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THE ROLE OF DIFFERENTIATED INSTRUCTION IN FOUNDATIONAL HEALTH SCIENCE EDUCATION: ENHANCING BIOLOGY LEARNING OUTCOMES IN PRE-UNIVERSITY CURRICULA

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ABSTRACT

Effective pedagogy in foundational sciences is critical for robust student preparation and subsequent success in specialized health science and medical education programs. Differentiated instruction (DI) is an essential educational approach that adapts teaching strategies, content, and activities to accommodate students' diverse learning styles, which is vital for mastering complex biological principles that underpin future clinical and medical understanding. This research investigates the impact of utilizing Differentiated Instruction tailored to student learning styles on achievement and engagement within the high school biology curriculum, framed as a key course in the pre-health science educational pipeline. Data were collected from 457 students through structured assessments, learning style inventories, and classroom performance records. The instructional intervention applied tailored teaching methods, including visual diagrams, hands-on experiments, group discussions, and multimedia presentations, aligned with the identified learning styles. Learning outcomes were analyzed using pretest-post test comparisons, and statistical evaluation was performed using IBM SPSS software, including paired t-tests, multivariate ANOVA, Chi-Square test for independence, Kruskal-Wallis Test, and Multiple Regression Analyses (MRA) to determine the significance and strength of the instructional effects. The results showed that differentiated training produced considerable benefits. Experimental group scores increased significantly (Visual: 53.2 → 72.1; Auditory: 51.5 → 66.8; Kinesthetic: 52.1 → 70.2, all $p<0.001$), but the control group's score increases were minor (≈2−4 points). MANOVA showed significant effects (Learning Style: $\Lambda=0.78$, $F=12.34$, $p<0.001$). Regression showed that learning style ($\beta=6.45$, $p<0.001$) and teaching type ($\beta=5.12$, $p<0.001$) were the most significant predictors, followed by prior knowledge ($\beta=4.38$) and class participation ($\beta=3.25$). The findings strongly support the implementation of DI in health science foundational courses to ensure equitable and effective student preparation. These results offer a valuable pedagogical model for medical and health science educators seeking to enhance comprehension of prerequisite scientific concepts and improve educational quality.

KEYWORDS: Pre-Medical Education, Health Science Education, Educational Equity, Foundational Science, Curriculum Alignment.

1. INTRODUCTION

A strong foundation in high school biology is a critical determinant of success in undergraduate and graduate health science and medical education programs. Differentiated Instruction (DI) is an educational process that adapts teaching methods to encounter individual students' academic requirements. It encourages teachers to recognize and address varied learning differences inside a classroom, thereby promoting effective learning for all. Through DI, educators assess students' prior knowledge and learning styles to create multiple entry points for learning and cultivate an inclusive environment that values and responds to diversity [1]. DI meets the requirements of all learners, reducing knowledge disparity and improving teaching and learning quality. This technique aligns with academic reforms and addresses equitable issues in mathematics education. Furthermore, differentiated education is established on several learning concepts, such as the zone of proximal growth [2]. DI is a modern teaching strategy used in many countries to address students' diverse needs, interests, and levels of awareness. This approach to education comprises distinguishing material, process, product, or instructional setting, using ongoing evaluation and adaptable classification to ensure success. To ensure successful education, pupils must be prepared, and teachers should assess their preparedness to accept the knowledge [3]. The educational system represents the quality of the chances to learn. Learning is an educational process that is simultaneously experienced by educators and learners with the end goal of experiencing academic success. It is viewed as successful when it produces an observable change in the learner. Educational events emphasize the interaction of educators and learners who share [4]. Content selection enables teachers to adjust cognitive demands for students, allowing them to access reading materials suited to their individual levels. By providing varied resources, including alternative books and tools from libraries, teachers can enhance learning beyond the limitations of a single textbook set [5]. Developing creative thinking abilities is a priority in education at all levels, as they are essential for addressing current concerns. Creative thinking is crucial for solving issues and producing innovative concepts. Creative thinking abilities attributes include fluency, adaptability, originality, and development [6].

While complex biological topics present significant learning barriers [7], these difficulties disproportionately impact students considering pre-medical or allied health career paths. Failure to grasp these fundamental concepts can become a major bottleneck in the health science curriculum. The whole-group approach of teaching relies primarily on 'teacher-talk', when the speaker transmits knowledge to passive listeners. DI encourages active engagement in the educational environment, rather than passive learning [7]. Biology is a discipline of science focused on learning about living organisms, which teaches students about biological processes and how organisms interact with one another and the environment. Biology in high school seeks to progress students' biological awareness, understanding of the world of life, and ability to apply it [8].

However, teachers frequently do not use DI in the schoolroom for a variety of reasons. Teachers, for example, often discover it hard to offer every student the educational experiences that best fit them, or possess an absence of instructional confidence [9]. Most educators and learners are still conscious of the possessions of the program and active laboratories on theoretical progress in biology at the school level. Educators have not implemented skills into their teaching for a variety of details, with a lack of knowledge of technological advances, online classrooms, time, and support [10]. Biology, despite its significance across various fields, often fails to engage students, particularly in lower secondary schools in developing countries. This lack of interest is attributed to negative attitudes toward the subject, largely stemming from inadequate teaching methods employed by educators, especially when conveying complex and abstract concepts in biology [11]. Teaching evolution by human instances appeals to a wide range of students. However, it can increase cognitive and emotional barriers to learning, particularly for students who find human evolution problematic. Integrating human examples into development training in an evidence-based manner is challenging due to the complexities involved [12].

The original intent of this study was to observe the impact of DI personalized to students' individual learning styles on high school biology learning outcomes, specifically whether aligning teaching methods with learners' preferences improves comprehension, retention, and overall academic performance across a wide range of biological topics. However, the current study is now framed to quantify the efficacy of DI in improving learning outcomes in this foundational health science course (high school biology), providing evidence for its necessity in a curriculum designed to prepare future health professionals.

