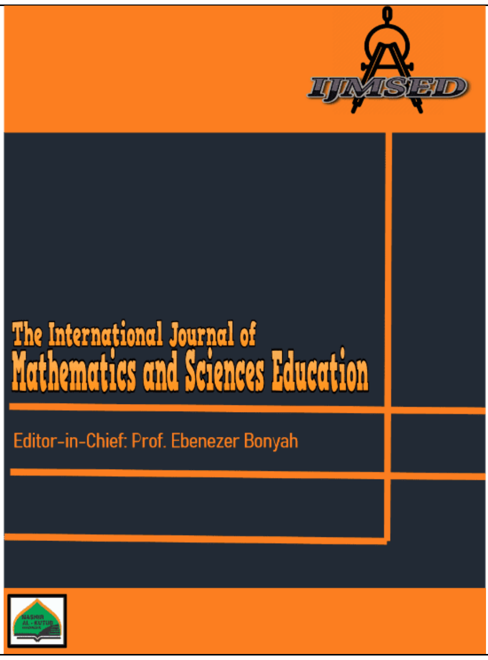
The International Journal of Mathematics and Sciences Education
Publication details, including instructions for authors and subscription information:
https://nakiscience.com/index.php/IJMSEd



Instructional design approaches in genetics education: ADDIE versus differentiated instruction

Charles Kenneth Addo
Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Khumasi, Ghana, charleskenneth1991@gmail.com

To cite this article:
Addo, C. K. (2025). Instructional design approaches in genetics education: ADDIE versus differentiated instruction. *International Journal of Mathematics and Sciences Education*, *3*(2), 71 – 83.
To link to this article:
https://nakiscience.com/index.php/IJMSEd
Published by:
Nasir Al-Kutub Indonesia
Residential Street Kila Rengganis, Block I, Number 11, Labuapi, Indonesia, 83361

International Journal of Mathematics and Sciences Education
Volume 3, Issue 2, pp. 71-83
https://nakiscience.com/index.php/IJMSEd

Instructional design approaches in genetics education: ADDIE versus differentiated instruction

Charles Kenneth Addo
Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Khumasi, Ghana, charleskenneth1991@gmail.com

Abstract
Genetics remains a conceptually challenging domain in senior high school biology in Ghana, as evidenced by persistently low student achievement despite ongoing curriculum reforms. These challenges are often attributed to teacher-centered instructional practices, large class sizes, and the limited use of pedagogical approaches that balance structure and flexibility. This study investigated the comparative effectiveness of two instructional frameworks: the structured, phase-based ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) and learner-centered Differentiated Instruction (DI). A quasi-experimental, non-equivalent pretest–posttest design was employed involving 120 senior high school students from two intact classes. One group was taught using the ADDIE model, while the other received instruction through DI strategies. Data were analyzed using descriptive statistics, independent samples t-tests, and two-way ANOVA. The findings revealed a statistically significant difference in posttest achievement, with students in the ADDIE group attaining higher mean scores (M = 28.92, SD = 3.84) than those in the DI group (M = 22.65, SD = 3.85), corresponding to a large effect size (Cohen's d = 1.63). The two-way ANOVA indicated significant main effects of instructional model and gender, with male students outperforming female students overall, but no significant interaction effect between instructional model and gender. These results suggest that the systematic and iterative nature of the ADDIE model more effectively supports students' understanding of complex genetics concepts in this context. The study recommends integrating the ADDIE framework into biology instruction while strategically incorporating differentiated strategies and gender-responsive practices to address learner diversity and promote equitable learning outcomes.

Article History
Received:
23 Septmebr 2025
Revised:
14 December 2025
Accepted:
30 December 2025
Published Online:
31 December 2025

Keywords:
Academic Performance;
ADDIE Model;
Differentiated Instruction;
Genetics Education;
Instructional Design;
Secondary Education.

1. Introduction

Genetics remains one of the most conceptually demanding topics in senior high school (SHS) biology, particularly within developing educational contexts such as Ghana. Despite sustained curriculum reforms, students' performance in genetics continues to be unsatisfactory, as reflected in national examination outcomes (Chu & Reid (2012). Instructional practices in many Ghanaian SHSs remain predominantly teacher-centered, emphasizing content transmission rather than conceptual understanding, which limits students' ability to interpret abstract processes such as meiosis, inheritance patterns, and genetic variation. These challenges are exacerbated in large classrooms where instructional uniformity often fails to accommodate learner diversity.

International Journal of Mathematics and Sciences Education
Volume 3, Issue 2, pp. 71-83
https://nakiscience.com/index.php/IJMSEd

Genetics plays a pivotal role in understanding foundational biological principles and serves as a gateway to advanced scientific fields, including medicine, agriculture, and biotechnology. However, persistent learning difficulties undermine students' scientific literacy and progression in science-related careers. Reports from the West African Examinations Council (WAEC, 2020–2022) consistently identify weaknesses in students' abilities to analyze genetic diagrams, solve inheritance problems, and apply genetic principles to unfamiliar contexts. Empirical studies corroborate these findings, indicating that students frequently avoid genetics-related questions due to low confidence and fragmented conceptual understanding (Ekong et al., 2015). Chu & Reid (2012) further argue that traditional instructional approaches—characterized by rote memorization and procedural teaching—contribute significantly to these learning difficulties.

Beyond classroom practices, systemic constraints such as large class sizes, uneven teacher preparedness for innovative pedagogy, and limited exposure to structured instructional design models compound the problem (Osei-Owusu, 2022). While several pedagogical interventions have been proposed to improve science learning in Ghanaian SHSs, many lack grounding in explicit, research-based instructional frameworks. Consequently, there is limited empirical evidence comparing the effectiveness of structured instructional design models and adaptive teaching approaches in addressing complex conceptual domains such as genetics. This gap highlights the need for studies that move beyond isolated teaching strategies to examine comprehensive instructional frameworks that guide both lesson design and classroom implementation.

