁰. In subjects like Genetics, where visualizing abstract processes is key, audio-visual interventions and simulation strategies can facilitate deeper learning and, consequently, higher academic achievement¹¹.

Additionally, academic achievement can be moderated by factors such as gender, socioeconomic status, and learning environment. Gender differences, in particular, have been noted in various studies, suggesting that male and female students may respond differently to instructional strategies, which can impact their academic achievement¹². For example, research found that interactive, hands-on learning approaches tend to benefit female students in science subjects, potentially because these methods align with their learning preferences¹³. Understanding these moderating factors is essential for designing inclusive educational programs that promote academic achievement across diverse student populations.

The assessment of academic achievement has also evolved with advancements in educational psychology and assessment practices. Contemporary models of assessment emphasize formative evaluation, which provides continuous feedback and encourages improvement, as well as summative assessments, which measure cumulative knowledge and skills¹⁴. Formative assessments, particularly in practical science subjects like Biology, allow educators to identify learning gaps and adjust instructional methods to better support students in achieving mastery¹⁵. Summative assessments, on the other hand, provide a comprehensive view of students' academic achievement over a term or course, enabling educators to make informed decisions about curriculum effectiveness and instructional quality.

In the context of this study, academic achievement in Genetics is measured through pre-tests, post-tests, and follow-up assessments to evaluate the impact of audio-visual and simulation strategies on pre-service Biology teachers' understanding and retention of Genetic concepts. As underscored by recent research, such interventions have been associated with improved academic achievement, particularly in content areas that require high levels of visualization and abstract reasoning^{16,17}. Therefore, this study situates academic achievement within the framework of instructional efficacy, examining how alternative teaching strategies can bridge the gap in knowledge and application among pre-service Biology teachers.

2.1.2 Biology

Biology often referred to as the science of life, is the natural science that deals with the study of living organisms and their interactions with one another and their environments. It is a vast and diverse field that encompasses various sub-disciplines such as Genetics, ecology, micro Biology, and evolutionary Biology. Biology is concerned not only with the structure, function, growth, and development of organisms but also with their behavior, adaptation to the environment, and the processes of reproduction and inheritance¹⁸.

Biology's primary goal is to understand the fundamental principles of life and the mechanisms that underpin the diversity of life forms on Earth. It is built upon the foundational concept of the cell, the basic unit of life, and the study of DNA and Genetics, which explain how traits are passed from one generation to the next¹⁹. One of the most significant advancements in Biology has been the discovery of the Genetic code, which

has led to an understanding of how living organisms inherit and express traits²⁰. This understanding has led to the development of modern biotechnologies such as Genetic engineering, cloning, and gene therapy, which have revolutionized the fields of medicine, agriculture, and environmental science²¹.

Biology also investigates the relationships between living organisms and their environments. Ecology, a branch of Biology, focuses on how organisms interact with one another and with their physical surroundings, and it provides insights into the sustainability of ecosystems and biodiversity conservation. The study of ecosystems and the role of species in maintaining ecological balance is critical to understanding the impact of human activities on biodiversity and the environment. With the growing concern over environmental issues such as climate change, pollution, and habitat destruction, Biology provides crucial knowledge to inform conservation efforts and sustainable practices²².

Evolutionary Biology is another important branch of the field, focusing on the processes that drive the diversity of life on Earth. The theory of evolution, proposed by Charles Darwin, has had a profound impact on our understanding of Biology by explaining how species evolve over time through natural selection²³. Evolutionary theory has not only shaped the way we view the history of life on Earth but also informs fields such as medicine, agriculture, and conservation. For example, understanding the principles of evolutionary Biology helps researchers combat antibiotic resistance and the spread of infectious diseases²⁴.

The study of Genetics within Biology has had a transformative impact, particularly with the advent of molecular Biology. Molecular Genetics investigates the

structure and function of genes at a molecular level and explores how Genetic information is encoded, replicated, and transmitted across generations²⁵. The ability to manipulate Genetic material has paved the way for significant advancements in biomedicine, including gene editing technologies such as CRISPR-Cas9, which allow for precise modifications to DNA and hold promise for treating Genetic disorders²⁶.

The importance of Biology in education has also grown significantly as society seeks to address complex challenges such as climate change, health crises, and food security. The teaching of Biology helps students develop critical thinking skills and an understanding of the natural world. It encourages students to engage with scientific inquiry and problem-solving techniques, equipping them with the tools necessary to tackle some of the most pressing global issues²⁷. As a result, Biology is considered a cornerstone of science education, with its principles being integral to many modern scientific fields, including biotechnology, medicine, and environmental science²⁸.

In the classroom, Biology is often taught using various methods such as lectures, laboratory experiments, and more recently, through digital simulations and virtual labs. These teaching strategies help students visualize complex biological processes that are otherwise difficult to comprehend, such as molecular interactions or Genetic inheritance patterns²⁹. The use of technology in Biology education has also made it possible to simulate biological experiments that would be too dangerous, expensive, or impractical to conduct in a real-world setting³⁰.

As the world continues to face significant biological challenges, including pandemics, climate change, and the loss of biodiversity, the role of Biology in research and education has never been more critical. Researchers in the field are actively working

to develop new medical treatments, sustainable agricultural practices, and conservation strategies that can help address global challenges³¹. Furthermore, the growing field of synthetic Biology, which combines engineering principles with Biology to create new, artificial life forms, holds potential for revolutionizing industries ranging from medicine to energy³².

Biology is a dynamic and interdisciplinary field that seeks to understand the complexities of life. It has practical applications in medicine, agriculture, environmental science, and biotechnology, and continues to evolve with advancements in technology and scientific understanding. As an area of study, it remains essential for educating future generations of scientists, healthcare professionals, and informed global citizens who can contribute to solving the world's most pressing issues.

2.1.5 Genetics

Genetics is the branch of Biology that focuses on the study of genes, heredity, and Genetic variation in organisms. It involves understanding how traits and characteristics are inherited from one generation to the next through the mechanisms of DNA, genes, and chromosomes. Genetics plays a pivotal role in explaining biological diversity, from the Genetic makeup of individuals to the evolution of species over time³³.

At the core of Genetics is the gene, a segment of DNA that carries the instructions for building proteins and regulating various cellular processes. Genes are inherited from parents to offspring, with variations in genes leading to different traits or phenotypic expressions, such as eye color, height, or susceptibility to certain diseases²⁵. The study of Genetics not only focuses on understanding how traits are passed down but also how

Genetic mutations or alterations can affect the function of genes and lead to Genetic disorders³⁴. This field has rapidly advanced over the years, providing insights into the molecular mechanisms that govern Genetic inheritance and expression, particularly with the advent of technologies such as CRISPR-Cas9, which allow for precise manipulation of Genetic material³⁵.

Genetics operates on the principles of Mendelian inheritance, which were first described by Gregor Mendel in the mid-19th century. Mendel's experiments with pea plants demonstrated that genes are inherited in discrete units, and that some traits are dominant over others. However, modern Genetics has expanded on Mendel's findings to include more complex inheritance patterns, such as incomplete dominance, co-dominance, and polygenic inheritance³⁶. For instance, while Mendel's work provided the foundation for understanding simple traits, it was later research that revealed that many traits are controlled by multiple genes (polygenes), and that environmental factors can also influence gene expression³⁷.

A fundamental concept in Genetics is the structure and function of DNA, the molecule that carries Genetic information. DNA is made up of nucleotides, which are composed of a sugar, phosphate group, and nitrogenous base. The sequence of these nitrogenous bases—adenine (A), thymine (T), cytosine (C), and guanine (G)—forms the Genetic code that dictates how proteins are produced in cells. The understanding of DNA's structure, pioneered by James Watson and Francis Crick in the 1950s, laid the groundwork for the entire field of molecular Genetics, which now studies how genes are expressed, how they interact, and how they can be manipulated for medical and agricultural purposes³⁸.

The sequencing of the human genome in the early 21st century was a monumental breakthrough that provided a complete map of the approximately 20,000-25,000 genes that make up human DNA³⁹. This genome-wide data has allowed researchers to explore Genetic links to a wide array of diseases, including cancer, heart disease, and neurological disorders, providing opportunities for more targeted treatments based on individual Genetic profiles. This has led to the emergence of personalized medicine, where Genetic information is used to tailor medical treatments to the Genetic makeup of individual patients, improving their outcomes and minimizing adverse effects⁴⁰.

Genetics also includes the study of Genetic variation within populations, which is crucial for understanding evolution and the Genetic basis of traits in populations. Genetic variation arises from mutations, which are changes in the DNA sequence, as well as from recombination during sexual reproduction. These variations contribute to the diversity of traits within a species and are essential for natural selection, the process by which advantageous traits become more common in a population over time³³. Evolutionary Genetics is a subfield that examines how Genetic changes over generations contributes to the adaptation of species to their environment, providing a deeper understanding of the mechanisms behind species evolution and speciation⁴¹.

In addition to natural selection, Genetics is also concerned with Genetic disorders that arise from inherited mutations. These disorders can be monogenic, resulting from mutations in a single gene, or polygenic, involving multiple genes. For instance, cystic fibrosis is a monogenic disorder caused by mutations in the CFTR gene, whereas conditions like heart disease and diabetes often involve complex interactions between Genetic and environmental factors²⁰. Recent advancements in gene therapy have provided

new avenues for treating Genetic disorders by directly altering defective genes, offering hope for patients with previously untreatable conditions³⁹.

Genetics has a wide range of practical applications in medicine, agriculture, and biotechnology. In medicine, Genetics is used to diagnose diseases, predict disease risk, and develop more effective treatments⁴². For example, Genetic testing can identify individuals at higher risk for diseases like breast cancer or Alzheimer, allowing for early interventions or preventive measures. In agriculture, Genetic engineering has been used to create genetically modified organisms (GMOs) that are resistant to pests, diseases, and environmental stress, improving crop yields and food security⁴³. Furthermore, Genetic tools are used in forensics to identify individuals or solve crimes and in conservation Biology to study Genetic diversity in endangered species and improve conservation efforts⁴⁴.

In educational settings, Genetics is an essential component of Biology curricula, as it helps students understand fundamental concepts such as inheritance, molecular Biology, and evolution. With the growing importance of Genetics in healthcare and biotechnology, it is increasingly important to equip students with a solid understanding of Genetic principles³³. Modern teaching methods, including virtual simulations and interactive models, are being used to enhance the learning experience in Genetics by allowing students to visualize complex Genetic processes, such as DNA replication, gene expression, and mutation⁴⁵.

Genetics is a rapidly advancing field that has transformed our understanding of life and provided numerous benefits to medicine, agriculture, and biotechnology. As research in Genetics continues to evolve, it promises to offer new insights into human

health, disease, and the development of sustainable solutions for the challenges faced by humanity.

2.1.4 Teaching Strategies

Teaching strategies encompass the various methods, techniques, and approaches that educators use to facilitate learning and improve students' academic achievement. Effective teaching strategies are critical to fostering understanding, critical thinking, and skill acquisition in diverse educational contexts. The choice of strategy often depends on factors such as subject matter, learning objectives, student characteristics, and available resources, with the goal of enhancing engagement and supporting learners' cognitive development^{46,47}. Contemporary education research suggests that a strategic approach to teaching, which considers both the learning environment and individual learning needs, leads to improved educational outcomes and better prepares students for real-world problem-solving⁴⁸.

Over the years, numerous teaching strategies have been developed and tested to address different types of learners and subject-specific challenges. Traditional teaching strategies, such as lectures and direct instruction, focus on delivering information in a structured manner and are especially useful for large groups or foundational knowledge delivery⁴⁹. However, as educational theories have evolved, more interactive and learner-centered strategies have gained prominence. These include inquiry-based learning, problem-based learning, team-based learning, and project-based learning, each of which emphasizes student engagement and critical thinking over rote memorization⁵⁰.

For example, inquiry-based learning encourages students to pose questions, explore answers, and develop understanding through investigation. This approach has been particularly effective in science education, where students benefit from actively constructing knowledge rather than passively receiving information⁵¹. Similarly, problem-based learning (PBL) focuses on real-world applications and critical problem-solving skills, which are essential in subjects such as Biology and chemistry⁵². Studies indicate that students exposed to problem-based learning and inquiry-based learning strategies tend to perform better in assessments requiring application and analysis, underscoring the role of interactive teaching strategies in fostering deeper learning⁵³.

One emerging focus in teaching strategy research is the integration of technology, particularly audio-visual aids and digital simulation, which cater to diverse learning preferences and allow for more interactive and engaging learning experiences. Audio-visual aids enhance learning by providing multiple representations of information, such as images, videos, and animations, making abstract concepts more accessible and understandable⁵⁴. For instance, audio-visual strategies are especially useful in complex subjects like Genetics, where visualizing DNA structures and processes aids in comprehension. Moreover, digital simulations offer interactive environments where students can experiment, make decisions, and see immediate outcomes, facilitating active learning and exploration of complex scientific processes⁵⁵.

Simulation-based teaching strategies have become increasingly popular in fields that require hands-on practice, such as Biology, engineering, and medicine. Simulation allows students to learn in risk-free environments, practicing skills and applying knowledge without the consequences associated with real-life scenarios. Research shows

that simulation improves both knowledge retention and skill proficiency, as it requires students to actively engage and make decisions within the simulated context. For pre-service Biology teachers, simulation-based strategies offer the opportunity to understand Genetics through practical application, building confidence and competence in teaching complex scientific content⁵⁶.

Teaching strategies are also evolving to address diverse learner needs and promote inclusivity. Differentiated instruction, for instance, is a strategy that tailors teaching methods and materials to accommodate varied learning styles, abilities, and interests within a single classroom⁵⁷. Differentiation may include providing various levels of reading materials, using a mix of individual and group work, and offering choices in assignments, which together enhance engagement and accessibility. This approach aligns with the Universal Design for Learning (UDL) framework, which emphasizes creating flexible learning environments that can accommodate all learners and remove barriers to academic success⁵⁸.

Moreover, cooperative learning, which involves students working in small groups to achieve shared learning goals, has proven effective in promoting both academic achievement and social skills⁵⁹. This strategy encourages peer-to-peer interaction, fostering communication, collaboration, and empathy among students. Research indicates that cooperative learning is particularly beneficial in subjects where discussion and idea exchange enhance understanding, such as Biology and social sciences⁶⁰. In the context of this study, examining team-based and project-based learning strategies within Genetics education highlights how cooperative strategies can enhance pre-service teachers' mastery of scientific concepts.

Gender-sensitive teaching strategies have also garnered attention, recognizing that students may experience and respond to instructional methods differently based on gender. Studies suggest that certain teaching strategies, such as interactive learning and visual aids, may be particularly beneficial for female students in traditionally male-dominated subjects like Science, Technology, Engineering, and Mathematics (STEM)⁶¹. In this study's context, understanding how audio-visual and simulation strategies affect male and female pre-service teachers differently can contribute to developing inclusive teaching approaches that address gender-based learning preferences and promote equal learning opportunities.

Finally, research underscores the importance of adaptive teaching strategies that enable teachers to respond to classroom dynamics and students' evolving needs. Adaptive teaching is a responsive approach that involves modifying instructional methods based on real-time assessment of student understanding⁶². Teachers who use adaptive strategies may adjust lesson pacing, revisit complex topics, or incorporate additional resources to support students who may be struggling. Adaptive teaching strategies align with formative assessment, a process where educators use ongoing feedback to guide instruction and improve learning outcomes, thereby supporting both struggling students and those who excel⁶³.

Teaching strategies have evolved from teacher-centered to student-centered approaches, emphasizing interactivity, technology integration, and inclusivity. By understanding and implementing effective teaching strategies, educators can significantly enhance student learning outcomes, particularly in challenging subjects like Genetics. This study's focus on audio-visual and simulation strategies, with consideration for

gender differences, contributes to the growing body of knowledge on adaptive and inclusive instructional practices in science education, offering insights that can benefit both educators and students in achieving higher academic performance.

2.1.2.1 Audio-visual Intervention Strategy

Audio-visual intervention strategy refers to the deliberate use of audio and visual aids in teaching to enhance learning experiences and improve academic performance. This strategy integrates materials such as videos, graphics, animations, and sounds into instruction, aiming to stimulate multiple sensory modalities, which can deepen students' understanding and retention of information^{64,65}. As educational theories emphasize that learning is enhanced when learners engage with content in diverse ways, audio-visual interventions have gained traction for their capacity to make abstract or complex concepts more accessible and engaging⁶⁶.

One of the key advantages of Audio-visual interventions is their ability to engage students actively. By presenting information in visually appealing and stimulating formats, these tools capture attention and maintain interest. For example, a historical event can be brought to life through a documentary, or a scientific concept can be illustrated with animated diagrams. This increased engagement fosters motivation and creates a more enjoyable learning environment, particularly for students who might otherwise struggle with traditional teaching methods⁶⁴.

Audio-visual tools are also effective in simplifying complex concepts. Visualizing intricate processes, such as chemical reactions or engineering mechanisms, makes them more accessible to learners. For auditory learners, tools like podcasts or narrated

explanations offer an effective way to process information. By combining auditory and visual elements, the strategy ensures that learners with different preferences can grasp the material. This dual approach aligns with the dual-coding theory, which suggests that combining verbal and visual information enhances memory and understanding⁶⁶.