A pre-test/post-test quasi-experimental method with talented learners included differentiated, extended activities based on Kolb's education elegances and Bloom's taxonomy [13]. The research attempted to develop creative thinking, and the findings demonstrated that these tactics effectively enhanced and revealed children's imaginative thinking abilities. A customized flipped biology classroom was established utilizing Classroom Action Research, which included assessments, interviews, tests, and rubric-based evaluations to progress students' intellectual education consequences, problem-solving abilities, and motivation [14]. The findings revealed considerable gains in cognitive results and problem-solving, while inspiration remained consistent but met success indications. The research used a concurrent embedded mixed-methods design with Analysis of Covariance (ANCOVA) and thematic analysis to look into the influence of Paper-Based Problem Scenarios (PBPS) on high school biology performance and the ability to solve problems [15]. The results revealed that Paper-Based Problem Scenarios greatly improved learners' academic presentation and cognitive capacities, with no significant gender differences detected. The Analysis, Design, Development, Implementation, and Evaluation (ADDIE) approach was used to build individualized science educational components in biological sciences [16]. Data from surveys and pretest-posttest evaluations revealed that the components were highly valid, effective in enhancing pupil retention, and extremely useful, validating their application in high school scientific instruction. A qualitative phenomenology technique was used for DI in high schools [17]. The student's data was collected through interviews, observations, and document analysis. The data analysis included collection, reduction, display, and assumptions about students. The research identified obstacles for teachers and schools while applying DI. Project-Based Learning (PBL) was used to create a suitable learning environment for student and cultural engagement in biology education in Indonesia [18]. According to the research’s findings, biology educators appreciated PBL as a valuable education technique that promotes amplified pupil assignation, interaction in the classroom, awareness of culture, and the efficient execution of differentiated approaches to learning.

DI based on multiple intelligences was developed through design and development research employing the ADDIE model in conjunction with quasi-experimental techniques [19]. The intent was to improve students' educational attitudes and scientific idea competence. The findings revealed increased engagement, pleasurable learning, and successful development of several intelligences and concept mastery [20]. The research utilized a quasi-experimental scheme with a non-equivalent post-test control group. The research used pre- and post-interviews, as well as field notes analyzed using Max Qualitative Data Analysis (MAXQDA), to investigate the impact of AR-integrated educational workshops on teachers' Gifted Technological Pedagogical Content Knowledge (GTPACK) [21]. The findings demonstrated increased IT integration as well as distinct competencies; however, further professional development was still required. The research employs a Plomp model-based development research technique that is divided into four phases: the initial examination, design, execution, assessment, and modification [22]. Using the Screening, Visualization, Elaboration, and Reflection (SrVER) method in conjunction with Active Reflection (AR) media makes learning more engaging and enables learners to better understand the content. Flipped Learning Methods (FLM) was used in high school biology classes [23]. The influence of the FLM method on pupil education completion was positive, and other teachers were encouraged to use FLM in Kuwaiti classrooms. Lembar Kerja Peserta Didik (LKPD) media constructed on DI was utilized to increase the attention and learning results of students in biology [24]. The quantitative research approach was used to analyze the results of filling out the instrument in multiple stages, including assessment, article evaluation, tool setup, instrument filling, and data tabulation. LKPD based on DI should be used in education, particularly in high school biology, by developing the practice of LKPD as a standard for education.

The research examined how diverse problem sets promote collaborative issue-solving in high school biology [25]. Eighty-seven students were picked among problems of varied difficulty, which were examined using a mixed-methods methodology. Results showed that the majority of students chose inquiries that matched their skills, with a few tricky questions being the most beneficial, emphasizing selection and resonance in learning. The Instrument to Assess Teachers’ Practice of DI (IATPDI) was utilized to assess the content validity [26]. The validity of the contents of the IATPDI assessment was measured using the content validity index (I-CVI and S-CVI) and adjusted kappa statistics, which showed high content validity. Overall, the outcomes indicate that the IATPDI assessment is a content-valid tool. The research conducted stimulated recall interviews with four secondary school teachers in the Netherlands to examine their interacting perceptions of DI in regular and talent development sessions, and understanding of how the teaching setting affects DI implementation [27]. The findings revealed that teachers emphasized individual or small-group instruction more in talent lessons, underlining the importance of context-specific professional development.

1.1 Research Aim and Contributions

The research intended to observe the impact of DI personalized to students' individual learning styles on high school biology learning outcomes, specifically whether aligning teaching methods with learners' preferences improves comprehension, retention, and overall academic performance across a wide range of biological topics. The key contribution of the research is listed as follows.

- This research investigates the impact of DI combined with students' learning styles on learning outcomes in a high school biology context. Data were collected from 457 students through structured assessments, learning style inventories, and classroom performance records.
- The instructional intervention applied tailored teaching methods to students, including visual diagrams, hands-on experiments, group discussions, and multimedia presentations, aligned with the identified learning styles.
- Data analysis of the research was performed by IBM Statistics version 29.0. Pre- and post-test score differences were assessed using paired t-tests, MANOVA examined multiple dependent variables across groups, Wilk's Lambda measured multivariate group differences, Chi-Square evaluated associations between learning styles and performance, Kruskal-Wallis H tested rank differences, and Multiple Regression examined relationships between performance and instructional factors.

The research is organized into 5 sections: Section 1 describes the background, and related works of the research, Section 2 depicts the methodology, Section 3 presents the results and discussion, and Section 4 concludes the research.

2. METHODOLOGY

The methodology section used a quasi-experimental pretest-posttest control group design with 457 high school biology students divided into visual, auditory, and kinesthetic learning styles. Data were gathered using standardized examinations, learning style inventories, and classroom performance records. DI interventions included the learning styles of students, and outcomes were assessed using statistical tests. The overall flow is represented in Figure 1.