To address this gap, the present study focuses on two theoretically distinct instructional approaches: the ADDIE instructional design model and Differentiated Instruction (DI). The ADDIE model—comprising Analysis, Design, Development, Implementation, and Evaluation—originates from systems theory and emphasizes alignment among learner needs, instructional objectives, learning activities, and assessment (Branch, 2021). Its structured yet iterative nature provides teachers with a coherent roadmap for designing instruction, which is particularly valuable when teaching hierarchical and abstract content such as genetics. Within Ghana's competency-based curriculum framework (Ministry of Education [MoE], 2020), ADDIE offers a practical mechanism for translating curriculum goals into systematic instructional practice.

In contrast, Differentiated Instruction emphasizes flexibility and responsiveness to learner diversity. Grounded in constructivist learning theory and Vygotsky's Zone of Proximal Development, DI advocates adjusting content, instructional processes, and learning products based on students' readiness levels, interests, and learning profiles (Tomlinson, 2017). In genetics classrooms, DI supports the use of tiered tasks, flexible grouping, and multiple representations to promote deeper engagement and conceptual understanding among heterogeneous learners. While DI has been widely promoted as an inclusive pedagogical approach, its effectiveness relative to structured instructional design models in improving conceptual learning outcomes remains underexplored in the Ghanaian SHS context.

The comparative examination of ADDIE and DI is therefore both timely and theoretically justified. ADDIE represents a comprehensive instructional design framework that prioritizes systematic planning and evaluation, whereas DI represents an adaptive instructional delivery approach focused on learner variability. Investigating these approaches in parallel allows for an empirical examination of whether instructional structure or pedagogical flexibility exerts a stronger influence on students' learning outcomes in genetics. Accordingly, this study examines the comparative effects of the ADDIE instructional model and Differentiated Instruction on students' academic performance in genetics, while also exploring whether the effectiveness of these instructional approaches varies by gender. By addressing these interrelated questions, the study seeks to generate evidence capable of informing instructional practice, curriculum implementation, and policy decisions aimed at improving genetics education, strengthening scientific literacy, and promoting equitable learning outcomes in Ghanaian senior high schools.

2. Literature Review

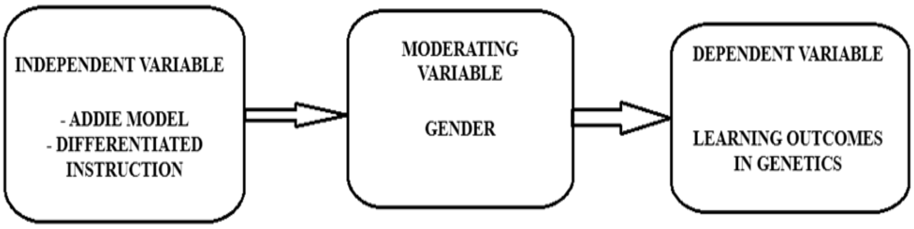
2.1 Conceptual Framework of the Study

This study is grounded in an integrated conceptual framework (Figure 1) that explains the relationships among instructional design approaches, learning processes, and learning outcomes in genetics education. The framework positions instructional design choices—namely, the structured ADDIE model and the flexible Differentiated Instruction (DI) approach—as the independent variables that shape teaching and learning processes. These processes are mediated by core learning theories, specifically Constructivist Learning Theory, which emphasizes active knowledge construction, and Bloom's Taxonomy, which conceptualizes learning as progressive cognitive development. Both theories are operationalized through the instructional activities, learning tasks, and assessment strategies embedded within each instructional model.

In addition, learner characteristics—particularly prior knowledge and gender—are incorporated into the framework as contextual variables that may influence how students respond to different instructional approaches. Gender is examined through the lens of Gender Schema Theory, which highlights how sociocultural expectations can shape learners' engagement and academic performance. The framework assumes that both instructional models ultimately influence the dependent variables, namely students' academic performance and conceptual understanding of genetics. However, the mechanisms through which these outcomes are achieved differ: the ADDIE model emphasizes a systematic, top-down instructional design that scaffolds learning sequentially, whereas DI emphasizes bottom-up adaptation to learner variability. Consequently, the framework enables an examination of both the main effects of instructional models and the potential moderating role of gender, offering a comprehensive perspective on how instructional design, learning theory, and learner characteristics interact to produce learning outcomes in genetics education.

Figure 1

Conceptual framework of the study



2.2 ADDIE Instructional Model in Science and Genetics Education

The ADDIE instructional model provides a systematic and practical framework for designing, implementing, and evaluating instruction, making it particularly relevant for science education and conceptually demanding subjects such as genetics. Previous studies have demonstrated that the structured nature of ADDIE supports improved conceptual understanding, active learner engagement, and enhanced academic performance (Mudjisusatyo et al., 2024). The model begins with the Analysis phase, during which teachers identify learners' prior knowledge, misconceptions, and instructional needs (Mensah & Adjei, 2021). This is followed by the Design phase, where instructional objectives, learning activities, and assessment strategies are carefully aligned.

During the Development phase, instructional plans are transformed into concrete learning resources, including visual models, simulations, and instructional materials that support abstract reasoning (Osei-Owusu, 2022). The Implementation phase emphasizes learner engagement through interactive and inquiry-based activities that promote active learning (Munna & Kalam, 2021). Finally, the Evaluation phase incorporates both formative and summative assessments to monitor learning progress and inform instructional refinement (Park et al., 2017). Overall, the strength of the ADDIE model lies in its capacity to translate complex scientific concepts into structured, coherent, and engaging learning experiences.