In modern education, audio-visual interventions play a crucial role in supporting various teaching models. They are essential in distance learning, where recorded lectures, virtual simulations, and interactive videos provide flexibility and depth. In traditional classrooms, tools like slideshows, videos and info-graphics add diversity to lesson delivery. Additionally, these strategies are particularly beneficial in special education, as they offer alternative ways for students with disabilities or language barriers to engage with content effectively^{64,66}.

However, successful implementation of audio-visual strategies requires careful planning. Over-reliance on technology can diminish critical thinking and creativity if not balanced with interactive or hands-on learning. Additionally, access to the necessary technological infrastructure remains a challenge for underserved schools and communities. Teachers must also ensure the quality and relevance of the content to align with educational goals and avoid unnecessary distractions⁶⁵.

Audio-visual intervention strategies are transformative tools in education, offering a multisensory approach to teaching and learning. By engaging students, simplifying complex topics, and accommodating diverse needs, these strategies enhance the overall learning experience. When thoughtfully integrated, they not only improve knowledge retention but also prepare students for the demands of an increasingly digital and visual world^{65,66}. In recent years, audio-visual intervention strategies have been increasingly

recognized as effective tools for teaching complex subjects, especially in fields such as science and technology, where visual representations can aid comprehension. For example, in Biology, where students often struggle with visualizing cellular processes and molecular structures, animations and 3D models help to make these abstract concepts concrete⁶⁷. By enabling students to see and hear content in ways that would be difficult to grasp through text alone, audio-visual materials encourage more active learning and can lead to higher levels of engagement and achievement⁶⁸.

Research shows that audio-visual interventions can be particularly beneficial in reinforcing students' understanding through the dual coding theory, which suggests that people learn better when information is presented through both verbal and visual channels⁶⁹. When learners receive information in multiple formats, it allows for encoding in multiple memory systems, leading to greater retention and easier retrieval⁷⁰. This principle underpins the success of audio-visual strategies in academic settings, where combining words with images or sounds can significantly improve learning outcomes. For instance, in a study, students who watched videos that visually demonstrated scientific processes performed better on assessments than those who learned through text-based materials alone⁷¹.

The use of audio-visual intervention has also become more feasible and effective due to advances in educational technology. Interactive video platforms, virtual simulations, and augmented reality provide immersive experiences that traditional methods lack, catering to different learning preferences and allowing for personalized learning. For example, interactive simulations in Genetics can enable students to manipulate DNA structures and observe Genetic outcomes, making learning more hands-

on and experiential⁴⁰. This is particularly valuable for pre-service teachers, who benefit from experiencing complex scientific content in ways they can later replicate in their own classrooms⁷².

Audio-visual interventions are aligned with the constructivist theory of learning, which posits that students construct their understanding through active engagement with material. By incorporating visual and auditory elements, educators facilitate a richer, more engaging environment where learners can interact with and relate to content meaningfully⁷³. For example, using videos in Genetics education not only clarifies the complex processes involved but also invites students to engage with real-world applications, making the material relevant to their lives and future careers as Biology teachers. Studies suggest that audio-visual tools help in breaking down these complex concepts, reducing cognitive load, and allowing students to focus on core ideas rather than becoming overwhelmed by abstract terminology⁷⁴.

The benefits of audio-visual interventions extend to various levels of cognitive and affective learning. At the cognitive level, they improve comprehension, memory retention, and application of knowledge⁷⁵. At the affective level, they enhance motivation, interest, and engagement, which are particularly important for maintaining students' attention in challenging subjects. For instance, research found that students demonstrated greater interest and a more positive attitude toward learning when audio-visual aids were used in instruction compared to traditional lecture-based methods. This increased engagement is linked to improved self-efficacy and a more positive learning experience, which are essential for developing future educators who feel confident in their subject matter⁷⁶.

Audio-visual strategies are also noted for their role in supporting inclusive education, addressing diverse learning needs, and enhancing accessibility for students with different learning styles or language backgrounds. Visuals can bridge language barriers and help students grasp content even when language proficiency may be a barrier⁷⁷. Additionally, students with learning disabilities, such as dyslexia, can benefit from video and audio resources as alternatives to text-heavy learning materials, allowing them to engage with content in ways that align with their strengths and needs⁷⁸. Audio-visual interventions thus contribute to an equitable learning environment where all students have access to content in formats that best support their learning.

A critical advantage of audio-visual intervention is its adaptability to modern classroom technology. With the increased availability of digital tools such as smartphones, tablets, and interactive whiteboards, audio-visual content can be easily integrated into classroom instruction, homework assignments, and online learning platforms⁷⁹. This flexibility allows educators to incorporate multimedia resources in real-time, enhancing the responsiveness of teaching to students' needs and supporting a dynamic and interactive learning environment.

Despite its benefits, the successful implementation of Audio-visual strategies requires thoughtful planning and alignment with instructional goals. Simply incorporating videos or graphics does not guarantee learning; the content must be meaningful and designed to enhance understanding rather than distract or overwhelm students. Effective audio-visual intervention should align with learning objectives, avoid extraneous details, and focus on core concepts to reduce cognitive load⁸⁰. This deliberate and focused

approach ensures that audio-visual materials support rather than hinder students' cognitive processing, making learning both effective and efficient.

Audio-visual intervention strategy is a powerful and flexible teaching approach that leverages multimedia elements to enrich the learning process. Through visual and auditory resources, educators can present complex information more accessibly, engage students more effectively, and support diverse learning needs. In the context of this study, the exploration of audio-visual strategies in Genetics education aims to assess their potential for improving academic outcomes among pre-service Biology teachers. Given the complex and abstract nature of Genetic concepts, audio-visual interventions hold promise for enhancing understanding, retention, and application, ultimately contributing to the preparation of well-equipped educators for the next generation.

2.1.2.2 Simulation-based Strategy

Simulation-based strategy is an educational approach that uses interactive and often immersive models to replicate real-world processes, scenarios, or environments. This method allows learners to practice skills, solve problems, and make decisions in a controlled, risk-free setting. Simulations can range from role-playing exercises and computer-based models to sophisticated virtual reality (VR) systems. By mimicking real-life conditions, simulation strategies provide hands-on, experiential learning opportunities that enhance comprehension and prepare learners for practical applications⁸¹.

A key feature of simulation-based strategies is their ability to provide experiential learning, where students actively engage in the learning process rather than passively absorbing information. For example, medical students may use patient simulators to

practice diagnosing and treating conditions, while pilots use flight simulators to train for various scenarios without real-world risks. This hands-on approach enhances critical thinking and problem-solving skills, allowing learners to apply theoretical knowledge in practical contexts⁸².

Simulations also offer the advantage of safe failure, enabling learners to make mistakes without real-world consequences. This is particularly valuable in high-stakes fields like medicine, engineering, and emergency management, where errors in real-life scenarios can have serious repercussions. By practicing in a simulated environment, students can refine their skills and decision-making abilities, gaining confidence and competence in their respective fields⁸³.

Another significant benefit of simulation-based strategies is their capacity to create realistic and immersive experiences. Advances in technology, such as augmented reality (AR) and virtual reality (VR), have made simulations more lifelike, enhancing their effectiveness. For instance, business students might use simulations to test strategies in virtual market environments, while soldiers train in combat scenarios using virtual reality (VR). These tools foster engagement, improve retention, and make learning more impactful^{81,83}.

However, simulation strategies also present challenges. They can be resource-intensive, requiring significant investment in technology, infrastructure, and training. Additionally, designing effective simulations that accurately replicate real-world scenarios while meeting learning objectives requires careful planning and expertise. Educators must also ensure that simulations are accessible and inclusive to prevent disparities in learning opportunities. Simulation strategies are powerful tools for bridging

the gap between theory and practice. By offering experiential, risk-free, and immersive learning experiences, they prepare students for real-world challenges and decision-making. Despite their challenges, when thoughtfully implemented, simulation strategies can significantly enhance educational outcomes and equip learners with the skills and confidence needed for success in their fields^{81,82}.

Simulation-based strategy in education refers to the use of artificially created scenarios or environments that mimic real-world processes, systems, or events to enhance learning by allowing students to practice, observe, and analyze outcomes in a controlled, risk-free environment. This approach is grounded in experiential learning theory, which asserts that individuals learn best through active engagement with real-life situations and by reflecting on their experiences⁸¹. In educational settings, simulations provide a means for students to engage in complex tasks, interact with dynamic systems, and explore theoretical concepts in a practical context⁸². Simulations can take various forms, including role-playing exercises, virtual environments, interactive models, or games that replicate the conditions of a specific field of study, such as Genetics, healthcare, engineering, or business⁸³.

Simulations have been recognized for their effectiveness in disciplines that require hands-on skills, critical thinking, and problem-solving. In science education, especially in fields like Biology and Genetics, simulations offer learners the opportunity to visualize and interact with abstract concepts, such as Genetic inheritance patterns or cellular processes that are difficult to represent through traditional methods like textbooks or lectures⁸⁴. For example, virtual lab simulations allow students to conduct experiments that might be too costly, dangerous, or time-consuming in real life, such as manipulating

Genetic sequences or observing the impact of Genetic mutations on phenotypic traits. These experiences not only help students grasp complex concepts but also build critical thinking and decision-making skills by requiring them to apply theoretical knowledge in practical situations⁸⁵.

Recent studies suggest that simulation-based learning environments promote deeper understanding and better retention of content compared to traditional instructional methods. A study found that students who used virtual simulations to learn about cellular Biology showed a significant increase in their ability to recall key concepts and apply them in novel contexts compared to those who learned using textbook-based methods alone. This is because simulations provide interactive and immersive experiences that engage multiple senses, thus reinforcing learning and promoting long-term retention^{86,87}. Simulations can also enhance motivation and engagement, as students tend to find these experiences more enjoyable and rewarding compared to passive forms of learning. By offering opportunities for experimentation, trial and error, and immediate feedback, simulations create a learning environment where students can safely make mistakes and learn from them without the fear of real-world consequences⁸⁸.

One of the key advantages of simulation-based learning is its ability to cater to diverse learning styles. Visual learners benefit from the interactive graphics and animations that illustrate abstract concepts, while kinesthetic learners can engage in hands-on activities within virtual labs. Auditory learners, on the other hand, may benefit from the verbal instructions and feedback provided in simulations. This multimodal approach helps ensure that all students, regardless of their preferred learning style, have an opportunity to engage with the material in a way that best supports their learning⁸⁹.

Additionally, simulations promote collaborative learning by allowing students to work together in team-based tasks, fostering communication, teamwork, and social interaction—skills that are essential in the workplace⁹⁰.

In the context of pre-service teacher education, simulations are particularly valuable because they enable students to engage with real-world teaching scenarios without being in an actual classroom. For example, in science teacher training, simulations can be used to model classroom teaching techniques, manage student behavior, or simulate challenging teaching moments, all of which prepare future teachers for the realities of the classroom⁹¹. Moreover, simulations allow pre-service teachers to experiment with different instructional methods and strategies, giving them the opportunity to learn from their actions in a reflective, low-risk environment⁹². These opportunities help pre-service teachers develop confidence in their abilities to manage complex classroom situations and use innovative teaching methods.

Simulations also provide valuable formative assessment opportunities, allowing both students and instructors to gauge understanding and skills development in real-time. Instructors can monitor students' interactions within simulations, providing immediate feedback and guidance to improve learning outcomes. This ongoing feedback loop enhances the learning process by helping students identify areas for improvement and make adjustments before moving on to more complex tasks⁹³. For instance, in a Genetics simulation, students can manipulate Genetic sequences and observe the resulting phenotypic outcomes. Instructors can assess students' understanding of Genetic principles based on their decisions within the simulation, offering insights into their grasp of the material and areas that may need further clarification.

The benefits of simulation-based learning extend beyond academic achievement. These strategies foster skills such as critical thinking, problem-solving, and decision-making, which are essential for success in both academic and professional settings. In the case of pre-service Biology teachers, using simulations to explore Genetics can equip them with the skills and knowledge to teach complex topics effectively, thereby improving the quality of education they deliver once they enter the classroom⁹⁴. Furthermore, the increasing integration of technology in education means that simulations can be accessed at any time, providing students with flexible, self-paced learning opportunities that cater to individual needs⁹⁵.

However, the successful implementation of simulation-based learning is not without challenges. One of the primary barriers is the cost and accessibility of high-quality simulation tools, particularly in resource-limited educational environments. Additionally, while simulations are effective, they require careful integration into the curriculum to ensure that they complement, rather than replace, traditional teaching methods. A well-designed simulation strategy should be aligned with learning objectives and offer a meaningful, context-rich experience that supports the development of essential skills⁸². Furthermore, educators must be trained to effectively facilitate simulation-based learning, ensuring that they can guide students in using these tools to their full potential⁸⁹.

Simulation strategy is an invaluable tool in modern education, particularly in disciplines like Biology and Genetics, where abstract concepts benefit from interactive, hands-on learning experiences. By offering a controlled environment for experimentation, simulations promote engagement, critical thinking, and problem-solving skills, all of

which contribute to higher levels of academic achievement. In the context of pre-service Biology teacher education, simulations are particularly beneficial for preparing future educators to teach complex scientific concepts with confidence and competence.

2.1.3.3 Traditional Teaching Strategy

Traditional teaching strategy also referred to as conventional or teacher-centered methods have been widely used in educational settings for centuries. These strategies typically involve direct instruction, where the teacher is the central figure in the classroom, delivering content to students through lectures, demonstrations, and other structured activities. The focus is on the transmission of knowledge from the teacher to the student, with the teacher primarily guiding the learning process through explanations, assignments, and assessments. This approach is often characterized by a passive role for students, who are expected to absorb the information presented, memorize facts, and apply knowledge to solve problems or complete tasks⁹⁶.

One of the hallmark features of traditional teaching strategies is the emphasis on rote learning and memorization, particularly in subjects such as mathematics, history, and Biology. In traditional Biology classrooms, for example, the teacher may explain Genetic concepts like inheritance patterns, DNA structure, or cellular processes through verbal lectures and written notes, while students are expected to listen attentively, take notes, and then recall the information during exams or quizzes⁹⁷. This approach tends to prioritize factual knowledge over the development of critical thinking, problem-solving, and collaborative skills.

Despite its widespread use and historical significance, traditional teaching strategies have faced significant criticism in recent years, particularly due to their limitations in fostering deep learning and student engagement. Critics argue that teacher-centered approaches often result in passive learning environments, where students are not encouraged to actively engage with the material or think critically about the content⁹⁸. This passive approach can lead to disengagement, lack of motivation, and a limited understanding of the subject matter, especially in complex and abstract disciplines such as Genetics, where students must be able to visualize, experiment, and hypothesize about Genetic processes and outcomes.

The shift away from traditional methods has been fueled by the rise of constructivist theories of learning, which advocate for more student-centered, active learning strategies. According to constructivism, learning is most effective when students are given opportunities to explore, experiment, and collaborate, allowing them to construct their own understanding of the content rather than simply memorizing facts. However, traditional teaching methods still have their place in education, particularly when used in combination with more modern, student-centered approaches. For instance, teachers may use traditional lectures as a starting point for introducing new concepts, but then integrate interactive activities, group discussions, or hands-on experiments to promote active engagement and deeper understanding⁹⁹.

In the context of Genetics education, traditional teaching methods have been criticized for their inability to adequately convey complex Genetic processes, which require visual and interactive representations to facilitate understanding¹⁰⁰. Genetics, with its abstract concepts such as gene expression, inheritance patterns, and molecular Biology,

demands a level of engagement that traditional lecture-based teaching struggles to provide. Thus, while traditional methods may be effective in conveying factual knowledge, they are less effective in promoting the critical thinking and problem-solving skills necessary for understanding complex biological systems.

However, traditional teaching strategies still play an important role in the classroom. In many educational systems, especially in large classrooms where resources are limited, teacher-centered methods may remain the most practical and feasible option for delivering content efficiently¹⁰¹. Traditional strategies can also serve as a foundation upon which more interactive and student-centered methods can be built. For example, a traditional lecture might be followed by a simulation or group activity that allows students to apply the knowledge they have just learned, bridging the gap between passive and active learning.

Moreover, research has shown that traditional teaching strategies can still be effective in improving academic performance when they are well-structured and supplemented with appropriate instructional tools and resources. For instance, a study demonstrated that when teachers employed clear explanations, organized lessons, and formative assessments, traditional teaching methods led to improved understanding in subjects like Biology, including topics in Genetics¹⁰². Therefore, while there is a growing emphasis on alternative teaching methods, traditional strategies continue to be a valuable component of the educational landscape, particularly in foundational learning environments.

2.1.5 Gender

The concept of gender is a multifaceted and dynamic construct that encompasses the roles, behaviors, identities, and expectations that societies associate with being male, female, or non-binary. Unlike biological sex, which is determined by physical attributes such as chromosomes, hormones, and reproductive anatomy, gender is a social and cultural phenomenon that evolves over time and varies across different societies. It influences how individuals perceive themselves and how they interact with others in their social and cultural contexts¹⁰³.