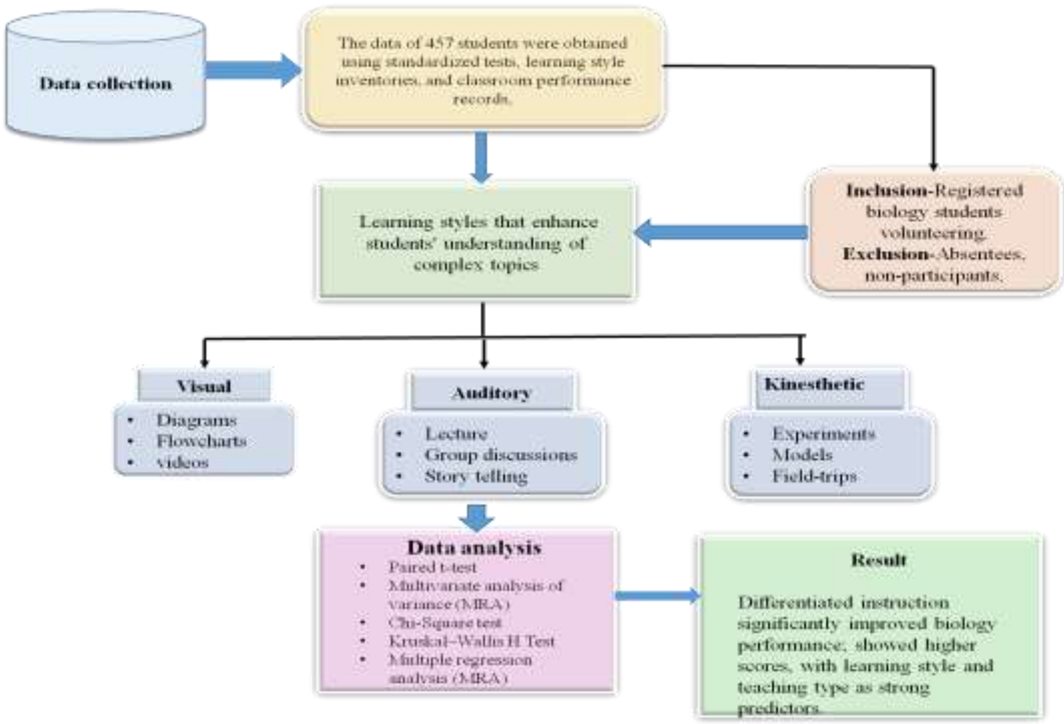

Figure 1: Overall Flow.

2.1. Research Design

The research employed a quasi-experimental pretest-posttest control group design to assess the impact of differentiated instruction on high school biology achievement. Students were separated into experimental and control groups, and the experimental group established instruction tailored to their learning styles. Pre-tests and post-tests assessed learning gains, allowing for group comparisons and evaluating the effectiveness of instructional strategies while controlling for baseline differences.

2.2. Participant's Details

Data were collected from 457 students through structured assessments, learning style inventories, and classroom performance records. The instructional intervention used specialized teaching methods, such as visual diagrams, hands-on experiments, group discussions, and multimedia presentations, to correspond with the indicated learning types. Learning style inventories were used to determine each student's preferred learning style, which included visual, auditory, and kinesthetic.

2.3. Selection Criteria

The selection criteria of the research are classified into two criteria: Inclusion criteria show the participants who are included in the research, and exclusion criteria depict the students with excessive absences and incomplete assessments. The selection criteria are clearly depicted in the below sub sections:

Inclusion criteria

- High school students are formally registered in biology courses and attend classrooms on a regular basis, ensuring active engagement and exposure to instructional strategies during the learning process.
- Students who volunteered to participate in the experiment were given informed permission and indicated a readiness to complete assessments properly.
- Learners were assigned an individual learning style, like visual, auditory, or kinesthetic, using an approved inventory, assuring correct classification for differentiated instruction implementation and analysis.

Exclusion criteria

- Students who are not enrolled in biology or have missed significant amounts of class time, lowering their involvement in instructional therapies and affecting the trustworthiness of their performance statistics.
- Individuals who refuse to participate, withdraw consent, or are absent during the pre-test or post-test, leading to inadequate or incorrect assessment data for meaningful assessment.
- Students with inadequate learning style assessment results or who require additional educational accommodations outside the research's design have limited proper classification and analysis within the educational framework.

2.4. Intervention

The intervention included DI for the experimental group, in which teaching methods were aligned with students identified learning styles: visual learners received diagrams, charts, and visual aids; auditory initiates engaged in lectures, discussions, and oral explanations; and kinesthetic learners participated in hands-on labs, role-playing, and interactive activities. The control group got conventional biology instruction that was not tailored to individual learning styles, consisting of regular lectures and textbook activities.

2.5. Pre-test Administration

A pre-test was controlled earlier in the instructional involvement to regulate students' biology knowledge. This accomplishment test was carefully tailored to the curriculum, including fundamental subjects such as cell structure, genetics, ecology, and human systems. Along with the pre-test, students took a standardized learning style inventory to determine their preferred modes of learning, which were classified as visual, auditory, or kinesthetic.

2.6. Learning Styles that Enhance Students' Understanding of Complex Topics

Visual Learning Visual learners absorb knowledge best when presented with visuals, graphs, charts, and written material. This approach is particularly useful in high school biology because many concepts include visible structures and processes. Labeled diagrams, flowcharts, and movies, for example, can help people understand cell division, DNA replication, and ecological cycles better. Teachers can help visual learners by including presentations, visualizations, and mind maps in their classes. Providing the opportunity to sketch or annotate diagrams improves retention. Visual learning enables pupils to connect abstract concepts to physical representations, thereby improving understanding and long-term memory.