2.3 Effectiveness of the ADDIE Instructional Model in Improving Academic Performance

Empirical evidence consistently supports the effectiveness of the ADDIE model in enhancing student learning outcomes, particularly in challenging science domains such as genetics. By guiding instruction through a sequenced and iterative process, ADDIE enables learners to build conceptual understanding gradually and systematically (Mudjisusatyo et al., 2024). One of the model's key strengths is its ability to decompose complex concepts into manageable instructional components, thereby reducing cognitive overload.

Furthermore, ADDIE encourages the integration of visual and hands-on learning resources, which have been shown to increase student motivation and accessibility of abstract genetic concepts (Gyamfi et al., 2026). The model's strong emphasis on evaluation fosters continuous feedback and reflective practice, allowing teachers to adjust instruction based on learners' progress and needs (Vo et al., 2017). Collectively, these features contribute to consistent instructional delivery, enhanced learner support, and improved academic performance (Park et al., 2017; Munna & Kalam, 2021).

2.4 Differentiated Instruction and Its Role in Genetics Learning

Genetics instruction is particularly challenging due to the abstract nature of its concepts and the heterogeneity of learners within the classroom. Differentiated Instruction offers a learner-centered pedagogical approach designed to address these challenges by accommodating individual differences. DI involves adjusting instructional content, learning processes, and assessment products in response to students' readiness levels, interests, and learning profiles (De Graaf et al., 2019; Tomlinson & Imbeau, 2019).

Content differentiation enables teachers to modify learning materials to match varying ability levels, while process differentiation focuses on providing diverse learning pathways and instructional strategies (Qushem et al., 2021; Deunk et al., 2021). Product differentiation allows students to demonstrate learning through multiple formats, thereby encouraging creativity and deeper conceptual engagement (Zohar & Dori, 2021). By recognizing and responding to learner variability, DI promotes equitable access to learning opportunities and supports meaningful engagement with complex genetic concepts (Subandiyah et al., 2025).

2.5 Comparative Effectiveness of ADDIE and Differentiated Instruction in Genetics Education

Both the ADDIE model and Differentiated Instruction have been shown to enhance learning in science education, albeit through different pedagogical mechanisms. ADDIE provides a structured, sequential framework that supports the systematic development of complex conceptual knowledge, whereas DI emphasizes instructional flexibility and responsiveness to learner diversity. Studies suggest that ADDIE's structured design is particularly effective in supporting comprehension and retention of hierarchical content such as genetics (Spatioti et al, 2022). In contrast, DI has been associated with increased student motivation and engagement by offering multiple pathways for interacting with content (Pozas et al., 2020).

Comparative evidence further indicates that ADDIE may be more effective for learners with higher self-regulation skills, while DI is especially beneficial for students requiring additional instructional support (Salar & Turgut, 2021). Moreover, recent research suggests that integrating ADDIE's systematic design with DI's adaptive strategies can yield optimal learning outcomes by combining structure with flexibility (Siburian & Sadikin, 2024). These findings highlight the importance of examining both models within a single empirical framework.

2.6 The Role of Gender and Instructional Models

Gender differences in science learning have been widely documented, with evidence suggesting that male and female students may respond differently to instructional approaches due to variations in confidence, learning preferences, and sociocultural expectations (Kahle, 1993). Female students often demonstrate stronger engagement in collaborative and context-rich learning environments, which align with the principles of Differentiated Instruction, whereas male students may respond more favorably to structured, goal-oriented instructional designs such as ADDIE (Nguyen & Huynh, 2022).

However, recent studies emphasize that gender-related differences are not deterministic. When instructional models are implemented using gender-responsive strategies—such as inclusive examples, equitable participation structures, and multiple modes of assessment—both ADDIE and DI can effectively support learners of all genders (Pozas et al., 2020; Siburian, & Sadikin, 2024). Thus, the effectiveness of instructional models in genetics education is shaped less by gender itself and more by how instruction is designed and enacted to promote inclusivity and equitable learning opportunities.

3. Methods

3.1 Research Design

This study employed a non-equivalent pretest–posttest quasi-experimental design to examine the effects of the ADDIE instructional model and Differentiated Instruction on students' learning outcomes in genetics. Two intact senior high school biology classes were assigned to different instructional conditions: one group received instruction based on the ADDIE model, while the other was taught using Differentiated Instruction strategies. Because random assignment of individual students was not feasible within the school context, pretest and posttest measures were used to control for initial group differences and to strengthen internal validity. The study was situated within a positivist research paradigm, emphasizing objective measurement, hypothesis testing, and statistical analysis to examine instructional effects (Kivunja & Kuyini, 2020).

3.2 Participants and Context

The study was conducted in two public senior high schools located in the Afigya Kwabre North District of the Ashanti Region, Ghana. These schools reflect typical characteristics of public SHS education in Ghana, including large class sizes, limited instructional resources, and examination-oriented timetables. Average class size was approximately 60 students, posing challenges for individualized instruction and influencing the implementation of both instructional models. Students demonstrated diverse levels of prior knowledge in biology and varying degrees of confidence in science learning, which is common at the senior high school level.

Instruction took place within the framework of the national biology curriculum, with limited access to specialized laboratory equipment for genetics instruction. The fixed instructional schedule restricted opportunities for extended project-based learning. These contextual conditions directly informed the implementation of the interventions: the structured sequencing of the ADDIE model facilitated systematic coverage of complex content within time constraints, whereas the implementation of Differentiated Instruction required adaptive strategies to accommodate learner diversity in large-class settings.