Historically, gender has often been viewed through a binary lens, dividing people into strictly male or female categories. This binary perspective is rooted in traditional norms and roles, where masculinity and femininity are assigned specific traits, behaviors, and responsibilities. Men were often associated with traits like strength, assertiveness, and leadership, while women were linked to nurturing, emotional expression, and caregiving. These roles reinforced power dynamics and societal structures, influencing the division of labor, access to education, and political participation¹⁰⁴.

In contemporary discourse, gender is increasingly understood as a spectrum rather than a binary. This perspective recognizes the diversity of gender identities, including non-binary, gender-queer and gender-fluid individuals who do not fit neatly into the categories of male or female. This shift is supported by growing awareness of the distinction between gender identity—how individuals experience and express their gender—and gender expression, which includes outward behaviors such as clothing,

speech, and mannerisms. The recognition of these nuances allows for a more inclusive understanding of human experiences^{103,105}.

The concept of gender is also deeply intertwined with power and inequality. Gender norms and expectations can lead to discrimination and marginalization, particularly for women and gender-diverse individuals. Issues such as the gender wage gap, unequal representation in leadership roles, and gender-based violence highlight systemic inequities perpetuated by rigid gender norms. Feminist and gender studies have been instrumental in challenging these inequities, advocating for gender equity and the dismantling of harmful stereotypes¹⁰⁴.

Gender is not a fixed or universal concept; it is shaped by cultural, historical, and individual factors. As societies continue to evolve, so too does the understanding of gender. Efforts to promote gender inclusivity and equity aim to create environments where individuals can express their identities freely and without fear of discrimination. By embracing the complexity of gender, societies can foster greater empathy, respect, and equality for all individuals, regardless of their gender identity or expression¹⁰³.

Gender, as a social construct, encompasses the roles, behaviors, and attributes that a society considers appropriate for men and women. Unlike biological sex, which is determined by physical characteristics, gender reflects the culturally defined roles and expectations associated with masculinity and femininity, which influence individuals' experiences, choices, and opportunities^{103,104}. In education, gender plays a significant role in shaping students' learning experiences, achievement levels, and responses to instructional strategies. Research highlights that gender can moderate learning outcomes, particularly in Science, Technology, Engineering, and Mathematics (STEM) fields,

where traditionally male-dominated areas show persistent disparities in achievement and participation^{105,106}.

Gender is an important consideration in education because it can affect both the learner's attitudes towards specific subjects and their academic achievement. Research found that gender differences in attitudes toward science often emerge early in the educational journey, impacting students' engagement and confidence in subjects like Biology and mathematics¹⁰⁷. Societal stereotypes that portray science as more suitable for males than females can influence young learners' choices, resulting in gender gaps that are later reflected in professional fields¹⁰⁸. These stereotypes can shape learning preferences and attitudes towards instructional strategies, meaning that interventions, such as those in this study—audio-visual and simulation strategies—may have different effects on male and female students.

Gender differences in learning preferences are widely documented, with studies suggesting that males often favor competitive and hands-on approaches, while females may excel in collaborative and communicative environments¹⁰⁹. These differences may influence how male and female students respond to various instructional methods, particularly in science subjects. For example, a study found that females tend to benefit more from interactive and visual learning strategies, as these methods often align with their learning preferences for collaboration and understanding through dialogue¹¹⁰. In this context, examining gender as a moderating variable is crucial in understanding the differential impact of audio-visual and simulation strategies on students' academic achievement.

Gender's influence on academic achievement is complex and multifaceted, as it interacts with other socio-cultural and environmental factors. In a recent study, research highlighted that, although gender-based preferences in learning are observable, the gap in academic performance can often be mitigated through gender-sensitive teaching approaches¹¹¹. In Science, Technology, Engineering, and Mathematics (STEM) education, approaches that foster inclusivity and actively engage female students have shown to narrow the gender achievement gap¹¹². In Genetics education, for example, incorporating simulation and visualization techniques might better support female students who face confidence issues in tackling abstract scientific content, thus improving their academic performance.

The importance of gender-sensitive pedagogy has led to the development of instructional strategies tailored to address these gender differences in science education. Interactive strategies, such as simulation and audio-visual aids, can potentially mitigate these disparities by offering alternative ways for students to engage with complex material¹¹³. Studies show that when instructional strategies are designed with an awareness of gendered learning differences, both male and female students can achieve better outcomes¹¹⁴. In this study, examining gender as a moderating factor allows for a deeper understanding of how male and female pre-service teachers experience and benefit from specific instructional interventions, ultimately contributing to a more inclusive approach in teacher training.

Gender also plays a role in teacher-student dynamics, which can influence academic outcomes. Female students, for example, may respond differently to instructional feedback from male teachers compared to female teachers, which can affect

their engagement and confidence in science subjects¹¹⁵. Similarly, gender stereotypes in the classroom may subtly affect teachers' expectations of male and female students, which in turn influence student motivation and academic performance¹¹⁶. As future educators, pre-service teachers' understanding of gender dynamics is critical in fostering equitable and supportive learning environments for all students, particularly in subjects like Genetics, where both content mastery and instructional sensitivity are needed to engage diverse learners effectively.

Additionally, in science education, gender biases and stereotypes can shape students' aspirations and self-efficacy, particularly in areas traditionally dominated by one gender¹¹⁷. Self-efficacy, which refers to a student's belief in their ability to succeed in a specific domain, can be significantly affected by gender, with female students often reporting lower self-efficacy in Science, Technology, Engineering, and Mathematics (STEM) subjects compared to male students¹¹⁸. Addressing gender-related barriers in Science, Technology, Engineering, and Mathematics (STEM) education, therefore, involves not only instructional adaptation but also efforts to enhance students' confidence and self-efficacy, thus promoting equal participation and performance across genders¹¹⁹.

Gender, as a socially constructed phenomenon, influences educational experiences in various ways, from learning preferences to academic achievement and career aspirations. For this study, gender is examined as a moderating variable, enabling an in-depth analysis of how male and female pre-service Biology teachers respond to audio-visual and simulation strategies in the context of Genetics. By exploring these dynamics, the study aims to provide insights into effective, gender-sensitive instructional

practices that can support academic achievement and foster equity in teacher education programmes.

2.2 Theoretical Framework

2.2.3 Multimedia Learning Theory

Multimedia Learning Theory is a foundational framework in the field of educational psychology, particularly within the context of how learners process information presented through multiple sensory channels. This theory was primarily developed by Richard Mayer, who proposed that students learn more effectively when they are presented with both visual and auditory information, rather than relying solely on one modality. The core principle of Multimedia Learning Theory is that humans have two distinct cognitive channels for processing information—one for visual inputs (such as images, diagrams, and animations) and one for auditory inputs (such as spoken words or sounds)—which, when used together, can enhance learning¹²⁰.

There are three fundamental assumptions about how people learn from multimedia materials based on Mayer's Cognitive Theory of Multimedia Learning (CTML): Dual-channel assumption: Humans have two separate channels—one for processing visual information and one for auditory information. Limited capacity assumption: Each channel has a limited capacity, meaning that people can only process a finite amount of information at a time. Active processing assumption: To learn effectively, students must actively engage in cognitive processes such as organizing, integrating, and making sense of the information provided through multimedia content¹²⁰.

The theory's central tenet is that learning occurs best when both auditory and visual elements are presented simultaneously, encouraging deeper engagement and reducing cognitive overload. By integrating both types of information, learners can more effectively form coherent mental representations of the content being presented⁶⁶. This is particularly important when teaching complex or abstract subjects such as Genetics, where visual representations—such as diagrams, flowcharts, or animations—can provide a clearer understanding of molecular processes, Genetic inheritance, and other difficult-to-visualize concepts.

Mayer identified several principles for optimizing multimedia learning, which have been widely applied in various educational settings, including science education. These principles are designed to minimize extraneous cognitive load and maximize intrinsic cognitive load to facilitate learning: Coherence principle suggests that learners understand better when extraneous material (such as irrelevant sounds or images) is excluded from the multimedia presentation. For instance; when teaching Genetics, unnecessary animations or irrelevant audio should not distract from the main content about Genetic processes¹²⁰.

Signaling Principle: Adding cues or highlights to key information within multimedia content can help guide learners' attention to the most important aspects of the lesson. For example, in a Genetics video showing DNA replication, highlighting key stages, such as the unwinding of the helix or the joining of nucleotide bases, can help students better focus on the critical elements of the process¹²⁰. **Redundancy Principle:** This principle suggests that learning is most effective when redundant information (such as displaying the same text both on-screen and in audio form simultaneously) is avoided.

Presenting the same information in both formats can overwhelm learners, so it is more effective to either use text or audio, but not both for the same content⁶⁶.

Modality Principle: Based on the modality principle, multimedia learning is enhanced when words are spoken rather than displayed as text. This is particularly beneficial in situations where there is complex or detailed visual content, such as Genetic diagrams or animations. When words are spoken, students can focus on interpreting the visuals, while simultaneously processing the spoken explanation. Contiguity principle advocates that corresponding words and images should be presented close together in space or time to reduce the cognitive load on learners. In Genetics education, showing a diagram of a chromosome alongside an explanation of its components, such as genes and alleles, helps students connect the visual information with the textual or verbal explanation more easily¹²⁰.

In the context of Genetics education, Multimedia Learning Theory is particularly relevant. The complexity of Genetic concepts—such as DNA structure, gene expression, inheritance patterns, and mutation processes—often requires the integration of visual aids to enhance understanding. For example, animated simulations that visually represent the process of DNA replication or Genetic cross-breeding allow students to visualize processes that are abstract and invisible in the real world. These animations, coupled with auditory explanations, can significantly improve students' understanding of Genetic concepts by engaging both cognitive channels.

Research has shown that the use of multimedia learning techniques in Genetics education leads to better academic performance compared to traditional text-based or lecture-based instruction⁵⁵. For example, an animated video demonstrating the process of

meiosis can help students visualize the separation of chromosomes, an otherwise abstract concept, while auditory narration provides an explanation of the key steps involved. By presenting both visual and auditory information in this way, multimedia learning allows students to construct a richer, more coherent mental model of the Genetic processes¹²⁰.

Moreover, multimedia learning materials can support diverse learning styles and accommodate various levels of prior knowledge. For students with visual learning preferences, diagrams and animations can provide intuitive representations of Genetic concepts, while auditory learners benefit from clear, spoken explanations of those concepts. This combination ensures that all students can engage with the material in a way that suits their learning needs, promoting better retention and deeper understanding.

Recent studies have validated the effectiveness of multimedia learning strategies, particularly in science education. A study explored the use of multimedia resources in teaching Genetics to high school students and found that students who were exposed to multimedia content performed better on tests of Genetic understanding compared to those who received traditional instruction. The study concluded that multimedia learning, by engaging both visual and auditory channels, led to more effective learning and better retention of Genetic knowledge¹²¹.

Similarly, a meta-analysis examined the impact of multimedia learning on students' academic achievement across various subjects and found significant improvements in students' performance when multimedia elements were incorporated into teaching, particularly in science-related disciplines such as Biology and Genetics. The study emphasized that the use of multimedia not only improved academic outcomes but also enhanced student engagement and motivation¹²².

The application of Multimedia Learning Theory in using audio-visual intervention strategies to teach Genetics provides a powerful and effective method for enhancing student understanding of complex Genetic concepts. By combining visual elements (e.g., animations, diagrams) with auditory explanations (e.g., voice-over narration, sound effects), educators can create engaging, dynamic learning experiences that help students visualize abstract Genetic processes, improve their comprehension, and retain information more effectively. This approach not only improves learning outcomes but also increases student motivation and engagement, making the study of Genetics more accessible and enjoyable for learners.

Simulation-based learning offers an interactive, hands-on approach to studying Genetics, which aligns with the active processing assumption of Multimedia Learning Theory. Students can experiment with various Genetic scenarios, such as manipulating traits in a Genetic cross, and observe how changes in Genetic input (e.g., different allele combinations) affect the phenotype of offspring. This process of trial and error, coupled with instant feedback from the simulation, encourages deeper cognitive engagement and exploration, which improves retention and conceptual understanding^{94,120}.

Many Genetic processes, such as DNA replication, Genetic mutation, and gene expression, are abstract and difficult to visualize. Simulations allow these processes to be modeled visually, providing students with a concrete representation of otherwise invisible phenomena. For instance, in a Genetic mutation simulation, students can visually observe how a single nucleotide change in the DNA sequence affects protein synthesis and, consequently, phenotype expression. These visual aids help students internalize complex Genetic concepts more effectively⁶⁶.

Interactive simulations offer immediate feedback, a critical feature that supports learning. As students engage with a simulation, they receive feedback on their decisions (e.g., predicting inheritance outcomes in a Genetic cross) and can adjust their understanding accordingly. This aligns with the scaffolding concept from Vygotsky's social constructivism, where learners are supported in their development until they can complete tasks independently. Simulation platforms can offer scaffolding by guiding students through more complex Genetic concepts, helping them gradually increase their mastery¹²⁰.

Using multimedia simulations in Genetics education can increase student engagement and motivation. The interactive nature of simulations, paired with the visual and auditory elements, often results in higher levels of interest and enjoyment compared to traditional lecture-based teaching methods. As students actively participate in the simulation; their intrinsic motivation to learn about Genetics increases, leading to improved learning outcomes⁹⁴.

A practical example of applying Multimedia Learning Theory with simulation in Genetics could be using a simulation platform to teach Mendelian inheritance. Students might be tasked with performing virtual crosses between pea plants with different Genetic traits (e.g., flower color or seed shape). The simulation could visually display the process of gamete formation, fertilization, and the inheritance of traits in the offspring. Audio explanations could describe the Genetic mechanisms behind each step, and immediate feedback could help students understand how different allele combinations influence the phenotype of the offspring^{94,95,120}.

Additionally, a DNA replication simulation could visually represent the process at the molecular level, showing enzymes like helicase and polymerase at work, while an audio narration explains how these processes are essential for cell division and Genetic transmission. Students could manipulate the simulation by selecting different types of mutations (e.g., point mutations or insertions) to observe how these changes affect the resulting protein structure^{94,120}.

The application of Multimedia Learning Theory in teaching Genetics through simulation strategies offers a powerful method for enhancing student understanding of complex Genetic concepts. By combining visual and auditory elements, simulations provide an interactive and engaging learning environment that helps students visualize abstract processes, experiment with Genetic scenarios, and receive immediate feedback. This approach not only improves learning outcomes but also motivates students by offering hands-on, inquiry-based experiences that align with modern constructivist approaches to education.

2.3 Review of Empirical Studies

2.3.2 Audio-visual Intervention Strategy and Academic Achievement in Genetics

The application of Audio-visual Intervention Strategies in the teaching of Genetics has been explored extensively as a means to enhance academic achievement. Audio-visual materials, such as videos, animations, interactive simulations, and multimedia presentations, have been widely recognized for their ability to cater to different learning styles and promote a deeper understanding of complex scientific concepts. The role of these interventions in improving academic outcomes, particularly in

Genetics education, has been the focus of numerous studies, with mixed but promising results. This empirical review examines recent research on the impact of audio-visual interventions on academic achievement in Genetics, focusing on their effectiveness, application in classrooms, and implications for teaching strategies.

A pre-test post-test quasi-experimental research design was used to investigate the effects of technology-mediated dynamic and static visuals on the retention of pre-service Biology teachers in North Central Nigerian colleges of education. The study was guided by two research questions and two null hypotheses. The sample consisted of 354 NCE two Biology students who were randomly selected from four colleges of education in North Central Nigeria; two of the four colleges were assigned to Experimental Group I, where students were taught using technology-mediated dynamic visuals, and the other two were assigned to Experimental Group II, where students were taught using technology-mediated static visuals. Following expert validation and a reliability check, forty multiple-choice questions from the Biology Retention Test were utilised to collect data for the pretest and posttest. The instrument's reliability for the study is demonstrated by the reliability coefficient of 0.78 that was obtained. Pre-service teachers received two hours of instruction per week for six weeks as part of the data collection procedure. Two weeks passed between the pretest and posttest administrations before the retention test (DSVGRT) was given. In order to address the study objectives, the data was analyzed using mean and standard deviations. The hypothesis was tested at the 0.05 level of significance using Analysis of Covariance (ANCOVA)¹²³.

The results showed that the mean retention scores of pre-service Biology teachers who taught Genetics using technology-mediated dynamic and static graphics differed

statistically significantly ($F(2,352) = 17.696$, $P\text{-value} = 0.000$ at $P < 0.05$). A moderate effect size was found by partial eta squared, with the independent variable accounting for almost 4% of the variation in the result ($\eta^2=.04$). Likewise, a statistically significant difference exists between the mean retention scores of male and female pre-service Biology instructors who taught Genetics utilizing technology-mediated dynamic and static graphics ($F(4,349) = 9.625$, $P\text{-value} = 0.000$ at $P < 0.05$, ($\eta^2=.07$). A medium effect size was found using partial eta squared, indicating that the observed variations had a moderate practical importance of roughly 7% of the variability in the outcomes attributable to the variables under study. Based on these results, it was suggested, among other things, that educators in North Central Nigerian colleges of education take into account a blended approach that carefully blends static and dynamic visuals, maximizing each one's unique advantages to accommodate a range of learning preferences and styles¹²³.