Auditory learning The best ways for auditory learners to learn are through vocal explanation, debate, and listening. This approach is important in high school biology for comprehending processes, terminology, and cause-and-effect linkages. Students with this choice benefit from lectures, collaborative conversations, narratives, and oral question-and-answer sessions. For example, narrating photosynthesis activities or describing hereditary patterns aloud might help auditory learners understand a series of activities. Classroom arguments, simulations, and peer teaching all help to cement comprehension. Teachers can improve learning for auditory pupils by including podcasts, recorded lectures, or mnemonic music. Listening and verbal contact help these students comprehend and recall biological topics efficiently.

Kinesthetic Learning In this learning, the learners understand best through hands-on accomplishments, movement, and physical involvement. This teaching style is extremely beneficial in high school biology since it promotes engaged learning through laboratory work, simulations, and real-world applications. Kinesthetic learners, for example, might interact directly with the topical matter through dissections, lab studies, or the use of 3D representations of the human body.

- Field trips to botanical gardens, ecosystems, or museums reinforce students' learning.
- Individuals can create activities that require movements and touch, such as:

i. Role-playing processes in biology
ii. Developing models
iii. Performing elementary tests.

- This interactive approach benefits kinesthetic learners:

i. Develop a greater conceptual understanding.
ii. Improve problem-solving skills.

2.7. Post-test Administration

At the finish of the teaching period, an organized evaluation was used to assess students' learning outcomes and the information gained from biology training. The test was thoroughly planned to complement the curriculum and contained multiple-choice, quick-answer, and problem-solving questions covering areas such as cell biology, genetics, ecology, and human systems. To ensure equality and accuracy, identical standardized techniques were used for both groups. Scores were calculated using a consistent scoring scheme, and the results served as the major data source for measuring the efficiency of differentiated instruction when compared to traditional teaching approaches. Figure 2 depicts the visual assistance, auditory exercises, and kinesthetic tasks as examples of strategies used in biology teaching to accommodate different learning styles.

Figure 2: Three Types of Learning Styles in Biology.

2.8. Data Analysis

Data analysis of the research was performed by IBM SPSS version 29.0. The results were analyzed using five statistical tests: Pre- and post-test score differences were assessed by means of paired t-tests, MANOVA examined multiple dependent variables across groups, Wilk's Lambda measured multivariate group differences, Chi-Square evaluated associations between learning styles and performance, Kruskal-Wallis H tested rank differences, and Multiple Regression examined relationships between performance and instructional factors.

Paired t-test Paired t-test compares the outcomes of a single pair, subtracting one from the other [36]. The Paired t-test was used to regulate whether there were important variances among students' pre-test and post-test marks in both groups. This test was especially appropriate because it examines two sets of responses from the same people, adjusting for individual variability.

The paired t-test enables the direct quantification of the learning improvements associated with educational strategies by comparing pre-test and post-test routines. In the experimental group, the success of the differentiated flipped biology classroom was demonstrated, whereas in the control group, it revealed standard instruction results. This statistical method ensured a thorough evaluation of instructional performance across situations. The paired t-test formula is as follows: the total of the variances between every pair, reduced by a square root of n times the total of the disparities multiplied by n, resulting in o-1, represented in Equation (1).

$$\boldsymbol{t} = \frac{\sum e}{\sqrt{\frac{o(\sum e^2)-(\sum e)^2}{o-1}}} \text{---------(1)}$$

Where t is the paired t-test measure used to examine the statistical importance of differences, e is the difference among paired scores (pre-test and post-test) for each student, $\sum e$ is the sum of all score differences across students, $\sum e^2$ is the sum of squared score differences, o is the number of pairs, and $o-1$ is the degree of freedom for the test.

Multivariate Analysis of Variance (MANOVA) MANOVA is a statistical method used to assess variances in DV across many groups. A MANOVA was used to investigate the outcome of diversified instruction and students' learning styles in high school biology. MANOVA, a simplification of univariate ANOVA for more than one DV, was chosen because it allows for the concurrent challenging of differences across many DV [37]. The analysis also assisted in identifying patterns and interactions between variables, demonstrating not just the primary effects of learning style and instructional approach, but also how these factors can combine to influence student accomplishment. The analysis is especially effective in educational research because learning is complex and advances in one area can be linked to success in another.

Wilk's Lambda (Λ) Wilk's Lambda (Λ) is a multivariate test statistic employed to regulate if there are alterations between groups on a combination of dependent variables, as represented in Equation (2).

$$\Lambda = \frac{|F|}{|F+I|} \text{--------- (2)}$$

Where F is the error (within-groups), H is the hypothesis between groups, and$|.|$ is the determinant of the matrix.

Chi-Square test for independence The Chi-Square test of independence is a non-parametric statistical approach that determines whether two categories of variables have a significant association by associating the detected data distribution to the predictable distribution if the variables were independent [38]. Unlike parametric tests, which rely on normality assumptions, the Chi-Square test is distribution-free, making it ideal for assessing categorical data. The test uses a Chi-Square statistic (χ^2) to measure the difference between observed and anticipated frequencies in each cell. A higher value of χ^2indicates a significant relationship between the factors under examination. The Chi-Square test of independence was used to regulate whether students' learning modes were related to their performance categories after instructions. This analysis provided a systematic way to determine achievement outcomes, providing useful knowledge into the influence of DI of biology. The Chi-Square test is represented in Equations (3) and (4).

$$\chi^2 = \frac{(P-F)^2}{F} \text{---------(3)}$$

Where P is the observed frequency in each cell and F is the expected frequency in each cell.

$$F_{jk} = \frac{(Rowtotal_j)\times(Columntotal_k)}{Grandtotal} \text{----------(4)}$$

Where F_{jk} is the predictable frequency in the i-th row and the j-th column.

Kruskal–Wallis H Test The Kruskal-Wallis H test is a nonparametric statistical approach that determines whether there are significant variations in biology learning outcomes between students with distinct learning styles who receive varied instruction. The Kruskal-Wallis test compares independent groups when one-way ANOVA requirements are not met, such as non-normal data or unequal sample sizes. It determines if rank variances are statistically comparable or if one collection departs substantially from the rest of the groups.