Participants were Senior High School Year 3 (SHS 3) biology students. Schools and classes were selected using a combination of cluster sampling, purposive sampling, and simple random sampling. A total of 120 students participated in the study, with 60 students assigned to each instructional group. Gender distribution was balanced within each group (30 males and 30 females), enabling the examination of gender-related effects alongside instructional model effects.

3.3 Alignment of Learning Objectives, Instructional Strategies, and Assessment

To enhance internal validity, explicit alignment was maintained among learning objectives, instructional strategies, and assessment instruments. This alignment ensured that observed differences in learning outcomes could be attributed to instructional approaches rather than inconsistencies in content coverage or evaluation.

Both groups pursued identical learning objectives focused on core genetics concepts, including heredity, variation, and Mendelian principles. Instruction was delivered over a six-week intervention period within a twelve-week study timeline. In the ADDIE group, instruction followed the model's five-phase sequence. The Analysis phase used pretest data to identify students' prior knowledge and misconceptions. During the Design phase, lessons were structured around clearly articulated learning objectives. In the Development phase, tailored instructional materials—such as step-by-step guides for genetic crosses and physical DNA models—were produced. The Implementation phase emphasized structured teacher-led instruction with embedded feedback opportunities, while the Evaluation phase incorporated formative assessments to guide instructional refinement.

In contrast, the Differentiated Instruction group experienced a flexible, learner-centered instructional approach. Instruction was adapted according to students' readiness levels, learning preferences, and interests. Content was modified to accommodate varying ability levels, instructional processes included diverse strategies such as concept mapping, debates, and hands-on modeling, and learning products were flexible, allowing students to demonstrate understanding through written reports, oral presentations, or visual artifacts.

Both groups completed a standardized pretest and posttest designed to assess the shared learning objectives without favoring either instructional approach. This alignment strengthened the attribution of outcome differences to the instructional models under investigation.

3.4 Validity of the Instrument

Multiple forms of validity were established to ensure that the assessment instrument accurately measured students' genetics learning. Content validity was ensured by aligning test items with the Ghanaian Senior High School Biology Curriculum and key genetics concepts. Expert reviews by experienced biology teachers and curriculum specialists were used to evaluate item relevance, clarity, and representativeness (Ghana Education Service, 2020). Construct validity was examined to confirm that the instrument adequately reflected the theoretical constructs underpinning genetics learning. This

International Journal of Mathematics and Sciences Education
Volume 3, Issue 2, pp. 71-83
https://nakiscience.com/index.php/IJMSEd

process involved expert judgment and factor analysis, which indicated that the items effectively captured the intended conceptual domains (DeVellis, 2016).

3.5 Reliability of the Instrument

Prior to the main study, the instrument was piloted with 40 students from a comparable school not included in the main sample. Based on pilot feedback, ambiguous items were revised, unclear wording was refined, and instructions were simplified. Internal consistency reliability was assessed using Cronbach's alpha, yielding a coefficient of .78, which is considered acceptable for educational research (Pallant, 2020). Items that reduced internal consistency were modified or removed to enhance reliability (DeVellis, 2016). Inter-rater reliability was also examined to ensure scoring consistency across raters (Cohen et al., 2018).

3.6 Data Collection Procedure

Data collection was conducted in three phases: pre-intervention, intervention, and post-intervention. During the pre-intervention phase, formal approval was obtained from the Ghana Education Service and school authorities. Teachers and students were informed about the study's objectives, procedures, and ethical safeguards. Informed consent was obtained, and participants were assured of confidentiality, anonymity, and voluntary participation. A pretest was administered to establish baseline understanding of genetics. The intervention phase lasted twelve weeks, during which the respective instructional approaches were implemented. In the post-intervention phase, a posttest equivalent in scope and difficulty to the pretest was administered to both groups. Students also provided feedback regarding their learning experiences.

3.7 Data Analysis Procedure

Quantitative data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 26. Preliminary analyses included descriptive statistics and assumption testing. Normality of pretest and posttest scores was assessed using the Shapiro–Wilk test ($p > .05$), and homogeneity of variance was confirmed using Levene's test. To examine the comparative effects of the ADDIE and Differentiated Instruction models, an independent samples *t*-test was conducted on posttest scores. Effect sizes were calculated using Cohen's *d* to assess the magnitude of observed differences. To examine the effects of instructional model and gender, as well as their interaction, a two-way analysis of covariance (ANCOVA) was performed, with instructional model and gender as independent variables, posttest scores as the dependent variable, and pretest scores as a covariate. Effect sizes were reported using partial eta squared (ηp^2).

3.7 Ethical Considerations

Ethical considerations were central to the conduct of this study. Approval was obtained from the Ghana Education Service and participating school administrations. Informed consent was secured from students and their parents or guardians after providing clear explanations of the study's purpose, procedures, and potential benefits. Participation was voluntary, and participants retained the right to withdraw at any time without penalty. Confidentiality and anonymity were strictly maintained throughout data collection, analysis, and reporting, ensuring adherence to established ethical standards in educational research.

4. Results and Discussion

4.1 Results

4.1.1 Demographics of Respondents

This study involved two public senior high schools (SHSs), from which a total of 120 students were selected to participate. The figure below illustrates the gender distribution of the participants (See Figure 2).