Visual learning gadgets are educational resources that teachers use all over the world. Nevertheless, understanding of its application has not been well established, despite its importance in education. Thus, in Ilorin, Nigeria, the study looked at how visual learning aids affected the academic achievement of secondary school (SS) Biology students. In Ilorin, Nigeria, 139 students and 100 teachers made up the sample for this descriptive survey study. A test, measurement, and evaluation specialist, two Biology educators, and two educational technologists validated the instrument, which was a questionnaire created by the researchers. In contrast, reliability coefficients were recorded at the 0.05 level of significance, and Cronbach alpha was used to observe the face, content, and pilot test. Three research hypotheses were developed and put to the test, and

seven research questions were posed and addressed. Findings revealed a significant difference between male and female students; between the students in SS I, II, and III and between the rural and urban schools students on impact of visual learning devices on students' academic performance. Thus, the study came to the conclusion that students' academic performance is impacted by visual learning tools. Therefore, it was advised that Biology be taught in all Nigerian secondary schools using visual aids¹²⁴.

This study examined how science ideas were taught in secondary schools in the Bwari Area Council of Abuja, Nigeria, using audio-visual instructional tools. A pre-test, post-test quasi-experimental design was used in the investigation. To direct the investigation, two hypotheses and two research questions were developed. One hundred students made up the study's sample. Data was collected using a Science Achievement Test (SAT), and the data was analysed using t-test, mean, and standard deviation statistics. Major finding revealed among others that audio-visual instructional material has a significant effect on students' achievement in sciences, also the use of audio-visual instructional material enhanced the effectiveness among male and female students learning science without gender disparity. Thus, among other things, it was suggested that teachers should encourage their students to use audio-visual aids to increase their interest and maintain their focus in class, as well as incorporate the use of appropriate audio-visual instructional materials when teaching their students⁵⁴.

The study looked into how well Biology students in senior secondary schools in Port Harcourt, Rivers State, performed academically when taught using video instruction. The study used a quasi-experimental approach with pretest, posttest, and control group. As the experimental group, two intact classrooms were instructed using the video

instructional technique, whereas the control group consisted of two groups that were instructed using instructional diagrams. To direct the investigation, two hypotheses and two research questions were developed. The 25-item Biology Performance Test on Genetics (BPTG) was created and verified. Before employing it for data collecting, a pilot test was conducted and a reliability coefficient of 0.76 was recorded. The test was first given as a pre-test, and then it was rearranged and given as a post-test. The study issues were addressed by analyzing the data using mean and standard deviation, and the hypotheses were tested at the 0.05 level of significance using ANCOVA. The findings showed that the experimental group achieved a higher mean performance score, and there was no significant difference between academic achievement and location. Therefore, since video instruction encourages internalization of abstract notions, it is advised that teachers employ it when teaching and studying the sciences¹²⁵.

The study looked at how multimedia instruction affected the academic achievement of special education students in the city of Minna. Three questions and three related hypotheses were formulated based on the three research objectives. The survey design used in the study was descriptive. There were one hundred employed responders. A structured questionnaire was employed as the data gathering tool. The supervisor validated the instrument. The instruments' reliability was established using test-retest reliability. Cronbach alpha was used to calculate the dependability coefficient, which came out to be 0.79. In order to examine the research topics, the obtained data was subjected to a mean score analysis with a decision rule of 2.5. The Chi-square statistical tool was used for inferential statistics, and the significance of the various statistical analyses was determined at 0.05 alpha levels. The findings demonstrated that students

with special needs differed significantly in their mean responses to three questions: how multimedia affects teaching and learning; how multimedia affects academic achievement; and how multimedia affects students' attitudes towards learning¹²⁶.

The study found that the usage of multimedia resources improves academic achievement, effective teaching and learning, and the attitude of students with special needs towards learning. The use of multimedia learning to foster a positive attitude towards learning and enhance the academic performance of students with special needs was suggested as one way to raise public awareness of the ways in which multimedia assets might support the teaching and learning process¹²⁶.

2.3.3 Simulation-based Strategy and Academic Achievement in Genetics

The use of Simulation-based strategies in teaching and learning has been widely researched, with numerous studies highlighting its positive impact on students' academic achievement, particularly in the sciences. In the context of Genetics, Simulation strategies ranging from virtual laboratories to interactive Genetic modeling software offer students an immersive and dynamic way to engage with complex Genetic concepts. These tools enable learners to visualize Genetic processes, experiment with Genetic crosses, manipulate virtual DNA, and explore Genetic inheritance patterns, which are often abstract and difficult to grasp through traditional teaching methods. This empirical review explores recent research on the use of simulation strategies and their effects on academic achievement in Genetics.

Recently, Nigerian students have found Genetics concepts to be quite challenging. Thus, this study examined how senior secondary students' attitudes and Genetics

achievement were affected by computer simulation training. This was in addition to the moderating effects of ability levels and gender. The study's design was quasi-experimental, and the sample size consisted of 209 students selected by purposive sampling methods from four intact courses. The study was led by six research questions, and new hypotheses were examined at the significance level of 0.05. Achievement exams and surveys were used to gather quantitative data. The findings showed that using computer simulation as a teaching tool greatly raises students' academic performance and improves their attitude towards Biology. Similarly, research showed that using computer simulations in the classroom greatly raised the achievement of low-ability students, who had bigger mean improvements than the medium and high-ability groups, respectively. The lack of significant results on gender differences in attitude and achievement suggests that computer simulations used in the classroom help close the achievement and attitude gaps between male and female students, respectively⁴⁵.

In Niger State, Nigeria, this study examined how computer simulation affected students' achievement and memory in sexual reproduction in plants. The population of the study comprised 11,275 Biology students, 5903 males and 5372 females, from all 240 public coeducation senior secondary school class two (SSII) in Niger State during the 2019–2020 academic year. The study used a pretest, post-test quasi-experimental control group design. The study was directed by two research objectives, and two null hypotheses were developed and tested at the 0.05 level of significance. 178 SS II Biology students (84 females and 94 boys) from four coeducational senior secondary schools in the state's zone B educational zone made up the study's sample size. Four intact classes from four separate schools were chosen using multi-stage random sampling approaches.

The tool used to gather data was the Plant Reproduction Achievement Test (PRAT). The data from the PRAT trial testing was analysed using the split half reliability approach. The reliability index came out at 0.88. The research issues were addressed using mean and standard deviations, and the hypotheses were tested using ANCOVA¹²⁷.

The results showed that students who were taught using the computer simulation strategy outperformed those who were taught using traditional teaching techniques. Additionally, the results of the ANCOVA test show that the group that was taught using the computer simulation technique had significantly higher achievement scores ($F=125.037$; $P=0.00 \leq 0.05$) and retention scores ($F=181.277$; $P=0.000 \leq 0.05$). The Federal Government, through the Ministry of Education, should make sure that teachers receive training on the use of computer simulation strategy so they can use it to teach and learn Biology in order to improve the students' achievement and retention in sexual reproduction in plants and related topics in Biology. Based on this result, it was suggested that computer simulation be used to teach Biology in secondary schools. The Science Teachers Association of Nigeria (STAN) should also host seminars, conferences, and workshops to educate teachers on the effectiveness of CSS¹²⁷.

This study looked at how multimedia instruction affected Biology students' performance in public secondary schools in Enugu State's Agbani Education Zone. To direct the investigation, three research questions were developed. The study's research design was a quasi-experimental non-randomized control group design with intact classes. All SSII pupils in Enugu State's Agbani Education Zone made up the study's population. For the study, 300 SSII students were selected from four coeducational schools using purposive sampling. Data regarding students' essay writing proficiency was gathered

using the Biology Achievement Test. Two professionals from the Science Education Departments face-validated the instrument and verified its content. Ten students from two schools in a different zone participated in the trial testing, and the instrument's reliability was evaluated by calculating inter-rater reliability using the Kuder-Richardson formula, which yielded a score of 0.76. The research issues were addressed using the mean and standard deviation. The study's null hypotheses were tested at the 0.05 level of significance using analysis of covariance. Key findings indicated that the mean Biology achievement of students was significantly impacted by multimedia instruction. These findings led to the following recommendations: the government, in collaboration with other professional associations, should arrange conferences, workshops, seminars, and in-service training to retrain Biology teachers on the use of multimedia; and Biology teachers should make an effort to teach Biology using multimedia¹¹.

2.3.1 Gender and Academic Achievement in Genetics

The relationship between gender and academic achievement in Genetics has been a subject of considerable academic interest. Understanding how gender influences learning outcomes in specific subjects like Genetics is critical for designing more inclusive and effective educational strategies. This empirical review examines recent studies that explore how gender affects academic performance in Genetics and similar scientific disciplines, with a focus on pre-service teachers, secondary school students, and higher education learners.

In the Nsukka Education Zone in Enugu State, Nigeria, the study assessed the impact of the Culturo-Techno-Contextual Approach (CTCA) on the academic

performance of secondary school Biology students. Using a quasi-experimental research approach, the study was directed by three hypotheses and two research questions. 2,870 senior secondary school year two (SS2) Biology students enrolled in the zone's government-owned coeducational secondary schools made up the study's population. Using a multistage sampling technique, eighty-one (81) SS2 pupils were selected from two of the zone's forty-one coeducational schools. The Biology Achievement Test (BAT) was the tool used to collect the data. Three specialists from Nnamdi Azikiwe University's Faculty of Education in Awka approved the tool. Richardson Kudder For BAT, a dependability coefficient of 0.87 was determined using Formula 20. While the control group received instruction via the traditional lecture approach, the experimental group received instruction via CTCA. The research issues were addressed using mean and standard deviation, and the null hypotheses were tested at the 0.05 alpha level using analysis of covariance¹²⁸.

The results showed, among other things, that CTCA considerably raised Biology students' achievement over that of the traditional lecture technique. Additionally, CTCA is a gender-neutral teaching strategy that might be applied to improve Biology lab scores for both male and female secondary school students uniformly. It was determined that CTCA is a successful teaching strategy that Nsukka Education Zone might use as an alternative to traditional Biology training. It was suggested that teachers receive training on how to use CTCA to raise student achievement through conferences, workshops, and seminars based on the study's findings. The use of CTCA for Biology instruction should also be promoted by school administrators to secondary school Biology teachers¹²⁸.

The effects of the Concept Mapping Instructional Strategy Combined with Discussion Web on the academic achievement of Navrongo Senior High School students in the subject of Genetics in general and on the basis of gender were investigated using this study. The study employed a quasi-experimental design (pretest, posttest non-equivalent design). The sample consisted of 80 science students from the Form Three Gold Track and Green Track programs at Navrongo Senior High School. Students from the Gold Track class and the Green Track class were assigned to a control group and an experimental group, respectively. The experimental group class consisted of twenty male and twenty female pupils. The control group class also consisted of 13 women and 24 males. The pretest was administered to each participant. Talk about Concept Mapping and the Web to instruct the experimental group, instructional strategies were employed. The control group was instructed using the traditional teaching approach. A posttest was administered to each group in order to evaluate the effectiveness of the treatment. The dependability of the test items was evaluated using the test-retest reliability coefficient. The instruments' test-retest reliability coefficients for the pretest and posttest were found to be 0.70 and 0.73, respectively. The gathered data was examined using the t-test¹²⁹.

The students' academic performance was homogeneous, based on the pretest results (t-value = 1.05, p-value = 0.30, $p > 0.05$). Posttest results for the experimental group differed significantly from those of the control group (t-value = 8.07, p-value = 0.000, $p < 0.05$). Based on the posttest results, teaching Genetics using idea mapping and discussion webs proved to be more effective than conventional teaching techniques. The academic performance of male and female students in the experimental group did not differ statistically significantly (t-value = 1.68, p-value = 0.11, $p > 0.05$)¹²⁹.

The integration of Information and Communication Technology (ICT) has the potential to significantly alter Genetics education. The study examined the ways in which two secondary schools in the Kitwe District used ICT to enhance Genetics instruction. The study's objective was to ascertain how using ICT as a supplement to traditional teaching and learning approaches affected the attitudes and academic performance of Genetics teachers and students in two secondary schools selected from the Kitwe region. The study used a concurrent triangulation design, which is a hybrid method approach. The study collected both qualitative and quantitative data using focus groups, interviews, questionnaires, pre- and post-test methods, and other methods. Focus group and in-person interview data were thematically analyzed, while student questionnaires and pretest and posttest results were quantitatively analyzed using the 2 X 2 design analysis as a reference¹³⁰.

The findings showed that students' performance significantly improved when Genetics instruction and learning were conducted utilizing ICT resources. The results also showed a substantial difference in the experimental groups' and control groups' genetic performance by group names and gender. However, no statistically significant difference in genetic performance was found amongst the different age groups of students. Both teachers and students had positive opinions on the use of ICT in Genetics, with mean values ranging from 4.5 to 5.5. The results also showed how ICT knowledge and abilities, poor ICT infrastructure, a lack of ICT training, and limited access to ICT negatively affected instructors' and students' opinions on the use of ICTs in Genetics education¹³⁰.

Gender differences in Biology retention, academic performance, and senior secondary school students in Ekiti State were examined in a study. An ex post facto design was employed in the study. 240 SS 2 students from six schools made up the sample. At a significance threshold of 0.05, three hypotheses were formulated and tested. The data was analysed using statistics that employed the independent t-test. The results showed a considerable disparity between male and female students' achievement mean scores¹³¹.

Finding out how students' demographic traits impacted their academic achievement in Biology in public secondary schools in the Calabar Municipality Local Government Area of Cross River State was the main objective of a study. While the independent variables examine the students' demographic traits, including gender, age, and birth order, the dependent variable shows the students' academic achievement in Biology. To assist the study in achieving its objective, three research questions and three research hypotheses were created and put forth, accordingly. Using the factors from the study, a review of the literature was done. For this study, an ex-post facto research design was selected. Two hundred and twenty (220) SS2 Biology students from public secondary schools were randomly selected for this study. The data was gathered using the Biology achievement test that the researcher had developed. An independent t-test statistic was used to test the first hypothesis, and an ANOVA statistical tool was used to test the second and third. Each hypothesis was investigated at the 0.05 level of significance¹³².

Findings from the study indicated that SS 11 Biology students' academic performance in the Calabar Municipality Local Government Area of Cross River State,

Nigeria, was highly impacted by their gender, age, and birth order. As a result of the study's findings, school administrators were advised to hold seminars on a regular basis to inform students about the importance of Biology and the influence of demographic variables. Students will be inspired to study Biology as a result, and they will develop a favorable attitude towards the subject¹³².

A study examined the effects of Web Quest and the 5E learning cycle on students' Genetics performance in Rivers State secondary schools. Three objectives and three research questions guided the study, and three null hypotheses were assessed at the significance level of 0.05. The study employed a quasi-experimental, non-equivalent control group design. Three coeducational private schools were chosen using purposive sampling. 96 Senior Secondary two (SS2) students were chosen as a sample from the 7,213 students that comprised the subject population. There were three complete classes used. The instrument utilized to collect data was the Genetics Performance Test (GPT), which consists of fifty (50) multiple-choice questions tailored for the study. This was confirmed by six experts. Internal consistency was determined using Kuder-Richardson formula 21, and a reliability coefficient of 0.98 was discovered. The mean and standard deviation were used to analyze the gathered data in order to answer the research objectives. The hypotheses were tested at the 0.05 level of significance using analysis of covariance (ANCOVA)¹³³.

The results of the study demonstrated that students' performance in Genetics was significantly impacted by online Quest and the 5E learning cycle. The 5E learning cycle and online quest did not significantly interact to affect the performance of Genetics students, either male or female. The findings of this study led to the suggestion that

online Quest and the 5E learning cycle be used in Genetics classes to enhance student performance¹³³.

Self-efficacy is the conviction that a person can perform specific actions that will lead to the intended result. Therefore, the confidence that educators have in their capacity to support students' learning is known as self-efficacy. The impact of instructors' self-efficacy on Biology students' academic performance in secondary schools in Enugu State was investigated in this study utilising an ex-post facto research approach. Using a deliberate sampling technique, 270 SS1 Biology students and 25 SS1 Biology teachers were chosen from a population of 5693 (2254 females and 3439 males) SS1 Biology students and 62 SS1 Biology teachers spread across all 48 public senior secondary schools in Obollo A for Education Zone of Enugu state. The Biology Achievement Test (BAT), the Eysenck General Intelligence Test (EGIT), and the Teachers' Self-Efficacy Index (TSEI) were the tools utilised to gather data. The study addressed three research topics and tested the three guiding hypotheses at the 0.05 level of significance using analysis of covariance (ANCOVA)¹³⁴.