Principles of Kruskal–Wallis H Test

- All students scored in the three learning style groups are ranked from lowest to highest, with rank 1 representing the lowest score, rank 2 demonstrating the next level and so on.
- The amount of positions for each learning style

group is determined, and the H statistic determines the degree of rank difference between the groups.

- The null hypothesis states that the alteration of biology scores is consistent across all learning style groups.
- An alternative hypothesis indicates that at least one learning style group differs in dominant pattern, implying a unique performance distribution [39].

Test statistics The H test is calculated in Equation (5).

$$H = \frac{(o-1)}{12} \sum_{j=1}^{l} \frac{o_j (\underline{S_J} - F_S)^2}{\sigma_S^2} \text{ --------- (5)}$$

Where o is the total number of students across all groups, l is the number of learning style groups, $\underline{S_J}$ represents the total of ranks for groups$j$, and o_j describes the number of students in group j.

Multiple Regression analyses (MRA) The MRA is a method for assessing the linear connections among a Dependent Variable (DV), students' overall biology performance, and multiple Independent Variables (IV), including learning styles, type of instruction (differentiated vs. traditional), and other relevant factors such as prior knowledge or class participation. It is an expanded version of basic regression [40]. In MRA, IVs are used to predict the DV, allowing the researcher to quantify how each element influences students' learning results. The overall MRA is represented in Equation (6).

$$Z = \alpha + \beta_1 Y_b + \beta_2 Y_c + \cdots + \beta_l Y_l \pm f \text{ ------- (6)}$$

In Equation 6, Y is the variable that influences the outcome, α is a stable, β_1 - β_l are the regression parameters, Y_1- Y_l are the random factors, and e is the error value. The MRA form uses the determination coefficient (S^2) to evaluate the authority of the association between the IV and DV in assessing the students' performance in biology.

Equation 7 provides the generic determination coefficient equation, with S^2 representing the change in the DV based on the IV. Increasing the number of IVs in a model improves the determination coefficient. The modified correlation coefficient (${S^2}_{adj}$) helps determine validity. Equations (7) and (8) represent $S^2$and ${S^2}_{adj}$, respectively.

$$S^2 = 1 - \frac{\sum \quad (\widehat{z_u} - \underline{z})^2}{\sum \quad (z_u - \underline{z})^2} \text{ -----------------(7)}$$

$${S^2}_{adj} = 1 - \frac{o-1}{(o-q-1)(1-R^2)} \text{ -----------(8)}$$

Where $\sum \quad (z_u - \underline{z})^2$ represents the measure of variation in the DV, $\widehat{z_u}$ is the forecast assessment, $\underline{z}$is the mean of the values tested, and z_u is the amount that was evaluated. In Equation 4, o represents the number of outcomes of experiments, and q is the quantity of IV in determining students' performance.

3. RESULTS AND DISCUSSION

The result section demonstrates that DI enhances biology performance across learning styles, with MANOVA, Chi-square, Kruskal-Wallis, and regression models repeatedly indicating that learning style and instruction type were strong predictors of achievement. Table 1 presents the distribution of students across various demographic and learning-related characteristics, showing the frequency and percentage for each category. Figures 3 and 4 demonstrate the pie chart of demographic characteristics.

Table 1: Demographic Profile of High School Biology Students.

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	220	48.1
	Female	237	51.9
Grade Level	9th Grade	115	25.2
	10th Grade	115	25.2
	11th Grade	114	24.9
	12th Grade	113	24.7
Learning Style	Visual	180	39.4
	Auditory	150	32.8
	Kinesthetic	127	27.8
Prior Academic Performance	High	145	31.7
	Medium	215	47.1
	Low	97	21.2
Interest in Biology	High	200	43.8
	Medium	180	39.4
	Low	77	16.8
Access to Technology	Full Access	230	50.3
	Partial Access	160	35.0
	No Access	67	14.7
Socioeconomic Status	High	120	26.3
	Medium	220	48.1
	Low	117	25.6
Study Habits	Regular	250	54.7
	Irregular	130	28.5
	Rare	77	16.8
Concentration in Learning	High (self-report/checklist)	210	45.9
	Medium (self-report/checklist)	165	36.1
	Low (self-report/checklist)	82	18.0

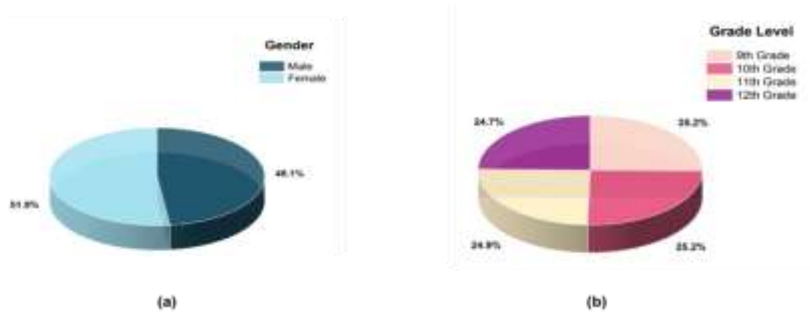

Figure 3: Demographic Characteristics of (a) Gender and (b) Grade Level.

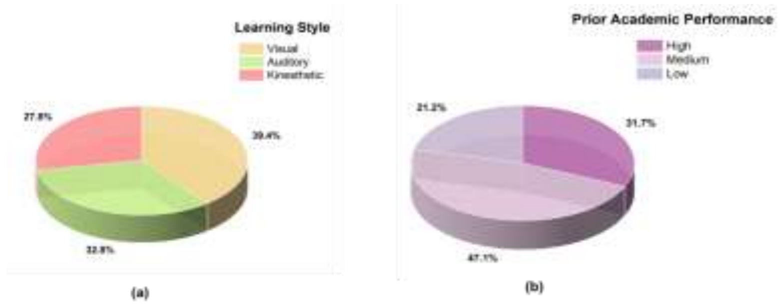

Figure 4: Representation of (a) Learning Style and (b) Academic Performance.