Figure 2
Gender distribution of Participants

International Journal of Mathematics and Sciences Education
Volume 3, Issue 2, pp. 71-83
https://nakiscience.com/index.php/IJMSEd

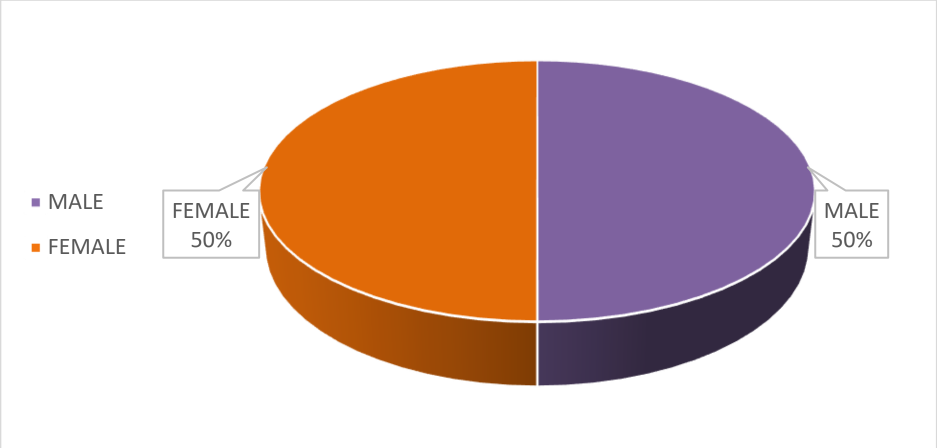


Figure 2 illustrates the gender distribution of the participants involved in this study. The total sample comprised 120 Senior High School students, with an equal representation of females and males. Specifically, 60 participants (50%) were female, while the remaining 60 participants (50%) were male. This balanced gender composition was intentionally maintained to ensure fairness and representativeness in the comparative analysis of instructional approaches. By providing equal participation opportunities for both genders, the study minimized potential bias related to gender imbalance and strengthened the validity of comparisons across instructional models. Such proportional representation is particularly important in educational research, as gender has been identified as a factor that may influence students' engagement, confidence, and academic performance in science subjects, including genetics. Consequently, the equal distribution of male and female students enhanced the reliability of the findings and allowed for a more accurate examination of gender-related effects and interactions within the ADDIE and Differentiated Instruction learning environments.

4.1.2 Data Suitability

Before analyzing the study results, normality checks were carried out to ensure that the data met the assumptions required for statistical testing. To assess normality, students' scores were evaluated using the Shapiro-Wilk test. The outcomes of these normality tests are summarized in Table 1.

Table 1

Results of Normality Tests for Students' Scores (Shapiro-Wilk)

Group	Statistic	df	Sig.
Pretest (ADDIE)	.962	59	.061
Posttest (ADDIE)	.968	59	.117
Pretest (Differentiated)	.974	59	.229
Posttest (Differentiated)	.986	59	.731

Table 1 presents the results of the Shapiro–Wilk normality tests conducted on the pretest and posttest scores of students in both the ADDIE and Differentiated Instruction groups. For the ADDIE group, the significance values for the pretest ($p = .061$) and posttest ($p = .117$) are greater than the .05 threshold, indicating that the score distributions do not significantly deviate from normality. Similarly, in the Differentiated Instruction group, the pretest ($p = .229$) and posttest ($p = .731$) results also exceed the .05 significance level, suggesting that the data are normally distributed. These findings demonstrate that students' scores in both instructional groups meet the assumption of normality. The confirmation of normal distribution across all datasets supports the appropriateness of using parametric statistical analyses in this study. Since both pretest and posttest scores for the ADDIE and Differentiated Instruction groups satisfy the normality assumption, subsequent analyses such as independent samples t-tests and ANCOVA can be conducted with greater confidence. This strengthens the robustness of the statistical conclusions regarding the comparative effects of the ADDIE model and Differentiated Instruction on students' learning outcomes in genetics.

International Journal of Mathematics and Sciences Education
Volume 3, Issue 2, pp. 71-83
https://nakiscience.com/index.php/IJMSEd

4.1.3 Results for Research Question 1: Comparative Effect of ADDIE and DI

To determine the comparative impact of the instructional models on students' academic performance in genetics, an independent samples t-test was conducted on the post-test scores. The results are summarized in Table 2.

Table 2
Independent Samples t-test Results Comparing Post-test Performance

Group	N	Mean	SD	$t_{(118)}$	p	Cohen's d
ADDIE	60	28.92	3.84	8.95	<.001	1.63
Differentiated	60	22.65	3.85			

Table 2 presents the results of the independent samples t-test comparing post-test performance between students taught using the ADDIE instructional model and those taught through Differentiated Instruction (DI). The analysis reveals a statistically significant difference between the two groups, with $t(118) = 8.95$ and $p < .001$, indicating that the instructional approach had a substantial influence on students' genetics learning outcomes. The ADDIE group achieved a markedly higher mean post-test score ($M = 28.92$, $SD = 3.84$) compared to the DI group ($M = 22.65$, $SD = 3.85$). This notable difference in mean scores suggests that students exposed to the ADDIE model developed a stronger understanding of genetics concepts following the intervention. Given the equal sample sizes in both groups ($N = 60$ each), the comparison is methodologically robust, supporting the conclusion that the ADDIE instructional framework was more effective than Differentiated Instruction in enhancing students' post-intervention academic performance.

Beyond statistical significance, the magnitude of the observed difference is further highlighted by the effect size. The Cohen's d value of 1.63 represents a very large effect, indicating that the superiority of the ADDIE model is not only statistically meaningful but also educationally substantial. Such a large effect size suggests that the structured and systematic nature of the ADDIE model contributed significantly to students' learning gains in genetics. By guiding instruction through clearly defined phases—analysis, design, development, implementation, and evaluation—ADDIE likely supported coherent lesson sequencing, explicit learning objectives, and continuous feedback, all of which are critical for mastering abstract and conceptually demanding topics such as genetics. While Differentiated Instruction offers flexibility and responsiveness to learner diversity, the findings imply that, in this context, a well-organized instructional design framework provides stronger support for deep conceptual understanding and improved academic achievement among senior high school students.