The study's findings revealed that: male and female students did not significantly differ in their academic achievement in Biology based on teacher teachers' self-efficacy behaviour; students who were taught by teachers with high and moderate levels of teacher self-efficacy demonstrated better academic achievement when compared to those whose teachers displayed low levels of teacher self-efficacy. To guarantee an efficient process of teaching and learning Biology utilising Teachers' Self-efficacy, it was suggested that a pleasant climate and a supportive working environment be established¹³⁴.

In order to compare the impact of printed books and electronic courseware on Biology students' performance, attitude, and retention in Genetics at Niger State's colleges of education, this study was conducted. The impact of gender was also investigated. Three levels of dependent variables (achievement, retention, and attitude), one moderating variable (gender), and two levels of independent variables (printed books and electronic courseware) comprised the study's quasi-experimental research design. The study was led by seven research topics and seven null hypotheses. 120 second-year Biology students from two local colleges of education made up the study's sample, which was chosen using a multi-stage selection procedure. First, NCE 2 students from the two Colleges of Education (FCE Kontangora and C.O.E. Minna) were chosen by paper vote using a straightforward random sampling technique. The two colleges were then divided into two groups: the Experimental Group (e-book) and the Control Group (printed book). The study was then conducted using whole classes of NCE 2 students from the two colleges¹³⁵.

The study made use of five research tools. These include the Genetics Achievement Test (GAT), Genetics Retention Test (GRT), Electronic Courseware on Genetics Concept (ECGC), Printed Book of Genetics Concept (PBGC), and Attitude Questionnaire towards Genetics. The ECGC is the electronic counterpart of the PBGC, which is a 30-page, well-structured lesson note on Genetics ideas written in coloured form on paper. Both are in colour, however the electronic version includes brief video clips and animations to satisfy the requirements of an e-book, rather than diagrams and photographs as in the printed version. The GAT consists of 40 multiple-choice objective questions with five possible answers (A–E). There is only one right answer, which is

worth 2.5 points each, for a total score of 100 points. Experts from the departments of biological science, science education, and educational technology at the Federal University of Technology Minna in Niger State approved these tools. Using the Kuder-Richardson-20 formula, the validity of GAT was determined, yielding a coefficient of 0.82. Additionally, the Cronbach alpha reliability coefficient was used to determine the attitudinal questionnaire's reliability, yielding a coefficient of 0.74. This suggests that the tools were trustworthy¹³⁵.

The results showed that, with a grand mean difference of 13.09 more than students taught with printed books, Biology students' performance in Genetics was greatly enhanced by electronic courseware. Additionally, there is no gender difference in the academic performance of students who have read the two kinds of books. Based on these results, it was suggested that students be given access to instructional materials in the form of electronic courseware, as this would encourage and improve their independent study as well as their academic performance, attitude, and retention¹³⁵.

In the current era, pre-service science teachers are a crucial group of stakeholders in a country's efforts to advance scientific literacy, scientific development, and technological advancement. This study used a descriptive research design to find out if there were any gender differences in the performance of third-year pre-service senior high school science teachers in Integrated Science at the University of Education, Winneba, Ghana. A sample of 168 students enrolled in five courses at that level was employed in the study. The study used the SPSS version 22.0 software to perform an independent samples t-test in order to ascertain whether male and female students performed differently. The results of this study demonstrate that there is no gender

difference in the attainment of integrated science among pre-service secondary school science teachers in the University of Education, Winneba's Department of Integrated Science Education. The study suggests that women should be made more aware of the importance of adopting more favorable attitudes towards studying science and related subjects, particularly the physical sciences¹³⁶.

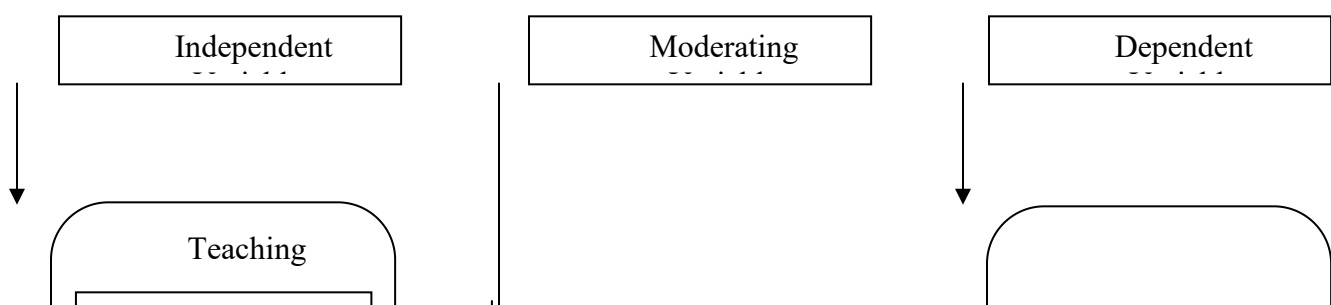
This study addresses the challenge of teaching Genetics effectively to high school students, a topic known to be particularly challenging. Utilising the increasing significance of artificial intelligence (AI) in education, the study investigates pre-service teachers' viewpoints, attitudes, and behavioural intentions with regard to incorporating AI-based applications into high school Genetics instruction. Understanding these pre-service teachers' perspectives is essential because, in our technologically dependent society, they are expected to smoothly integrate technology into their future classrooms. These instructors are known as digital natives. Ninety Biology-focused teacher candidates from Nigerian higher education institutions participated in the study. The Theory of Planned Behaviour was used to analyse survey data using independent sample t-test and structural equation modelling techniques¹⁰.

The findings show that subjective norms and perceived utility are important determinants of AI use, with pre-service teachers' behavioural intentions being significantly influenced by subjective norms. Interestingly, intentions are not significantly predicted by perceived behavioural control, which is similar to the finding that perceived utility does not ensure AI adoption. Gender differentially affects subjective norms, particularly among female pre-service teachers, while no significant gender differences are observed in other variables, suggesting comparable attitudes. The study

emphasises how attitudes and social norms play a crucial role in influencing pre-service teachers' choices on integrating AI technology. There are also in-depth talks about the limitations, implications, and possible future lines of inquiry¹⁰.

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2.4 Conceptual Model



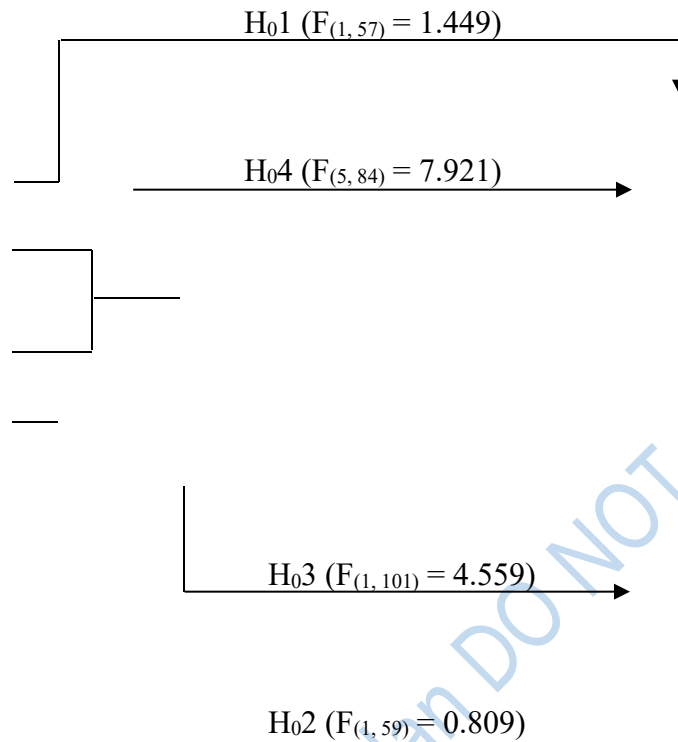


Figure 2.1: Conceptual Model of Audio-visual and Simulation-based Learning Strategies on Academic Achievement in Genetics

Source: Researcher's Fieldwork, 2025

2.5 Summary of Literature Reviewed

The conceptual review highlights the key ideas central to the study. Academic achievement refers to students' performance as measured through tests and assessments, reflecting their understanding of subject content. In Biology, Genetics plays a vital role as it deals with heredity and variation, focusing on molecular and chromosomal inheritance. Given its complexity, teaching Genetics effectively requires strategies that simplify content and promote student engagement. Audio-visual strategy using videos, animations, and interactive media make abstract ideas more accessible, improving retention. Simulation strategies, through digital or physical models, provide hands-on learning

experiences that help students grasp complex genetic processes. While the traditional learning strategy is still widely used, it often lacks the flexibility to meet diverse learning needs or encourage critical thinking, especially in challenging subjects like Genetics. Gender also plays a role in academic outcomes, influencing students' interest, engagement, and performance in Biology and Genetics.

Based on Richard Mayer's Multimedia Learning Theory, students learn better when both visual and auditory information are combined. This theory supports the use of multimedia tools in Genetics education. Research shows that such tools enhance understanding, critical thinking, and overall academic achievement. Moreover, they help bridge gender gaps by creating a more inclusive learning environment. The conceptual model links teaching strategies, academic achievement, and gender, proposing that innovative strategies can improve outcomes for all students.

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Chapter Three Methodology

The research design, population of the study, sample and sampling techniques, description of research instruments, validity of research instrument, reliability of research instrument, data collection and data analysis were all covered in this chapter.

3.1 Research Design

The quasi-experimental design with a 3×2 Factorial matrix using pre-test and post-test approach was adopted for this study. Two experimental groups and one control group were the three levels of treatment; the experimental groups were treated with Audio-visual intervention for Group A and Simulation-based learning strategy for Group B, while the control group, Group C was treated with traditional teaching strategy. Further information regarding the research design can be found in Table 3.1 and 3.2.

Table 3.1: Schemata Diagram for the Study

Group	1 (Pretest)	Treatment	2 (Posttest)
E ₁	O ₁	X ₁	O ₂
E ₂	O ₃	X ₂	O ₄
E ₃	O ₅	X ₃	O ₆

Source: Researcher's Fieldwork, 2025

Where O₁, O₃, O₅ = Pretest Scores

O₂, O₄, O₆ = Posttest Scores

E₁, E₂, E₃ = Treatment Groups

X₁ = Treatment 1 (Audio-visual intervention)

X₂ = Treatment 2 (Simulation-based learning strategy)

X₃ = Control (Traditional teaching strategy)

Table 3.2: Schematic Representation of the 3×2 Factorial Matrix

Treatment	Gender	Academic Achievement
Audio-visual intervention	Male /	
X ₁	Female	
Simulation-based learning strategy	Male /	

X ₂	Female
Traditional teaching strategy	Male /
X ₃	Female

Source: Researcher's Fieldwork, 2025

Variables in the study

1. Independent variable includes:

Treatment 1 (Audio-visual strategy)

Treatment 2 (Simulation-based learning strategy)

Control (Traditional learning strategy)

2. Moderating variable includes: Gender

Male

Female

3. Dependent variable include:

Academic Achievement in Genetics.

3.2 Population of the Study

The study population comprises 90 year two Biology students found in three tertiary institutions offering Biology as a course of study in Ogun State as of the time of conducting this research. Further information regarding the population of the study is on Table 3.3.

Table 3.3: Study Population

S/N	Tertiary Institutions	200L
1.	Institution A	28

2.	Institution B	30
3.	Institution C	32
	Total	90

Source¹

3.3 Sample and Sampling Techniques

Total enumeration method was used for this study. This approach involves collecting information from all members of the target population. It is typically adopted when the study population falls within a manageable size, as is the case in this study. Consequently, the entire population were served as the sample size, meaning the data collection instrument was administered to all intact classes of 90 Biology pre-service teachers in three tertiary institutions offering Biology as a course of study in Ogun State. Further information regarding the study sample is on Table 3.4.

Table 3.4: Study Sample

Treatment	Tertiary Institutions	M	Fem	T
Groups		al	ale	ot
		e		al
Group A	Institution A	1	14	28
		4		

Group B	Institution B	1	15	30
		5		
Group C	Institution C	1	16	32
		6		
Total	3	4	45	90
		5		

Source¹

A balloting procedure was used to randomly assign the selected institutions to different groups for the study. The names of the institutions were written on individual slips of paper, folded, thoroughly shuffled, and then drawn one after the other. The first institution drawn was placed in the Experimental Group A, the second institution drawn was designated as Experimental Group B, while the third institution drawn was assigned to the Control Group C. As a result of the draw: Institution A was placed in the Experimental Group A and received instruction using Audio-visual intervention. In contrast, Institution B was designated as Experimental Group B and was treated with Simulation-based learning strategy, while Institution C was assigned to the Control Group C and was taught using the traditional learning strategy, as shown in Table 3.4.

3.4 Description of the Research Instruments

Data for this study were gathered using the following instruments:

1. Genetics Achievement Test (GAT)
2. Guide for Instruction in Teaching and Learning of Genetics (Audio-visual strategy)

3. Guide for Instruction in Teaching and Learning of Genetics (Simulation-based learning strategy)
4. Guide for Instruction in Teaching and Learning of Genetics (Traditional learning strategy)

3.4.1 Genetics Achievement Test (GAT)

This instrument was used to collect data for this study to assess pre-service teachers' academic achievement in Genetics. The instrument consists of different 25 items source from all genetics related topics taught in the selected institutions. The items were multiple-choice options which were label lettered A – D for the participants to shade only one correct answer at a time. The given time frame to answer all the items was 45 minutes.

The Genetics Achievement Test (GAT) consists of two sections (A and B). Section A is for the participants' demographic information such as: Institutions name and gender. Section B is for the 25 multiple choice items which consist of Genetic concepts. The following Table 3.5 consists of item specifications for the 25 questions based on the first four order of cognitive levels.

Table 3.5: Table of Specification

Skills	Number of Items	Total	Percentage %
Knowledge	1, 2, 5, 10, 12, 14, 16, 20, 21, 22	10	40

Comprehension	3, 6, 7, 8, 9, 11, 15, 25	8	32
Application	4, 13, 18, 24	4	16
Analysis	19, 23, 17	3	12
Total	25	25	100

Source: Researcher's Fieldwork, 2025

Further information regarding Genetics Achievement Test (GAT) and its Marking Guide refers to in Appendix I and II, respectively.

3.4.2 Guide for Instruction in Teaching and Learning of Genetics (Audio-visual strategy)

Using the Audio-Visual Strategy in teaching genetics allows for an interactive and engaging learning experience. The combination of videos, animations, and simulations supports diverse learning styles, facilitates better comprehension of complex genetic processes, and increases students' academic achievement. By incorporating these multimedia tools, teachers can provide a rich, visual, and hands-on learning environment that enhances students' understanding of genetics.

This guide for instruction was taken in teaching and learning process in the selected institutions for this treatment during fieldwork consist of lesson overview (topic, target group, duration and materials), objective, presentation, assessment and evaluation, closure and homework. The following were the steps taken in the treatment (Audio-visual strategy) presentation:

Instructional guide for experimental Group A: Learning instructional guide presentation using Audio-visual strategy to teach Genetics were as follows:

- A. Introduction
- B. Presentation of new content
- C. Guided practice
- D. Class discussion and reflection

Further information regarding Instructional guide for experimental Group A refers to in Appendix III.

3.4.3 Guide for Instruction in Teaching and Learning of Genetics (Simulation-based learning strategy)

The Simulation Strategy in teaching genetics allows students to engage actively with genetic concepts by experimenting in a virtual environment. This hands-on, interactive approach not only makes complex processes more understandable but also enhances student engagement and learning outcomes. By integrating simulations into the lesson plan, teachers can foster deeper comprehension and mastery of genetics, equipping students with both theoretical and practical knowledge.

However, the guide for instruction was taken in teaching and learning process in the selected institutions for treatment during fieldwork consist of lesson overview (topic, target group, duration and materials), objective, presentation, assessment and evaluation, closure and homework. The following were the steps taken in the treatment (Simulation-based learning strategy) presentation:

Instructional guide for experimental Group B: Learning instructional guide presentation using Simulation strategy to teach Genetics were as follows:

- A. Introduction
- B. Presentation of new content using simulation
- C. Guided practice
- D. Class discussion and reflection

Further information regarding Instructional guide for experimental Group B refers to in Appendix IV.

3.4.4 Guide for Instruction in Teaching and Learning of Genetics (Traditional learning strategy)

The traditional teaching strategy involves direct instruction, practice, and reinforcement through teacher-led demonstrations, independent exercises, and class discussions. By using methods like lectures, and guided practice, this strategy helps students grasp foundational concepts in Genetics. Although more teacher-centered than interactive method.

Furthermore, the guide for instruction was taken in teaching and learning process in the selected institutions for this treatment during fieldwork consist of lesson overview (topic, target group, duration and materials), objective, presentation, assessment and evaluation, closure and homework. The following were the steps taken in the treatment (Traditional learning strategy) presentation:

Instructional guide for control Group C: Learning instructional guide presentation using Traditional learning strategy to teach Genetics were as follows:

- A. Introduction
- B. Direct instruction
- C. Guided practice
- D. Independent practice
- E. Class discussion and reflection

Further information regarding Instructional guide for control Group C refers to in Appendix V.