Table 2 and Figures 5 (a-b) show the paired-sample t-test results for pre-test and post-test biology achievement scores across learning styles in both groups. Students in the experimental group demonstrated significant score improvements ($p < 0.001$), showing the efficiency of differentiated instruction. In the experimental group, visual learners improved from 53.2 (SD = 7.8) to 72.1 (SD = 6.5) ($t = 15.21$, $p < 0.001$), whereas auditory learners improved from 51.5 to 66.8 and kinesthetic learners from 52.1 to 70.2. In contrast, the control group exhibited only modest improvements; for example, visual learners rose from 52.8 to 56.5 ($t = 3.42$, $p = 0.001$).

Table 2: Pre-Test and Post-Test Comparison of Biology Achievement Scores.

Group / Learning Style	Pre-test Mean (SD)	Post-test Mean (SD)	t-value	df	p-value	Interpretation
Experimental group						
Visual	53.2 (7.8)	72.1 (6.5)	15.21	179	<0.001	Significant improvement
Auditory	51.5 (8.0)	66.8 (7.2)	12.48	149	<0.001	
Kinesthetic	52.1 (8.2)	70.2 (6.9)	14.03	126	<0.001	
Control group						
Visual	52.8 (8.1)	56.5 (7.6)	3.42	179	0.001	Minimal improvement
Auditory	51.2 (8.5)	54.0 (7.9)	2.89	149	0.004	
Kinesthetic	50.9 (8.6)	53.1 (8.1)	2.45	126	0.016	

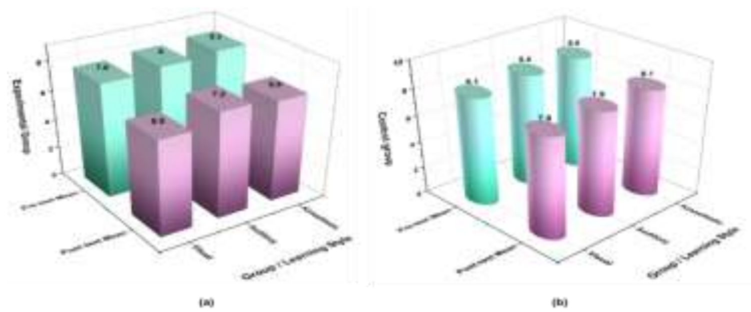

Figure 5: Visualization of the (a) Experimental Group and (b) Control Group Across Three Different Learning Styles.

Table 3 indicates the MANOVA results for the impacts of learning style, instruction type, and their interaction on several biology achievement outcomes. Both learning style (Wilks' $\Lambda = 0.78$, $F = 12.34$, $p < 0.001$) and instruction type ($\Lambda = 0.81$, $F = 10.12$, $p < 0.001$) had a substantial influence on performance. The interaction effect ($\Lambda = 0.92$, $F = 4.56$, $p < 0.001$) was significant. Topic-wise analysis found substantial differences across Cell Biology, Genetics, Ecology, and Human Systems (all $p < 0.001$).

Table 3: MANOVA Results of Learning Styles on Biology Achievements.

Effect	Wilks' Λ	F-value	df1	df2	p-value
Learning Style	0.78	12.34	6	906	<0.001
Instruction Type	0.81	10.12	6	906	<0.001
Interaction (Style × Instruction)	0.92	4.56	6	906	<0.001
Topic 1 (Cell Biology)	0.84	9.78	3	452	<0.001
Topic 2 (Genetics)	0.80	11.45	3	452	<0.001
Topic 3 (Ecology)	0.82	10.67	3	452	<0.001
Topic 4 (Human Systems)	0.79	12.02	3	452	<0.001

Table 4 shows the chi-square test findings that investigate the association between learning style and biology accomplishment categories (high, medium, and low). Visual learners performed the best, with 50.0% scoring high, compared to 30.0% for auditory and 43.3% for kinesthetic learners. The research found a significant correlation ($\chi^2 = 32.48$, $df = 4$, $p < 0.001$) between learning style and performance distribution. Visual and kinesthetic learners outperformed auditory learners.

Table 4: Chi-Square Test of Association between Learning Style and Biology Performance Levels.

Learning Style	High (%)	Medium (%)	Low (%)	χ^2	df	p-value
Visual	90 (50.0)	65 (36.1)	25 (13.9)	32.48	4	<0.001
Auditory	45 (30.0)	70 (46.7)	35 (23.3)			
Kinesthetic	55 (43.3)	55 (43.3)	17 (13.4)			

Table 5 shows the Kruskal-Wallis test results used to compare biology achievement among students with various learning styles. Overall biology performance differed significantly between groups ($H = 18.45$, $df = 2$, $p < 0.001$). Visual learners (mean rank = 240.5) scored the highest overall, followed by kinesthetic learners (230.8), while auditory learners (180.2) regularly underperformed. Topic-specific examination showed distinct strengths: visual learners performed much better in Cell Biology ($H = 16.72$, $p < 0.001$), kinesthetic learners displayed strong achievements in Genetics, aligning with their choices for efficient and hands-on learning, while auditory students performed comparatively poorly in Ecology compared to their peers.

Table 5: Learning Style Variations in Biology Performance Using the Kruskal–Wallis Test.

Variables	Group	Mean Rank	H	df	p-value	Interpretation
Total Biology Score	Visual	240.5	18.45	2	<0.001	Significant differences across learning styles
	Auditory	180.2				Auditory learners scored lower than visual and kinesthetic learners
	Kinesthetic	230.8				Kinesthetic learners scored similarly to visual learners
Cell Biology	Visual	238.4	16.72	2	<0.001	Visual learners performed best
Genetics	Kinesthetic	233.9				Kinesthetic learners excelled in hands-on topics.
Ecology	Auditory	182.1				Auditory learners scored lower than other groups.