4.1.4 Results for Research Question 2: Interaction Effect of Model and Gender

To examine the interaction effect between instructional model and gender, a two-way ANCOVA was performed with pretest score as a covariate. The results are summarized in Table 3.

Table 3
Two-Way ANCOVA Results for Post-test Scores (with Pretest as Covariate)

Source	Type III Sum of Squares	df	Mean Square	F	*p*	Partial η^2
Corrected Model	2150.12	4	537.53	45.21	<.001	.611
Intercept	950.47	1	950.47	79.94	<.001	.410
Pretest (Covariate)	310.45	1	310.45	26.12	<.001	.185
Instructional Model	949.21	1	949.21	79.84	<.001	.410
Gender	60.87	1	60.87	5.12	.026	.043
Model * Gender	3.82	1	3.82	0.32	.572	.003
Error	1367.15	115	11.89			

Table 3 presents the results of the two-way Analysis of Covariance (ANCOVA) conducted to examine the interaction effect between instructional model and gender on students' post-test performance in genetics, while controlling for pretest scores. The overall corrected model was statistically significant, $F(4, 115) = 45.21$, $p < .001$, with a large effect size (partial $\eta^2 = .611$). This indicates that, taken together, the instructional model, gender, and pretest scores accounted for a substantial proportion of variance in students' post-test achievement. The significance of the covariate further confirms the importance of controlling for initial differences in students' prior knowledge.

Specifically, the pretest score showed a significant effect on post-test performance, $F(1, 115) = 26.12$, $p < .001$, partial $\eta^2 = .185$, demonstrating that students' baseline understanding of genetics meaningfully influenced their learning outcomes. By statistically adjusting for these initial differences, the ANCOVA strengthened the validity of the findings, ensuring that the observed effects could be more confidently attributed to the instructional interventions rather than pre-existing ability differences.

With respect to the main effects, the analysis revealed a highly significant effect of instructional model on students' post-test scores, $F(1, 115) = 79.84$, $p < .001$, with a large effect size (partial η^2 = .410). This result confirms that the choice of instructional framework had a substantial impact on students' learning outcomes, with the ADDIE model leading to significantly higher adjusted mean scores than Differentiated Instruction. The magnitude of this effect suggests that the systematic and iterative structure of the ADDIE model provided stronger instructional support for mastering complex genetics concepts. In addition, a statistically significant main effect of gender was observed, $F(1, 115) = 5.12$, $p = .026$, partial $\eta^2 = .043$. Although the effect size was relatively small, the result indicates that male students (adjusted M = 26.45) slightly outperformed female students (adjusted M = 24.98) overall. This finding aligns with previous research suggesting that gender-related factors, such as confidence and prior exposure, may influence performance in science subjects, including genetics.

Crucially, the interaction effect between instructional model and gender was not statistically significant, $F(1, 115) = 0.32$, $p = .572$, with a negligible effect size (partial $\eta^2 = .003$). This result indicates that the effectiveness of the instructional models did not differ by gender. In other words, the advantage of the ADDIE model over Differentiated Instruction was consistent for both male and female students. The absence of a significant interaction suggests that neither instructional approach disproportionately benefited one gender over the other. From a pedagogical perspective, this finding is important because it implies that the ADDIE model can be implemented as an effective and gender-neutral instructional framework in genetics education. While a small overall gender difference was observed, it was not influenced by the type of instructional model used. Therefore, improvements in learning outcomes are more strongly associated with instructional design quality than with gender-specific effects, underscoring the potential of well-structured instructional models to support equitable learning in diverse classroom contexts.

4.2 Discussion

This section interprets the findings in relation to the research questions and the integrated conceptual framework underpinning the study, synthesizing empirical results with relevant learning theories and prior research.

4.2.1 Comparative Effect of ADDIE and Differentiated Instruction (Research Question 1)

The findings provide a robust response to Research Question 1, demonstrating a clear and statistically significant advantage of the ADDIE instructional model over Differentiated Instruction in improving students' genetics achievement. The large effect size (Cohen's $d = 1.63$) indicates not only statistical significance but also strong practical relevance, underscoring the instructional potency of a systematic design framework for complex scientific content. From a theoretical perspective, this outcome aligns closely with Constructivist Learning Theory, which emphasizes the importance of structured scaffolding in supporting learners' progression from foundational knowledge to higher-order reasoning. The phased nature of ADDIE appears to have operationalized this scaffolding effectively, guiding learners through increasingly sophisticated cognitive processes consistent with Bloom's revised taxonomy (Anderson & Krathwohl, 2001). Moreover, the ADDIE model's emphasis on deliberate sequencing and iterative evaluation likely reduced students' cognitive load by organizing abstract genetics concepts into coherent instructional units (Castro-Alonso, 2021). In contexts such as Ghanaian SHSs, where class sizes are large and instructional time is constrained, such systematic structuring may be particularly critical. In contrast, while Differentiated Instruction yielded positive learning gains, its comparatively smaller impact suggests limitations in sustained implementation. Although DI's learner-centered philosophy promotes engagement and inclusivity (Tomlinson, 2017), its effectiveness is highly contingent on teacher capacity, planning time, and classroom manageability. As Goodnough (2010) argues, high-quality differentiation is demanding, and in resource-constrained environments, its pedagogical potential may be difficult to fully realize. This finding highlights a key tension between theoretically ideal adaptive pedagogies and the practical realities of typical secondary school classrooms.