3.5 Validity of the Research Instruments

Face, construct, and content validity of the instruments were carried out by the thesis promoter and two other lecturers in the Department of Science Education at Lead City University, Ibadan, and two lecturers in the Department of Biology at the Federal College of Education, Osiele, Abeokuta, Ogun State. All corrections and suggestions provided by these experts were addressed before producing the final drafts for administration and data collection.

3.6 Reliability of the Genetics Achievement Test (GAT)

The reliability of the research instrument, the Genetics Achievement Test (GAT), was tested on 20 year-two Biology education students at Tai Solarin University of Education in Ijebu-Ode Local Government Area, Ogun State. This tertiary institution, selected for the reliability test, was not part of the schools chosen for the main study but shared similar attributes, being located in the same state and offering Biology education

as a course of study. The reliability coefficient of the instrument was calculated using the Kuder-Richardson 20 (KR-20) formula, yielding a reliability value of 0.79.

3.7 Method of Data Collection

In a quasi-experimental study that used an achievement test, data collection involved carefully gathering information on participant performances or findings for the particular construct being studied. Lecturers or research assistants received training, which included a thorough explanation of the study's goals and the steps required to complete it in eight weeks. During the first week of fieldwork, research assistants were trained on study-specific methodologies for instruction. The pretest was administered to participants in the second week. The implementation of the treatment plan, based on the assigned learning strategy for each of the purposively selected tertiary institutions, took place over the next five weeks (week three to week seven). In week eight, the posttest was administered.

Biology education lecturers (Research Assistants) from the purposively selected tertiary institutions for the study received training on how to lead students in experimental group A using the audio-visual strategy instructional guide, in experimental group B using the simulation-based learning strategy instructional guide, and in control group C using the traditional learning strategy, while utilizing the researcher's prepared instructional guides. Following the training, the researcher observed the research assistants (Biology education lecturers) as they continued the experiment under the researcher's supervision for 30 minutes, testing their knowledge of the material. Participants in both the experimental and control groups were exposed to the same

duration of time (periods). Every week for five weeks (week three to week seven), one lecture period (60 minutes) was used in each of the schools where the treatments were administered. Before the commencement of the experiment, the participants took the pre-test, and at the end of the experiment, they took the post-test.

3.8 Method of Data Analysis

The data was analyzed using inferential statistics and the hypotheses that were formulated for the study were tested using Analysis of Covariance (ANCOVA) at 0.05 level of significance.

3.9 Ethical Approval

This study adhered to ethical research practices to ensure respect, confidentiality, and voluntary participation of all stakeholders. The researcher obtained a Letter of Introduction from the Head of Department, which was presented to the authorities of the purposively selected institutions. This letter sought formal permission to engage with participants and conduct the study, including administering the achievement test for data collection. Informed consent was obtained from all participants before the commencement of the study. A detailed consent form was provided, clearly outlining the study's purpose, methodology, potential benefits, and any possible challenges. Participants were assured of their rights, including the option to withdraw from the study at any point without any repercussions. The researcher ensured that all data collected was kept strictly confidential and used solely for academic purposes. Participants' identities and responses were anonymized to protect their privacy. Participation in the study was entirely voluntary, and no participant was coerced into taking part. The research process

was designed to minimize any form of harm or discomfort to the participants. This ethical approach ensured the study adhered to the highest standards of research integrity and respect for participants autonomy.

Endnote

1. The Directorates of Lagos State University; National Open University of Nigeria; University of Ibadan Study Centres, Ogun Central Senatorial District, Ogun State, 2025.

Lead City University Ibadan DO NOT COPY

Chapter Four

Results and Discussion of Findings

This chapter presents the analysis of data collected at the 0.05 level of significance, results tables, the interpretation of results and discussion of findings.

4.1 Demographic Data Analysis

Table 4.1.0: Audio-visual Strategy (AVS), Simulation Learning Strategy (SBLs) and Traditional Learning Strategy (TLS)

Teaching Strategies	Gender		Total
	Male	Female	
AVS	14	14	28
SBLs	15	15	30
TLS	16	16	32
Total	45	45	90

Source: Researcher's Fieldwork, 2025

4.2 Presentation of Data

4.2.1 Hypotheses

Null Hypothesis (H_0): There will be no significant main effect of audio-visual strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.

Table 4.1.1 presents the result of ANCOVA on the effect of audio-visual strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria. From the Table 4.1.1, the F-statistics ($F_{(1; 57)} = 1.449$) and the probability (significant) value = 0.234. This indicated that the null hypothesis (H_0) that audio-visual strategy has no significant main effect on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria is not rejected. Hence, there was no significant main effect of Audio-visual Intervention strategy on Achievement in Genetics among pre-service Biology teachers in Ogun Central Senatorial District of Ogun State, Nigeria ($F_{(1; 57)} = 1.449$, $p > 0.05$). The Partial Eta Squared value in the Table 4.1.1 indicates the effect size of audio-visual strategy and traditional learning strategy. This value was 0.025,

which was small when compared with Cohen's guidelines (0.2 – small effect, 0.5 – moderate effect, 0.8 – large effect). This suggested that about 2.5% of the variance in the posttest score of pre-service Biology teachers' academic achievement in Genetics was explained by the audio-visual strategy.

Table 4.1.2 shows the results of the estimated marginal mean, which gives the adjusted means (controlling for the covariate 'pretest score') for each strategy group. This simply means that the effect of 'pretest score' has been statistically removed. The outcomes of the estimated marginal means showed that higher academic performance was recorded for the pre-service Biology teachers in Genetics in Ogun Central Senatorial District of Ogun State, Nigeria with traditional Learning strategy (mean = 15.308 unit) on average after adjusting for pretest score, compared to the audio-visual strategy (mean = 15.041).

Table 4.1.1: Tests of Between-Subjects Effects of Audio-visual Strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4992.996 ^a	2	2496.498	3745.994	0.000	0.992
Intercept	3.006	1	3.006	4.510	0.038	0.073
PRETEST	4555.089	1	4555.089	6834.908	0.000	0.992

STRATEGY	0.966	1	0.966	1.449	0.234	0.025
Error	37.987	57	0.666			
Total	18863.000	60				
Corrected Total	5030.983	59				

a. R Squared = 0.992 (Adjusted R Squared = 0.992)

Source: Researcher's Fieldwork, 2025

Table 4.1.2: Estimates of Audio-visual Strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

STRATEGY	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Audio-visual Intervention	15.041 ^a	0.159	14.723	15.358
Traditional Teaching	15.308 ^a	0.148	15.012	15.604

a. Covariates appearing in the model are evaluated at the following values:

PRETEST = 11.4333.

Source: Researcher's Fieldwork, 2025

Null Hypothesis (H₀2): There will be no significant main effect of simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.

Table 4.2.1 presents the result of ANCOVA on the effects of simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria. From the Table 4.2.1, the F-statistics ($F_{(1; 59)} = 0.809$) and the probability (significant) value = 0.372. This indicated that the null hypothesis (H_0) that simulation-based learning strategy has no significant main effect on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria is not rejected. Hence, there was no significant main effect of simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 59)} = 0.809$, $p > 0.05$). The Partial Eta Squared value in the Table 4.2.1 indicates the

effect size of simulation-based learning strategy and traditional learning strategy. This value was 0.014, which was small when compared with Cohen's guidelines (0.2 – small effect, 0.5 – moderate effect, 0.8 – large effect). This suggested that about 1.4% of the variance in the posttest score of the Pre-service Biology teachers' Academic Achievement in Genetics was explained by simulation-based learning strategy.

Table 4.2.2 shows the results of the estimated marginal mean, which gives the adjusted means (controlling for the covariate 'pretest score') for each strategy group. This simply means that the effect of 'pretest score' has been statistically removed. The outcomes of the estimated marginal means showed that higher academic performance was recorded for the pre-service Biology teachers in Genetics in Ogun State, Nigeria with simulation-based learning strategy (mean = 15.037 unit) on average after adjusting for pretest score, compared to the traditional learning strategy (mean = 14.840).

Table 4.2.1: Tests of Between-Subjects Effects of Simulation-based Learning Strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4389.190 ^a	2	2194.595	3192.976	0.000	0.991

Intercept	6.008	1	6.008	8.741	0.004	0.129
PRETEST	4045.634	1	4045.634	5886.103	0.000	0.990
STRATEGY	0.556	1	0.556	0.809	0.372	0.014
Error	40.552	59	0.687			
Total	18260.000	62				
Corrected Total	4429.742	61				

a. R Squared = 0.991 (Adjusted R Squared = 0.991)

Source: Researcher's Fieldwork, 2025

Table 4.2.2: Estimates of Simulation-based Learning Strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

Strategy	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Simulation-Based Learning	15.037 ^a	0.154	14.728	15.346
Traditional Teaching	14.840 ^a	0.149	14.542	15.139

a. Covariates appearing in the model are evaluated at the following values:

PRETEST = 11.0645.

Source: Researcher's Fieldwork, 2025

Null Hypothesis (H₀3): There will be no significant main effect of gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Table 4.3.1 presents ANCOVA result on the effect of gender on senior secondary school students' academic achievement in Genetics. From the Table 4.3.1, the F-statistics ($F_{(1; 87)} = 4.559$) and the probability (significant) value = 0.036. This signified that the null hypothesis (H₀) that gender has no significant main effect on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria is rejected. Therefore, there was significant main effect of gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 101)} = 4.559$, $p < 0.05$). The Partial Eta Squared value in the Table 4.3.1 shows the effect size of the female and male genders. This value was 0.050, which was small when compared with Cohen's

guidelines (0.2 – small effect, 0.5 – moderate effect, 0.8 – large effect). This implied that about 5% of the variance in the posttest score of the pre-service Biology teachers' academic achievement in Genetics posttest score was explained by both the female and male genders.

Table 4.3.2 shows the results of the estimated marginal mean, which gives the adjusted means (controlling for the covariate 'pretest score') for each gender group. This signifies that the effect of 'pretest score' has been statistically removed. The results of the estimated marginal means signified that more academic performance was documented for the female pre-service Biology teachers (mean = 16.101 unit) on average after adjusting for pretest score, compared to the male pre-service Biology teachers (mean = 15.721 unit).

Table 4.3.1: Tests of Between-Subjects Effect of Gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6285.632 ^a	2	3142.816	4742.315	0.000	0.991
Intercept	11.562	1	11.562	17.446	0.000	0.167
PRETEST	5757.588	1	5757.588	8687.844	0.000	0.990
GENDER	3.021	1	3.021	4.559	0.036*	0.050
Error	57.656	87	0.663			

Total	29128.000	90
Corrected Total	6343.289	89

a. R Squared = 0.991 (Adjusted R Squared = 0.991)

Source: Researcher's Fieldwork, 2025

Table 4.3.2: Estimates of Gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

Gender	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Female	16.101 ^a	0.124	15.855	16.347
Male	15.721 ^a	0.124	15.475	15.967

a. Covariates appearing in the model are evaluated at the following values: PRETEST = 11.9111.

Source: Researcher's Fieldwork, 2025

Null Hypothesis (H₀4): There will be no significant interaction effect of audio-visual strategy, simulation-based learning strategy and gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.

Table 4.4.1 presents ANCOVA result on the interaction effect of audio-visual strategy, simulation-based learning strategy and gender on Achievement in Genetics among pre-service Biology teachers in Ogun Central Senatorial District of Ogun State, Nigeria. From the Table 4.4.1, the F-statistics ($F_{(5; 84)} = 7.921$) and the probability (significant) value = 0.000. This signified that the null hypothesis (H₀) that there will be no significant interaction effects of audio-visual strategy, simulation-based learning strategy and gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria is rejected. Therefore, there was a significant interaction effects of audio-visual strategy, simulation-based learning strategy and gender on Achievement in

Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(5; 84)} = 7.921$, $p < 0.05$).

The Partial Eta Squared value in the Table 4.4.1 shows the size of the interaction effect of audio-visual strategy, simulation-based learning strategy and gender. This value was 0.320, which was moderate when compared with Cohen's guidelines (0.2 – small effect, 0.5 – moderate effect, 0.8 – large effect). This implied that about 32% of the variance in the posttest score of the pre-service Biology teachers' academic achievement in Genetics was explained by the interaction of audio-visual strategy, simulation-based learning strategy and gender.

Table 4.4.2 shows the results of the estimated marginal mean of the interaction of audio-visual strategy, simulation-based learning strategy and gender, which gives the adjusted means (controlling for the covariate 'pretest score') for each group. This signifies that the effect of 'pretest score' has been statistically removed. The outcomes signified that higher academic performance was achieved by the female pre-service Biology teachers in Ogun State, Nigeria, when audio-visual strategy was adopted (mean = 20.571 unit) on average after adjusting for pretest score, compared to when the interaction of simulation-based learning strategy and female gender is adopted (mean = 15.667 unit), and when traditional learning strategy and female gender is adopted (mean = 18.875 unit). However, higher academic performance was achieved by the male pre-service Biology teachers in Ogun State, Nigeria, when simulation-based learning strategy was adopted (mean = 19.067 unit) on average after adjusting for pretest score, compared to when the interaction of traditional learning strategy and male gender is adopted (mean

= 6.437 unit), and when the interaction of audio-visual strategy and male gender is adopted (mean = 15.571 unit).

Table 4.4.1: Tests of Between-Subjects Effect of Audio-visual Strategy, Simulation-based Learning Strategy and Gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2032.478 ^a	5	406.496	7.921	0.000	0.320
Intercept	23062.023	1	23062.023	449.384	0.000	0.843
Strategy x Gender	2032.478	5	406.496	7.921	0.000*	0.320
Error	4310.811	84	51.319			
Total	29128.000	90				
Corrected Total	6343.289	89				

a. R Squared = 0.320 (Adjusted R Squared = 0.280)

Source: Researcher's Fieldwork, 2025

Table 4.4.2: Estimates of Audio-visual Strategy, Simulation-based Learning Strategy and Gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria

Dependent Variable: POSTTEST

Gender	Strategy	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Female	Audio-visual Intervention	20.571	1.915	16.764	24.379
	Simulation-based Learning	15.667	1.850	11.988	19.345
	Traditional Teaching	18.875	1.791	15.314	22.436
Male	Audio-visual Intervention	15.571	1.915	11.764	19.379
	Simulation-based Learning	19.067	1.850	15.388	22.745
	Traditional Teaching	6.437	1.791	2.876	9.999

Source: Researcher's Fieldwork, 2025

4.3 Discussion of Findings

There was no significant main effect of the audio-visual strategy on achievement in Genetics among pre-service Biology teachers Ogun State, Nigeria. This finding is not

consistent with the results of a previous study titled “Effect of Technology-Mediated Dynamic and Static Visuals on Pre-Service Biology Teachers’ Retention in Colleges of Education in North Central, Nigeria¹.” Although the studies were conducted in different geographical locations, they were contextually similar but yielded differing results. The previous study found that the mean retention scores of pre-service Biology teachers taught Genetics using technology-mediated dynamic and static graphics differed statistically significantly, which contradicts the findings of this study¹. Furthermore, despite both the present and previous studies utilizing similar treatments (Visual Learning Devices), differences in educational levels and geographical locations may account for the discrepancies. This study’s findings also contradict the results of another study titled “Impact of Visual Learning Devices on Secondary School Biology Students’ Academic Performance in Ilorin, Nigeria”, which revealed a significant impact of visual learning devices on students’ academic performance². Similarly, the study’s findings are not in alignment with a study titled “Effects of Audio-Visual Instructional Materials on Teaching Science Concepts in Secondary Schools in Bwari Area Council Abuja, Nigeria”, which demonstrated that audio-visual instructional materials have a significant effect on students’ achievement in science³. Another conflicting result is found in the study titled “Video Instructional Strategy on Biology Students’ Academic Performance in Port Harcourt, Nigeria”, which reported that the experimental group achieved a higher mean performance score. These differences suggest that, while video instruction encourages the internalization of abstract concepts, its effectiveness may vary depending on the context, location, and educational level of the participants⁴.

There was no significant main effect of the simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria. This finding is not consistent with the results of a previous study titled “Effect of Computer Simulation Instructional Strategy on Students’ Attitude and Academic Achievement in Genetics”, which showed that using computer simulations as a teaching tool significantly improved students' academic performance and enhanced their attitudes toward Biology⁵. Similarly, research has demonstrated that using computer simulations in the classroom substantially improved the achievement of low-ability students, who exhibited greater mean improvements compared to medium- and high-ability groups. The results of the study also contradict those of another study titled “Effect of Computer Simulation on Students’ Achievement and Retention in Sexual Reproduction in Plants in Niger State, Nigeria⁶.” This study found that students taught using the computer simulation strategy outperformed those taught using traditional learning strategy. Moreover, the results of the ANCOVA test in the previous study indicated that the group taught using the computer simulation strategy had significantly higher achievement and retention scores⁶. These findings contrast with the study results, despite both studies examining the effect of the same treatment (computer simulation strategy) as the independent variable, albeit on different dependent variables.