Table 6 and Figure 6 depict the findings of various regression models that looked at how learning style, instruction type, prior knowledge, and class involvement predicted achievement in specific biological topics. In Cell Biology, learning style ($\beta = 4.85$, $t = 4.71$, $p < 0.001$) and teaching type ($\beta = 3.98$, $p < 0.001$) were significant predictors, alongside prior knowledge and class engagement. Similar results were observed for Genetics, Ecology, and Human Systems, where all four indicators exhibited substantial positive effects ($p < 0.01$).

Table 6: MRA of Biology Dependent Variables.

Dependent Variable (DV)	Predictor (IV)	β (Unstandardized)	SE	t-value	p-value	Interpretation
Cell Biology Score	Learning Style (dummy-coded)	4.85	1.03	4.71	<0.001	Significant predictor
	Instruction Type	3.98	0.95	4.19	<0.001	Significant predictor
	Prior Knowledge	3.12	0.90	3.47	0.001	Significant predictor
	Class Participation	2.56	0.85	3.01	0.003	Positive contributor
Genetics Score	Learning Style	5.12	1.10	4.65	<0.001	Significant predictor
	Instruction Type	4.25	0.98	4.34	<0.001	Significant predictor
	Prior Knowledge	3.48	0.92	3.78	<0.001	Positive contributor
	Class Participation	2.78	0.88	3.16	0.002	Positive contributor
Ecology Score	Learning Style	4.65	1.05	4.43	<0.001	Significant predictor
	Instruction Type	3.78	0.96	3.94	<0.001	Significant predictor
	Prior Knowledge	3.05	0.91	3.35	0.001	Positive contributor
	Class Participation	2.41	0.83	2.91	0.004	Positive contributor
Human Systems Score	Learning Style	4.98	1.08	4.61	<0.001	Significant predictor
	Instruction Type	4.05	0.97	4.18	<0.001	Significant predictor
	Prior Knowledge	3.28	0.89	3.68	<0.001	Positive contributor
	Class Participation	2.63	0.84	3.13	0.002	Positive contributor

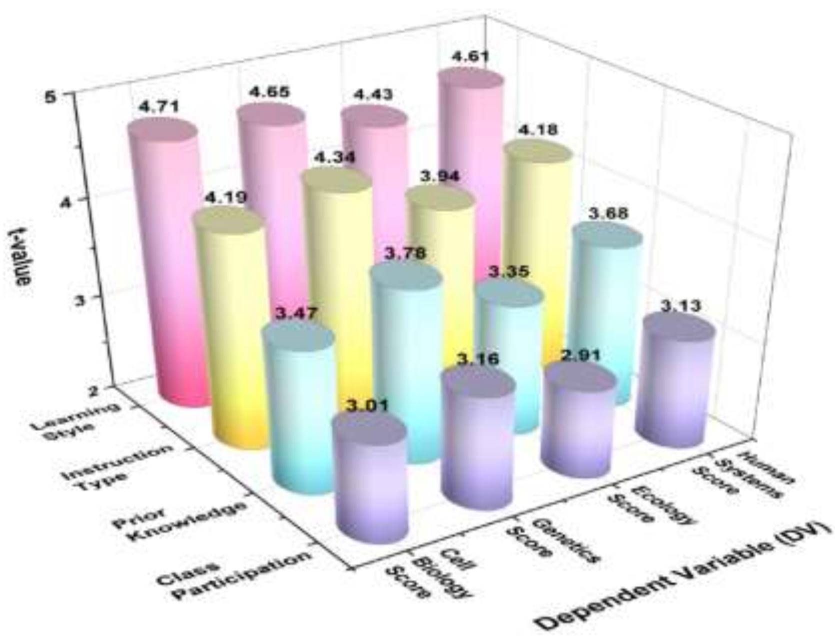

Figure 6: t-Values on Different Biology Learning Domains.

Table 7 and Figure 7 indicate the multiple regression results, which investigate the impact of many IVs on students' overall biology performance. Learning style was the most significant predictor (β = 6.45, t = 5.76, $p < 0.001$), followed by instruction type (differentiated vs. traditional, β = 5.12, t = 4.92, $p < 0.001$). Significant contributions were made by prior knowledge (β = 4.38, $p < 0.001$) and class participation (β = 3.25, $p < 0.001$). Attendance also had a beneficial impact on performance (β = 2.12, p = 0.005). The constant (β = 42.10, $p < 0.001$) indicates the student achievement.

Table 7: Impact of Learning, Instruction, and Behavioural Factors on Overall Biology Scores.

Predictor (IV)	β (Unstandardized)	SE	t-value	p-value	Interpretation
Learning Style	6.45	1.12	5.76	<0.001	Significant predictor
Instruction Type (Differentiated vs. Traditional)	5.12	1.04	4.92	<0.001	Significant predictor
Prior Knowledge	4.38	0.97	4.52	<0.001	Significant predictor
Class Participation	3.25	0.88	3.69	<0.001	Significant predictor
Attendance	2.12	0.75	2.83	0.005	Positive contributor
Constant	42.10	2.01	20.95	<0.001	Baseline performance