4.2.2 Interaction Between Instructional Model and Gender (Research Question 2)

With regard to Research Question 2, the two-way ANCOVA results provide a more nuanced understanding of how instructional design and learner characteristics intersect. The significant main effect of gender indicates that male students outperformed female students overall, a pattern consistent with prior research identifying persistent gender disparities in science achievement and confidence (Kerr & Lyford, 2022). Interpreted through the lens of Gender Schema Theory, this difference may reflect socially constructed beliefs and expectations that influence students' engagement and self-perceptions in science learning.

Critically, however, the absence of a significant interaction effect between instructional model and gender represents a pivotal finding. It indicates that the superiority of the ADDIE model over Differentiated Instruction was consistent across genders. In other words, neither instructional approach disproportionately advantaged or disadvantaged male or female students. This challenges assumptions in the literature suggesting that structured, goal-oriented models may favor male learners, while flexible and collaborative approaches may better support female learners (Salar & Turgut, 2021). Instead, the findings suggest that well-designed instructional frameworks can function as gender-neutral mechanisms for improving learning outcomes. Consequently, the observed gender gap appears to be driven by broader sociocultural and affective factors—such as science self-efficacy and prior educational experiences—rather than by the instructional model itself. This underscores the need to embed explicit gender-responsive strategies within both ADDIE and DI to address equity concerns more directly (Çetin-Dindar et al., 2023).

4.2.3 Synthesis and Implications Within the Conceptual Framework

Viewed holistically through the integrated conceptual framework, the findings suggest that instructional design quality plays a more decisive role in shaping learning outcomes than adaptive delivery alone, particularly for abstract and hierarchical content such as genetics. The ADDIE model's systematic design process emerged as a stronger driver of conceptual understanding and academic performance, while its effectiveness remained stable across gender lines. Although Differentiated Instruction remains pedagogically valuable for addressing learner diversity, its impact may be constrained without sufficient structural support. Together, these results highlight the importance of aligning instructional design, learning theory, and classroom realities to achieve both effectiveness and equity in science education.

4.2.4 Limitations of the Study

Despite its contributions, this study has several limitations that warrant careful consideration. Methodologically, the quasi-experimental design using intact classes limited random assignment, and although pretest scores were controlled statistically, unmeasured group differences may remain. In terms of design, the 12-week intervention period may not have been sufficient for the full maturation of Differentiated Instruction practices, which often require sustained implementation and professional development. The use of a single teacher ensured instructional consistency but limits insights into variability in implementation fidelity across educators. Contextually, large class sizes and resource constraints characteristic of Ghanaian SHSs influenced both interventions, particularly the feasibility of intensive differentiation. Finally, the reliance on quantitative achievement measures restricted the analysis to cognitive outcomes; future studies should incorporate qualitative data on engagement, motivation, and self-efficacy to provide a more comprehensive understanding of instructional impact.

5. Conclusion

This study investigated the comparative effects of the ADDIE instructional design model and Differentiated Instruction on senior high school students' learning outcomes in genetics within the Ghanaian context. The findings provide compelling evidence that the structured, phase-based ADDIE model produced significantly stronger learning gains than Differentiated Instruction. While both approaches positively influenced student achievement, ADDIE's systematic design framework proved more effective in supporting conceptual understanding of complex and abstract genetics content. Importantly, although gender-based differences in achievement were observed, these differences were not moderated by the instructional model employed. This indicates that the superiority of ADDIE was consistent across male and female students, underscoring its instructional robustness and gender-neutral effectiveness. Collectively, the results highlight the critical role of instructional design quality in shaping learning outcomes, particularly in large, resource-constrained classrooms. By demonstrating that a carefully sequenced and evaluative design process can outperform flexible delivery strategies alone, this study contributes empirical evidence to ongoing debates about structure versus adaptability in science pedagogy, especially in secondary education contexts in Sub-Saharan Africa.

The findings carry important implications for educational practice and policy. For teachers and teacher educators, the results suggest that professional development should prioritize instructional design literacy rather than focusing solely on general pedagogical techniques. Equipping teachers with a replicable framework such as ADDIE can enhance coherence, consistency, and effectiveness in lesson planning for challenging topics like genetics. At the same time, the study does not diminish the value of Differentiated Instruction; instead, it points to the potential benefits of embedding adaptive strategies within a structured design process. For curriculum leaders and policymakers, particularly within the Ghana Education Service and NaCCA, the results support the integration of explicit instructional design models into curriculum guides, textbooks, and teacher manuals. Providing exemplar ADDIE-based lesson plans could help standardize instructional quality across schools. Additionally, the persistence of gender differences, irrespective of instructional model, highlights the need for deliberate gender-responsive pedagogical initiatives. Such strategies—including inclusive representations, equitable classroom interactions, and bias-aware teaching—should be systematically incorporated within any instructional framework.

This study also opens several directions for future research. A promising avenue is the development and empirical testing of hybrid instructional models that intentionally integrate ADDIE's systematic design phases with the adaptive principles of Differentiated Instruction. Design-based research could explore how such blended models function in real classrooms over extended periods. Longitudinal studies are also needed to examine the durability of learning gains and the transfer of genetics knowledge and skills to other areas of science. Moreover, future research should move beyond outcome measures to include process-oriented investigations using mixed methods, such as classroom observations, teacher reflections, and student interviews, to better understand how learners cognitively and affectively engage with each instructional approach. Replication studies in different educational contexts—such as private schools, other regions, or different countries—would further clarify the role of contextual factors. Overall, this study underscores that improving science education requires a balanced emphasis on powerful instructional design tools and adaptive teaching practices, informed by rigorous, context-sensitive research.

6. References

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives.* Longman.

Branch, R. M. (2021). *Instructional design: The ADDIE approach.* Springer.

Deunk, M. I., Smale-Jacobse, A. E., de Boer, H., Doolaard, S., & Bosker, R. J. (2021). Differentiation within and across classrooms: A systematic review and meta-analysis. *Educational Research Review, 34*, 100402.