There was a significant main effect of gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria. This finding aligns with the results of a previous study titled “Effect of Culturo-Techno-Contextual Approach on Secondary School Students’ Academic Achievement in Biology in Nsukka Education Zone”. The study showed that CTCA is a gender-neutral teaching strategy that can uniformly

improve Biology achievement scores for both male and female secondary school students⁷. Conversely, the study result did not align with the findings of a previous study titled “Effect of Concept Mapping Instructional Strategy Accompanied by Discussion Web on Students’ Academic Achievement in the Concept of Genetics”, where the academic performance of male and female students in the experimental group did not differ statistically significantly⁸. Despite both studies focusing on Genetics but conducted in different geographical locations, the study result remains consistent with another study titled “Integration of ICT in the Teaching and Learning of Genetics in Selected Secondary Schools in Kitwe District, Zambia”. The findings of this study revealed a statistically significant difference in genetic performance by group names and gender in the experimental and control groups⁹. Similarly, the study aligns with the results of a study titled “Gender Differences and Academic Achievement and Retention of Students in Biology among Senior Secondary School Students in Ekiti State”, which found a considerable disparity between the mean achievement scores of male and female students¹⁰. Additionally, the findings are consistent with the study titled “Students’ Demography Variables and Academic Achievement in Biology in Calabar Municipality Local Government Area of Cross River State”, which indicated that the academic performance of Senior Secondary School 11 Biology students in the Calabar Municipality Local Government Area was significantly influenced by their gender, age, and birth order¹¹. However, the current study result does not align with the findings of the study titled “Enhancing Students’ Performance in Genetics Using 5E Learning Cycle and WebQuest in Secondary Schools in Rivers State”, which found that the 5E learning cycle

and online quest did not significantly interact to affect the performance of Genetics among students, regardless of gender¹².

There was a significant interaction effect of the audio-visual strategy, simulation-based learning strategy, and gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria. This finding aligns with a previous study titled “Effect of Technology-Mediated Dynamic and Static Visuals on pre-service Biology Teachers’ Retention in Colleges of Education in North Central, Nigeria¹.” Although the studies were conducted in different geographical locations, they are contextually similar but yielded varying outcomes. The previous study revealed a statistically significant difference between the mean retention scores of male and female pre-service Biology teachers taught Genetics using technology-mediated dynamic and static graphics.

Endnotes

1. F. Ali, I. K. Ibrahim, O. C. Falode & O. A. Y. Daudu, *Effect of Technology-Mediated Dynamic and Static Visuals on Pre-Service Biology Teachers’ Retention in Colleges*

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Chapter Five

Conclusion

5.1 Summary of Findings

A total of 90 Biology education students, comprising 45 male and 45 female participants, took part in this study as the sample size. At the University A, 28 participants, comprising 14 male and 14 female students, were treated with the Audio-visual for Group A (experimental group). At University B, 30 participants, comprising 15 male and 15 female students, were treated with the Simulation-based learning strategy for Group B (experimental group). Meanwhile, at University C, 32 participants, comprising 16 male and 16 female students in the control group (Group C), were treated with the traditional learning strategy.

From the Analysis of Covariance (ANCOVA) results: There was no significant main effect of audio-visual strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 57)} = 1.449$, $p > 0.05$).

There was no significant main effect of simulation-based learning strategy on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 59)} = 0.809$, $p > 0.05$).

There was significant main effect of gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(1; 101)} = 4.559$, $p < 0.05$).

There was a significant interaction effect of audio-visual strategy, simulation-based learning strategy and gender on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria ($F_{(5; 84)} = 7.921$, $p < 0.05$).

5.2 Conclusion

The findings of this study indicate that, while audio-visual strategies (AVS) and simulation-based learning strategies (SBLS) did not improve achievement in Genetics, significant interaction effect was observed between these strategies and gender. Specifically, the combination of audio-visual strategy, simulation-based learning strategy, and gender considerations significantly improved achievement in Genetics. Thus, this study concluded that a blended approach, incorporating both audio-visual strategy, simulation-based learning strategy, and gender can enhance Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria.

5.3 Recommendations

Base on the findings of this study, the following recommendations are made.

- i. Educators should integrate audio-visual strategy with complementary strategies like simulations or collaborative learning to maximize its impact, as Audio-visual Strategy alone may not sufficiently enhance Academic Achievement in complex topics like Genetics.
- ii. Simulation-based learning should be combined with structured instructional approaches like guided discussions or audio-visual aids to address its limitations and enhance academic outcomes in Genetics.
- iii. Educators should adopt gender-responsive teaching methods that cater to the distinct cognitive and engagement preferences of male and female students in Genetics education.

- iv. Educators should consider gender differences when combining audio-visual strategy and simulation-based learning strategy, ensuring that instructional strategies are adapted to meet the learning needs of both male and female students effectively.

5.4 Contributions to Knowledge

The research on the "Effects of Audio-visual Intervention and Simulation-based Strategies on Achievement in Genetics among Pre-service Biology Teachers in Ogun State, Nigeria" contributes to knowledge in the following ways:

5.4.1 Implications for Researchers

Methodological Contribution: The research provides insights into the effects of using audio-visual and simulation-based strategies in teaching Genetics, which can inform future research on instructional strategies.

Theoretical Contribution: The research contributes to the understanding of how different teaching approaches impact Achievement in Genetics among Pre-service Biology teachers.

Contextual Contribution: The research findings can be used to inform future research on teaching Genetics in similar contexts, particularly in Nigeria.

5.4.2 Implications for Practitioners

Teaching Strategies: The research findings can inform the development of effective teaching strategies for Genetics, enabling practitioners to improve academic achievement among pre-service Biology teachers.

Curriculum Development: The research can inform curriculum development and instructional design for Genetics Education, incorporating audio-visual and simulation-based strategies.

Professional Development: The research findings can be used to design professional development programmes for Biology teachers, enhancing their ability to teach Genetics effectively.

5.5 Suggested Area for Further Research

Future studies on the effects of audio-visual and simulation-based strategies on achievement in Genetics among pre-service Biology teachers could explore broader and complementary areas. Research could focus on the effects of these strategies across different educational levels, such as secondary schools, to assess their adaptability and impact. Additionally, extending the study to include different areas, or regions would enhance the generalizability of findings. Investigating the role of student engagement and motivation as moderating factors in the effects of audio-visual and simulation strategies could also provide deeper insights. Another potential area is examining the integration of these strategies with other innovative learning strategies, such as flipped classrooms or project-based learning, to determine combined impacts on academic achievement. Finally, studies could explore the cost-effectiveness and scalability of these interventions, particularly in resource-constrained environments, to facilitate broader implementation in similar educational contexts.

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Genetics Achievement Test

Instructions:

Section A: Please provide an appropriate answer to the following questions

Section B: Please shade only one answer at a time from the given options

Duration: 45 Minutes

Section A

Demographic Characteristics of Participants

Institution's Name: _____

Gender:

Male

☐

Female

☐

Section B

1. The physical appearance of a trait is known as _____
 - A) Genotype
 - B) Phenotype
 - C) Allele
 - D) Chromosome
2. Who is considered the "father of Genetics"?
 - A) Charles Darwin
 - B) Gregor Mendel
 - C) James Watson
 - D) Francis Crick
3. A gene that has two different alleles is called _____
 - A) Heterozygous
 - B) Homozygous
 - C) Dominant
 - D) Recessive
4. Genetic information is passed from one generation to the next by _____
 - A) Mutation
 - B) Genetic drift
 - C) Gene flow
 - D) Heredity
5. The term for a gene that will always be expressed if an individual has one copy of the allele is _____
 - A) Dominant
 - B) Recessive
 - C) Codominant
 - D) Incomplete dominant

6. Which term is used for the movement of genes from one population to another?
- A) Gene flow
 - B) Genetic drift
 - C) Mutation
 - D) Natural selection
7. Change in the DNA sequence of an individual is known as _____
- A) Mutation
 - B) Genetic drift
 - C) Gene flow
 - D) Heredity
8. The process by which an individual's genotype determines their phenotype is _____
- A) Expression
 - B) Penetrance
 - C) Dominance
 - D) Segregation
9. Probability that an individual will express a particular trait called _____
- A) Penetrance
 - B) Expressivity
 - C) Dominance
 - D) Segregation
10. An individual that expresses a particular trait is known as _____
- A) Expressivity
 - B) Penetrance
 - C) Dominance
 - D) Segregation
11. Separation of alleles occur during gamete formation as a process of _____
- A) Segregation
 - B) Independent assortment
 - C) Crossing over
 - D) Mutation
12. _____ is term for the random combination of alleles during gamete formation
- A) Independent assortment
 - B) Segregation
 - C) Crossing over
 - D) Mutation
13. _____ is the exchange of genetic material between homologous chromosomes
- A) Crossing over
 - B) Independent assortment
 - C) Segregation

- D) Mutation
14. The study of the structure, behavior, and evolution of chromosomes is known as__
A) Cytogenetics
B) Molecular Biology
C) Population genetics
D) Quantitative genetics
15. The study of the interaction between genes and the environment _____
A) Quantitative genetics
B) Population genetics
C) Molecular Biology
D) Ecological genetics
16. Which of the following is the study of the frequency and distribution of alleles in a population?
A) Population genetics
B) Quantitative genetics
C) Molecular Biology
D) Ecological genetics
17. What is the term for the process by which a population becomes reproductively isolated from other populations?
A) Speciation
B) Adaptation
C) Natural selection
D) Genetic drift
18. The process by which a population becomes adapted to its environment is _____
A) Adaptation
B) Natural selection
C) Genetic drift
D) Speciation
19. An individual with certain traits is more likely to survive and reproduce by_____
A) Natural selection
B) Genetic drift
C) Mutation
D) Gene flow
20. Random change in the frequency of an allele in a population is called _____
A) Genetic drift
B) Mutation
C) Gene flow
D) Natural selection

21. _____ is the process by which genetic information is passed from one generation to the next through the transmission of DNA
- A) Heredity
 - B) Genetic drift
 - C) Mutation
 - D) Gene flow
22. The physical structure that carries genetic information in the nucleus of a cell is known as _____
- A) Chromosome
 - B) Gene
 - C) Allele
 - D) DNA
23. A single gene can have multiple effects on an organism's phenotype by _____
- A) Pleiotropy
 - B) Polygenic inheritance
 - C) Epistasis
 - D) Dominance
24. The term for the interaction between two or more genes that affects the expression of a particular trait is called _____
- A) Epistasis
 - B) Pleiotropy
 - C) Polygenic inheritance
 - D) Dominance
25. The study of the relationship between genes and behavior is known as _____
- A) Behavioral genetics
 - B) Molecular Biology
 - C) Population genetics
 - D) Quantitative genetics

**Genetics Achievement Test
Marking Guide**

Answer:

1. B
2. B
3. A
4. D
5. A
6. A
7. A
8. A
9. A
10. A
11. A
12. A
13. A
14. A
15. D
16. A
17. A
18. C
19. A
20. A
21. A
22. A
23. A
24. A
25. A

Teaching and Learning Instructional Guides

Instructional Guide for Experimental Group A

Teaching Instructional Guide Using Audio-Visual Intervention Strategy to

Teach Genetics

1. Lesson Overview

Topic: Genetics (including concepts like DNA structure, Mendelian Genetics, genetic mutations, and inheritance patterns)

Target Group: Biology Education Students

Duration: 60 minutes

Materials:

Video clips explaining Genetics concepts (e.g., DNA replication, Mendelian inheritance)

Animations (showing genetic processes like meiosis or mitosis)

Interactive simulations (such as online genetic crosses or DNA replication models)

Projector or screen for displaying content

Computers, tablets, or devices with access to educational websites or apps (optional)

2. Objective:

To enhance the understanding of key concepts in Genetics using audio-visual interventions, such as videos, animations, and interactive simulations, designed to improve student comprehension, engagement, and academic achievement.

3. Presentation:

Content Development	Time (Mins)	Teacher's Activities	Students' Activities
A. Introduction	10	1. Engage Students: Begin by asking the class about their prior knowledge of Genetics. For example: "What do you know about DNA?" "Can anyone explain what Mendel's experiments on pea plants showed?" 2. Set the Learning Goal: Inform students that the lesson will use videos, animations, and simulations to help them understand how genes are inherited and how genetic material works in	1. Participate in a short discussion about their prior knowledge. 2. Listen attentively to the introduction and expectations of the lesson.

		organisms. 3. Introduce Audio-Visual Tools: Briefly introduce the videos and simulations that will be used. Explain how these tools will help in visualizing complex genetic processes.	
B. Presentation of New Content	30	1. Start with a Video: Show a short introductory video on the basics of Genetics (e.g., a 5-minute video on DNA structure or inheritance patterns). Ensure the video is engaging, with clear visuals and an accessible	1. Watch and Participate: Watch the video attentively and participate in the Q&A after each section.

		explanation. Example Video: "DNA Structure and Function" from Khan Academy or Crash Course Biology. 2. Guide Through the Video: Pause the video intermittently to ask questions, ensuring that students are following along and to clarify any concepts that may seem difficult. Teacher Prompt: "What are the four nitrogenous bases in DNA? Can anyone explain the base-pairing rule?" 3. Use Animations: After the video, show an animation demonstrating a genetic	2. Discuss Key Concepts: After watching the video, students will discuss with a partner or in small groups what they have learned (e.g., base-pairing, inheritance laws). 3. Engage with Animations: Take notes while watching animations, making sure to focus on the specific genetic processes being
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		process such as DNA replication or meiosis. These animations will help students visualize how genetic information is transferred or mutated. Example Animation: Show an animation of how DNA replicates during cell division or how Mendel's pea plant experiment works. 4. Interactive Simulations: Allow students to engage with interactive simulations. For example, they could simulate genetic crosses (e.g., crossing two pea plants with different traits) or explore a model of genetic mutations.	explained. 4. Interactive Learning: Use the simulations to experiment with genetic traits and observe the outcomes. For example, they could try different genetic crosses and predict the results.
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		Example Simulation: Use PhET Interactive Simulations (like Genes in a Bottle or Natural Selection), which allow students to explore how genetic traits are inherited.	
C. Guided Practice	15	1. Provide Guided Activities: Have students complete a set of guided activities using the simulations or worksheets that reinforce the concepts learned. The activities might include: Predicting genetic outcomes (e.g., the probability of offspring having certain traits). Identifying the stages of DNA replication or meiosis using the animation.	1. Complete Guided Activities: Work individually or in pairs to complete the guided practice activities using the simulations or animation-based questions. 2. Apply Knowledge: Use the

		2. Monitor and Assist: Walk around the class and assist students with the simulations or animations. Answer questions and ensure they are applying the concepts correctly. Teacher Prompt: “What is the role of meiosis in genetic diversity? How does crossing over contribute to this?”	interactive simulation to create genetic crosses or simulate a genetic mutation. Students should work through different scenarios and predict the outcomes based on their understanding of genetic principles. 3. Ask Questions: If needed, ask the teacher for clarification
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			about the concepts or activities.
D. Class Discussion and Reflection	5	1. Facilitate a Discussion: Ask students to reflect on the activities and the use of audio-visual tools. Questions for Discussion: "How did the animations and simulations help you understand genetic concepts better?" "What did you find most interesting or difficult in this lesson?" 2. Summarize the Lesson: Briefly recap the key concepts covered in the lesson (e.g., DNA structure,	1. Reflect and Discuss: Reflect on what they have learned and engage in the class discussion. Share thoughts about how the visual and interactive tools helped them learn. 2. Ask Clarification Questions: If any concepts remain unclear, students should

		Mendelian inheritance, genetic mutations). 3. Provide Feedback: Offer immediate feedback on student participation and understanding.	ask questions or request additional examples.
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4. Assessment and Evaluation

Teacher's Activity:

1. Formative Assessment: During the guided practice and class discussion, assess students' understanding by asking targeted questions about genetic concepts (e.g., "Can you explain what happens during crossing over?").
2. Summative Assessment: At the end of the lesson, provide a short quiz or written activity that asks students to apply what they've learned about Genetics (e.g., interpreting Punnett squares, explaining genetic mutation effects).

Student's Activity:

1. Participate in the Formative Assessment: Answer questions from the teacher during the class activities.
2. Complete the Summative Assessment: Take the quiz or complete a short reflection on the lesson, applying their understanding of the Genetics topics discussed.

5. Closure and Homework

Teacher's Activity:

1. Summarize Key Points: Recap the key takeaways from the lesson and reinforce how audio-visual interventions helped students understand Genetics concepts.
2. Assign Homework: Assign students a task related to the lesson, such as watching another video on genetic mutations or researching a specific genetic disorder. Ask them to prepare a report or presentation summarizing the key points.

Student's Activity:

1. Review Notes: Review the notes taken during the lesson, focusing on key concepts and terms (e.g., DNA, Mendelian inheritance, genetic mutations).
2. Complete Homework: Follow up on the homework assignment, ensuring that they apply the concepts learned during the lesson.

Conclusion

Using the Audio-Visual Intervention Strategy in teaching Genetics allows for an interactive and engaging learning experience. The combination of videos, animations, and simulations supports diverse learning styles, facilitates better comprehension of complex genetic processes, and increases students' academic achievement. By incorporating these multimedia tools, teachers can provide a rich, visual, and hands-on learning environment that enhances students' understanding of Genetics.

Appendix IV

Teaching and Learning Instructional Guides

Instructional Guide for Experimental Group B

Teaching Instructional Guide Using Simulation Strategy to Teach Genetics

1. Lesson Overview

Topic: Genetics (including concepts such as DNA structure, Mendelian inheritance, genetic mutations, and inheritance patterns)

Target Group: Biology Education Students

Duration: 60 minutes

Materials:

Computers or tablets with access to genetic simulation programs (e.g., PhET Interactive Simulations, Explore Learning Gizmos)

Projector or screen to demonstrate simulations

Student worksheets or online quizzes for recording results and observations

2. Objective:

To enhance student understanding of genetic concepts by using simulations that allow them to interact with genetic processes, conduct virtual experiments, and apply theoretical knowledge in a practical, hands-on manner.

3. Presentation:

Content Development	Time (Minutes)	Teacher's Activities	Students' Activities
A. Introduction	10	1. Introduce the Topic: Begin the lesson by introducing the topic of Genetics. Explain the importance of Genetics in Biology and its real-world applications (e.g., genetic disorders, inheritance of traits). 2. Set Learning Goals: Inform students that they will be using simulation tools to explore how genetic traits are inherited and to simulate genetic experiments (e.g., crossing plants, studying DNA	1. Listen attentively to the introduction and objectives of the lesson. 2. Ask questions or express excitement about using the simulation tools for the lesson.

		replication). 3. Introduce the Simulation Tool: Briefly demonstrate the simulation program that will be used in the lesson, showing how it can simulate genetic crosses or mutations. Example Simulation: PhET Interactive Simulations – “Genes in a Bottle” or Explore Learning Gizmos – “Genetic Crosses.”	
B. Presentation of New Content Using Simulation	30	1. Demonstrate the Simulation: Show how to set up a genetic cross using the simulation (e.g., crossing pea plants with different	1. Set Up and Run Simulations: Each student (or pair of students) runs simulations on their computers/tablets,

		traits such as color or height). Explain the simulation's interface and how students can manipulate variables (e.g., dominant/recessive traits, homozygous/heterozygous). Teacher Prompt: "In this simulation, you can choose the traits of two parent plants. What do you think the resulting offspring will look like?" 2. Guide Students Through the First Simulation: Walk students through the first set of	manipulating variables such as the traits of the parent plants. Student Questions to Answer: "What traits did the offspring inherit? Were the traits expressed dominantly or recessively?" 2. Record Observations: Students should record their observations (e.g., number of offspring showing dominant or recessive traits) in their worksheets or on an online form. Student Worksheet Example: "How many offspring displayed the dominant trait? What was the genotype of the
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		experiments, such as simulating a simple Mendelian cross (e.g., crossing a tall plant with a short plant and observing the inheritance of the trait). Teacher Prompt: “Let’s try crossing a pea plant with a round seed (RR) and a plant with wrinkled seeds (rr). What do you think the offspring will inherit?” 3. Introduce Additional Simulations: Once students are comfortable with the tool, introduce more complex simulations, such as exploring	offspring?” 3. Experiment with Different Scenarios: Students can experiment with different types of crosses, including test crosses or homozygous/heterozygous combinations, to see how inheritance patterns change. Student Activity: “Try crossing two heterozygous plants and observe the distribution of traits in the offspring.”
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		multiple traits (e.g., crossing plants for both height and seed shape). Teacher Prompt: “Let’s now look at a dihybrid cross. What will happen when we cross two plants with two different traits?”	
C. Guided Practice	15	1. Facilitate Group Work: Divide students into small groups, each with a set of simulations to complete. Each group will use the simulation tool to conduct different genetic experiments. For example, Group 1 can work on single-gene crosses, Group 2 on dihybrid crosses, and	1. Collaborate with Peers: Work in groups to conduct more complex genetic experiments using the simulation tool. Groups will work through their assigned scenarios, analyze the results, and prepare to share their findings with the class. 2. Record Results:

		Group 3 on genetic mutations. 2. Monitor and Assist: Walk around the room, observing student progress and providing support as needed. Offer clarifications and help troubleshoot any issues with the simulation software. Teacher Prompt: “What did you observe when you crossed two heterozygous pea plants for seed color? Was the ratio of offspring consistent with what you expected?”	Students continue to record the results of their experiments in their worksheets or on an online form. 3. Analyze Data: After completing their experiments, students analyze the results. They should be able to explain inheritance patterns and predict genetic outcomes based on their observations.
D. Class Discussion	5	1. Facilitate a Class-wide Discussion: Bring the	1. Share Findings: Each group shares their

and Reflection		class together and ask groups to share their findings from the simulations. Teacher Prompt: “Can anyone explain the results of your dihybrid cross? How did the simulation help you understand the concept of independent assortment?” 2. Encourage Critical Thinking: Challenge students to explain what they learned about genetic inheritance and how the simulations helped reinforce the concepts.	results and observations with the class. 2. Engage in Discussion: Students respond to each other’s findings, share insights, and clarify concepts. 3. Reflect on the Learning Experience: Students should reflect on how using simulations changed their understanding of Genetics and whether they found the process easier to grasp.
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		Teacher Prompt: “What did the simulation reveal about genetic probabilities? Did it match your expectations based on Mendelian laws?”	
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4. Assessment and Evaluation

Teacher’s Activity:

1. Formative Assessment: Throughout the lesson, assess students’ understanding by observing their participation in the simulations and the accuracy of their recorded results.

Ask targeted questions to assess their comprehension of Genetics concepts.

Teacher Prompt: “How would you explain the inheritance pattern we saw in this experiment? What factors did you consider when analyzing the genetic ratios?”

2. Summative Assessment: At the end of the lesson, provide a short quiz or written test on the topics covered in the simulations (e.g., explaining Mendelian inheritance, interpreting Punnett squares, analyzing genetic outcomes from simulations).

Student’s Activity:

1. Participate in Formative Assessment: Answer questions and demonstrate understanding during group work and class discussions.

2. Complete Summative Assessment: Take the quiz or complete an assignment that evaluates their understanding of Genetics and the application of simulation tools.

5. Closure and Homework

Teacher's Activity:

1. Review Key Concepts: Briefly recap the key takeaways from the lesson, reinforcing how simulations helped in understanding genetic concepts.
2. Assign Homework: Assign students a task that extends the lesson, such as researching a genetic disorder or creating a Punnett square for a complex genetic cross. Students can also be asked to watch a related video or read a chapter from the textbook on genetic mutations.

Student's Activity:

1. Review Notes: Students should review their notes, ensuring they understand the concepts covered in the lesson.
2. Complete Homework: Follow up on the homework assignment, using the knowledge gained from the simulation lesson to further investigate Genetics.

Conclusion

The Simulation Strategy in teaching Genetics allows students to engage actively with genetic concepts by experimenting in a virtual environment. This hands-on, interactive approach not only makes complex processes more understandable but also enhances student engagement and learning outcomes. By integrating simulations into the lesson plan, teachers can foster deeper comprehension and mastery of Genetics, equipping students with both theoretical and practical knowledge.

Appendix V

Teaching and Learning Instructional Guides

Instructional Guide for Control Group C

Teaching Instructional Guide Using Traditional Teaching Strategy to Teach

Genetics

1. Lesson Overview

Topic: Genetics (including DNA structure, Mendelian inheritance, dominant and recessive traits, genetic mutations, and Punnett square calculations)

Target Group: Biology Education Students

Duration: 60 minutes

Materials:

Chalkboard or whiteboard

Markers/chalk

Projector (optional, for visual aids)

Textbooks or handouts

Worksheets for student exercises

Punnett square templates

2. Objective:

To teach fundamental genetic concepts, such as inheritance patterns, DNA structure, and Mendelian Genetics, using traditional methods of instruction, such as lectures, discussions, and written exercises.

3. Presentation:

Content Development	Time (Mins)	Teacher's Activities	Students' Activities
A. Introduction	10	1. Introduction to Genetics: Begin the lesson by introducing the topic of Genetics. Explain that Genetics is the study of heredity and the variation of inherited traits in living organisms. Discuss why understanding Genetics is crucial in fields like medicine, agriculture, and Biology. Teacher Prompt: "Genetics helps us understand how traits are passed from one generation to the next. For example, why do children inherit traits like eye color from their parents?" 2. Set Learning Objectives:	1. Listen to the Introduction: Pay attention to the teacher's explanation of Genetics and its importance. 2. Ask Questions: Students can ask any initial questions they may have about the topic or the objectives for the lesson.

		Inform students that they will learn about Mendelian Genetics, dominant and recessive traits, and how to use Punnett squares to predict offspring genotypes. Teacher Prompt: “By the end of this lesson, you should be able to explain the basics of Mendelian inheritance and use Punnett squares to predict genetic outcomes.”	
B. Direct Instruction	20	1. Lecture on Genetic Concepts: Provide a lecture on key genetic concepts, focusing on: DNA Structure: Describe the double-helix structure of DNA and the role of genes in inheritance. Mendelian Inheritance: Explain the basic principles	1. Take Notes: Students listen attentively to the lecture and take notes on the key concepts (e.g., Mendelian inheritance, genotype vs.

		of inheritance based on Gregor Mendel's experiments with pea plants. Define terms like genotype, phenotype, allele, dominant, recessive, homozygous, and heterozygous. Punnett Square: Demonstrate how to use a Punnett square to predict the genotypes and phenotypes of offspring. Example: Cross a homozygous dominant (AA) plant with a homozygous recessive (aa) plant. Teacher Prompt: "A Punnett square helps us visualize how alleles are inherited and what the chances are for offspring to inherit specific traits." 2. Provide Visual Aid (Optional): Draw diagrams	phenotype). 2. Ask Questions: Students may ask questions for clarification about the terms or examples. 3. Follow Along: Students should follow along with the teacher's explanations of genetic concepts, making sure they understand how the Punnett square is used.
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		of the DNA structure, Punnett squares, and examples of genetic crosses on the chalkboard or whiteboard. You may also use a projector to display slides. Teacher Prompt: “Let’s look at this example. If we cross a homozygous dominant tall plant (TT) with a homozygous recessive short plant (tt), what will the offspring look like?”	
C. Guided Practice	10	1. Practice Problems: Provide students with practice problems on the board or distribute worksheets with genetic cross examples. Example Problem: “If a heterozygous tall plant (Tt) is crossed with a homozygous	1. Complete the Practice Problems: Students should individually or in pairs work on the practice problems provided by the

		recessive short plant (tt), what are the possible genotypes and phenotypes of the offspring?" 2. Work through Examples: Work through a few practice problems with the students, explaining each step of the process. Teacher Prompt: "First, let's draw the Punnett square. We place the alleles from each parent on the top and left sides. Then, fill in the square to find the offspring genotypes." 3. Monitor Student Progress: Walk around the classroom, offering assistance to students as they complete the problems individually or in small groups. Provide immediate feedback if	teacher. 2. Record Results: Students should complete the Punnett squares and write down the predicted genotypes and phenotypes of the offspring. 3. Ask for Clarification: Students can ask questions if they are unsure about how to complete the Punnett squares or how to interpret the results.
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		needed. Teacher Prompt: “What do you get when you cross these two genotypes? Remember, we’re looking for the dominant and recessive traits here.”	
D. Independent Practice	10	1. Assign Independent Exercise: Give students a worksheet or ask them to complete a set of problems independently. These should be more complex problems that involve both monohybrid and dihybrid crosses. Teacher Prompt: “Now, I’d like you to try this on your own. Please solve the problem on your worksheet and use a Punnett square to show the possible offspring.” 2. Circulate and Provide	1. Work Independently: Students should complete the worksheet or exercise on their own, using the concepts learned in the lesson. 2. Review Results: After completing the exercises, students should check their

		Assistance: Walk around to offer support as students work through the exercises. Help students who are struggling but encourage them to complete the task independently.	answers and revise any mistakes they made.
E. Class Discussion and Reflection	10	1. Facilitate a Discussion: Lead a class-wide discussion to review the students' findings. Ask students to share the results of their independent practice and explain how they arrived at their answers. Teacher Prompt: "Let's discuss your answers to the exercise. What did you find when you crossed these two plants? How do the genotypes relate to the phenotypes of the offspring?"	1. Share Results: Students share their answers and explain their reasoning behind the Punnett square results. 2. Engage in Discussion: Students ask questions if they're unsure about any part of the lesson

		2. Clarify Misunderstandings: Address any common misconceptions or errors that students may have made during the practice.	and contribute to the discussion on Genetics.
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4. Assessment and Evaluation

Teacher's Activity:

1. Formative Assessment: Throughout the lesson, monitor students' understanding through their participation in class discussions, practice problems, and independent exercises. Offer feedback and assistance as needed.

Teacher Prompt: "Do all the Punnett squares match your expectations? What might be the reason if something is off?"

2. Summative Assessment: At the end of the lesson, assign a short quiz or test on Mendelian inheritance, the use of Punnett squares, and the application of genetic concepts.

Student's Activity:

1. Participate in Formative Assessment: Engage in discussions and complete practice problems to demonstrate understanding.

2. Complete Summative Assessment: Take the quiz or complete the assignment for formal evaluation of understanding.

5. Closure and Homework

Teacher's Activity:

1. Review Key Concepts: Recap the main concepts covered during the lesson, focusing on the use of Punnett squares and genetic inheritance patterns.

Teacher Prompt: “What are the key things you need to remember about Genetics and Punnett squares? How do we use these to predict the traits of offspring?”

2. Assign Homework: For homework, ask students to research a genetic disorder (e.g., cystic fibrosis, sickle cell anemia) and write a short report explaining its inheritance pattern and genetic causes.

Student’s Activity:

1. Review the Lesson: Students should review their notes and ensure they understand the concepts discussed.

2. Complete Homework: Complete the homework assignment on genetic disorders, using textbooks or online resources.

Conclusion

The traditional teaching strategy involves direct instruction, practice, and reinforcement through teacher-led demonstrations, independent exercises, and class discussions. By using methods like lectures, Punnett square exercises, and guided practice, this strategy helps students grasp foundational concepts in Genetics. Although more teacher-centered than interactive methods, traditional teaching remains effective for imparting essential knowledge, especially when combined with structured exercises and real-world applications.

Bio-data

A Personal Data

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B. Educational Background

Gwagwarwa Primary school:	1978 – Primary Sch. Certificate
Kano Teachers College, Kano State	1983 – TC II Certificate
A.T.C/A.B.U Zaria, Kaduna State	1989 – N.C.E Certificate
Ahmadu Bello University, Zaria, Kaduna State:	1992 – B.Sc. (Ed) Integrated Science
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C. Working Experiences with Dates

- (i) Grade II Teacher (Kano State L.E.A) 1983
- (ii) Secondary School Tutor (Zaria L.E.D Zaria) 1989
- (iii) Staff Federal College of Education, Abeokuta 1994 till date

D. Member: Science Teachers Association of Nigeria (STAN)

Member: Teachers Registration Council of Nigeria (TRCN)

Member: Nigerian Red Cross Society

E. Awards and Distinctions:

- (i) 1st Best Corp Distinguish Award (NYSC) 1994
- (ii) Outstanding Performance Award for Research and Publication/ Selfless Service to the College (FCE ABEOKUTA) 1997 Annual Performance Reports and Appraisal Exercise
- (iii) Long Service Award F.C.E Abeokuta 2024

F. Research Functions:

- (i) Member Research and Publication Committee (F. C. E ABEOKUTA)
- (iv) Editorial Board Member / Secretary Journal of Science Education (F.C.E ABEOKUTA)
- (v) Secretary School of Science Conference Committee

G. Publications:

Theses/Dissertations:

- i) Mohammed, I. (1992) Parental attitudes on the students' learning Integrated Science and their Future Prospects and Career Progression: B.Sc. (Ed) Research Project, Faculty of Education, A.B.U., Zaria.
- ii) Books and monographs/ chapters in books (already published)

Text:

1. Mohammed, I. Et al. (2005): Introduction to Science Education, Zenith Press, Abeokuta.
2. Mohammed, I. Et al. (2008): Science, Society & Healthy Leaving, Good Ventures, Abeokuta.
3. Mohammed, I. Et al. (2017) : F.C.E. Abeokuta, General Study Series Vol. II No. 1 (2 chapters) Published by Political and Administrative Resource Centre, Lagos.
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Mohammed, I & Sam-Kayode C.O (2025) Effect of Audio-visual Intervention on Achievement in Genetics among Pre-service Biology teachers in Ogun Central Senatorial District, Ogun State

Current research activities:

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Conference: School Science National Conference 2023 (F. C. E Abeokuta)

Paper: Technological Trends and the Use of Instructional Media by Lecturers in Federal College of Education Abeokuta Ogun State

Seminars/workshops:

- (i) N.C.C.E./ E.T.F. (2014) workshop on 'Train the Trainees' F.C.E. Abeokuta.
- (ii) Research training for all Postgraduate Students: AI Research and Grant Writing Training (Nov. 2024)

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