De Graaf, A., Westbroek, H., & Janssen, F. (2019). A practical approach to differentiated instruction: How biology teachers redesigned their genetics and ecology lessons. *Journal of Science Teacher Education*, *30*(1), 6-23. https://doi.org/10.1080/1046560X.2018.1523646

Ekong, N. J., Anongo, M. C., Okrikata, E., & Akpan, G. A. (2015). Influence of selected variables on students' academic performance in genetics and their implications for effective application of Stem Education. *Journal of Emerging Trends in Educational Research and Policy Studies, 6*(4), 331-337. https://hdl.handle.net/10520/EJC181665

Goodnough, K. (2010). Investigating pre-service science teachers' developing professional knowledge through the lens of differentiated instruction. *Research in Science Education, 40*(2), 239-265. https://doi.org/10.1007/s11165-009-9120-6

Kahle, J. B., Parker, L. H., Rennie, L. J., & Riley, D. (1993). Gender differences in science education: Building a model. *Educational psychologist*, *28*(4), 379-404. https://doi.org/10.1207/s15326985ep2804_6

Moral, R., Insong, A. K., & Santos, J. (2023). Effects of ADDIE model as an instructional system design for senior high school students in natural science through alternative delivery learning. *EIKI Journal of Effective Teaching Methods*, *1*(4), 42-48. https://doi.org/10.59652/jetm.v1i4.63

Munna, A. S., & Kalam, M. A. (2021). Impact of active learning strategy on the student engagement. *GNOSI: an interdisciplinary journal of human theory and praxis*, *4*(2), 96-114. https://gnosijournal.com/index.php/gnosi/article/view/96

Ministry of Education Ghana. (2020). *Curriculum framework for senior high schools in Ghana*. Ministry of Education.

Mudjisusatyo, Y., Darwin, D., & Kisno, K. (2025). The use ADDIE model to improve the competence of the higher education task force in obtaining competitive funding for the independent campus program. *Journal of Applied Research in Higher Education*, *17*(5), 2109-2138. https://doi.org/10.1108/JARHE-12-2023-0580

Castro-Alonso, J. C., de Koning, B. B., Fiorella, L., & Paas, F. (2021). Five strategies for optimizing instructional materials: Instructor-and learner-managed cognitive load. *Educational Psychology Review*, *33*(4), 1379-1407. https://doi.org/10.1007/s10648-021-09606-9

Salar, R., & Turgut, U. (2021). Effect of differentiated instruction and 5E learning cycle on academic achievement and self-efficacy of students in physics lesson. *Science Education International*, *32*(1), 4-13.

Osei-Owusu, B. (2022). Impact of professional development programmes on teachers' knowledge and academic performance of senior high school students in Ghana. *European journal of education and pedagogy*, *3*(2), 60-69. https://doi.org/10.24018/ejedu.2022.3.2.276

Chu, Y. C., & Reid, N. (2012). Genetics at school level: addressing the difficulties. *Research in Science & Technological Education*, *30*(3), 285-309.

Park, M., Liu, X., Smith, E., & Waight, N. (2017). The effect of computer models as formative assessment on student understanding of the nature of models. *Chemistry Education Research and Practice*, *18*(4), 572-581. https:/doi.org/10.1039/C7RP00018A

Pozas, M., Letzel, V., & Schneider, C. (2020). Teachers and differentiated instruction: exploring differentiation practices to address student diversity. *Journal of Research in Special Educational Needs*, *20*(3), 217-230. https://doi.org/10.1111/1471-3802.12481

Qushem, U. B., Christopoulos, A., Oyelere, S. S., Ogata, H., & Laakso, M. J. (2021). Multimodal technologies in precision education: Providing new opportunities or adding more challenges?. Education sciences, 11(7), 338. https://doi.org/10.3390/educsci11070338

Spatioti, A. G., Kazanidis, I., & Pange, J. (2022). A comparative study of the ADDIE instructional design model in distance education. *Information*, *13*(9), 402. https://doi.org/10.3390/info13090402

Subandiyah, H., Nasrullah, R., Ramadhan, R., Supratno, H., Raharjo, R. P., & Lukman, F. (2025). The impact of differentiated instruction on student engagement and achievement in Indonesian language learning. *Cogent Education*, *12*(1), 2516378. https://doi.org/10.1080/2331186X.2025.2516378

Gyamfi, M., Owusu, I., Agyei, C. A., & Appiah-Twumasi, E. (2026). Visualizing the Invisible: The Impact of Computer Simulations on Student Attitude Towards Genetics Education. *Journal of Research in Science, Mathematics and Technology Education*, *9*(1), 45-71.

Tomlinson, C. A. (2017). *How to differentiate instruction in academically diverse classrooms* (3rd ed.). ASCD.

Tomlinson, C. A., & Imbeau, M. B. (2019). *Leading and managing a differentiated classroom.* ASCD.

Vo, H. M., Zhu, C., & Diep, N. A. (2017). The effect of blended learning on student performance at course-level in higher education: A meta-analysis. *Studies in Educational Evaluation*, *53*, 17-28. https://doi.org/10.1016/j.stueduc.2017.01.002

West African Examinations Council. (2022). *Chief examiners' report on the West African Senior School Certificate Examination (WASSCE).* WAEC.

Siburian, J., & Sadikin, A. (2024). Biology Learning Models Based on Higher Order Thinking Skills; A Book Research and Development. *Jurnal Penelitian Pendidikan IPA*, *10*(11), 8827-8836.

Zohar, A., & Dori, Y. J. (2021). *Higher order thinking in science education: Students' learning and teachers' professional development.* Springer.