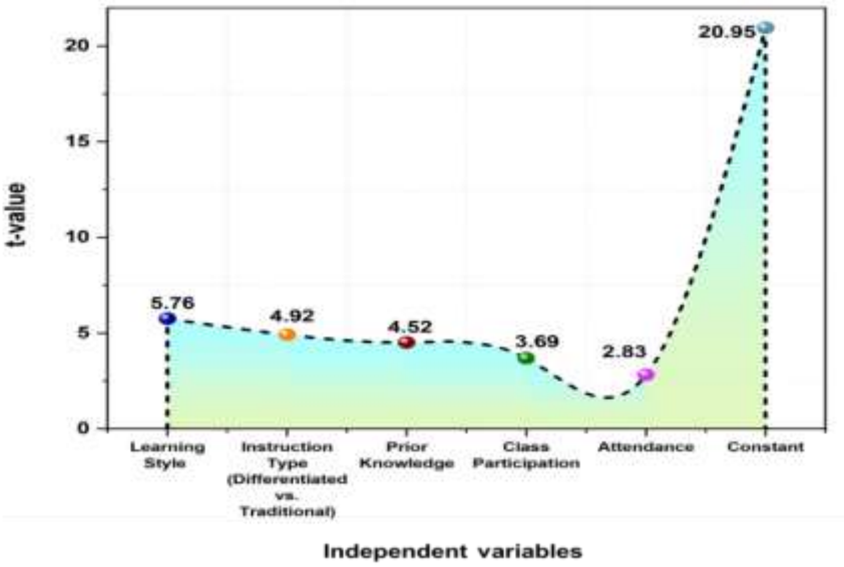

Figure 7: MRA of Independent Biology Variables.

3.1. Discussion

The key findings demonstrate that the implementation of Differentiated Instruction (DI) significantly enhances student achievement in high school biology across all learning styles (Visual: 53.2 → 72.1; Auditory: 51.5 → 66.8; Kinesthetic: 52.1 → 70.2, all $p<0.001$). Furthermore, learning style ($\beta=6.45, p<0.001$) and teaching type ($\beta=5.12, p<0.001$) were identified as the most significant predictors of performance.

Interpretation for Medical Educators: The finding that DI significantly improved conceptual understanding has direct implications for medical writing and education. This enhanced grasp of foundational biology translates to a stronger base for comprehending the complex subject matter, such as human physiology, pharmacology, or pathology, encountered in advanced health science curricula. This study validates that intentional, style-based pedagogy provides the necessary scientific rigor for students entering the health science pipeline.

Linking Learning Styles to Clinical Skills: The instructional modalities used in DI directly correlate with essential professional and clinical skills: Visual-based learning (e.g., using diagrams and charts) is essential for interpreting medical imaging, clinical flowcharts, and diagnostic pathways. Kinesthetic/Hands-on learning (e.g., experiments and labs) helps develop the manual dexterity, procedural thinking, and problem-solving skills necessary for laboratory techniques and clinical procedures.

Implication for Curriculum Design: Medical educators should advocate for or implement DI principles in prerequisite courses to mitigate knowledge gaps before students enter professional programs, thereby reducing potential attrition and improving overall educational quality. The present study offers a tangible pedagogical model that aligns with the journal's focus on evidence-based strategies to enhance health science education and ensure rigorous, effective preparation for students aiming at medical careers. This research emphasizes the benefits of diversified instruction by demonstrating its potential to raise student commitment, accommodate altered learning styles, and progress biology performance. It presents empirical evidence of large score increases, practical teaching tactics, and a methodology for incorporating individualized approaches into science curricula to improve accomplishment.

The research examines only seven German biology textbooks and chosen chapters, perhaps overlooking broader or more diversified NOS representations. Although the FRA provides a thorough structure, it still relies on subjective interpretation, which can introduce bias [28]. Lower educational attainments are underutilized, making it harder to draw broad conclusions for all student groups. Furthermore, contextual considerations such as curricular changes, instructor experience, and learning contexts are not completely explored, limiting the results' versatility and thorough applicability to other biology educational institutions [29].

The research's limitations were reliance on self-reported data, which could bring subjectivity and bias. Unequal involvement across degree programs may have an impact on representativeness, and the limited focus group sample size limits generalizability, making findings less applicable to all medical undergraduates [30]. The research focuses on higher education, which limits insights for secondary schools; there is little input from core biology fields; the use of mixed and quantitative approaches can obscure qualitative nuances; and the results' applicability across a range of educational contexts and technologies is limited [31]. The research intended to investigate the problems that teachers and school officials experience when implementing DI in an Australian secondary school. However, the research has several limitations: it was carried out on a small scale within one institution, limiting generalizability; it was based on self-reported interviews, which can create discrimination; it failed to assess the actual control of DI on pupil learning; and it ignored additional variables, such as school culture and educational constraints that can influence the effective implementation of DI practices [32]. The research's limitations include its reliance on individual perceptions of usability and mental strain, which could lead to discrepancies. The outcomes are incomplete for a single biology course and have a short length; therefore, they lack broad generalizability across academic contexts, and long-term academic effects [33]. The research's small sample size of only four teachers reduces generalizability; it focuses on a single district in Nepal, limiting contextual applicability; the reliance on self-reported conversations can introduce bias; and it does not accurately measure the effect of DI on pupil learning outcomes [34]. The research sought to investigate pre-service teachers' multicultural attitudes and differentiated teaching skills in Chinese teacher teaching curriculums. However, it has limitations: the use of self-reported surveys and interviews can introduce bias; the emphasis on China limits generalizability; it highlights an intention-action gap without assessing long-term educational outcomes; and the number of respondents cannot fully represent all pre-service teacher perspectives across regions or educational institution types [35].

4. CONCLUSION

The impact of individualized instruction paired with students' learning styles on learning outcomes in a high school biology environment was analyzed in this research. In summary, this study provides strong evidence that implementing Differentiated Instruction (DI) based on student learning styles significantly enhances achievement in foundational health science courses, specifically high school biology. The data of 457 students were obtained using standardized tests, learning style inventories, and classroom performance records. The results showed that differentiated training produced considerable benefits, with experimental group scores increasing significantly across all learning styles (Visual: 53.2 →72.1; Auditory: 51.5 → 66.8; Kinesthetic: 52.1 → 70.2, all $p<0.001$). Regression analysis further confirmed that learning style ($\beta=6.45, p<0.001$) and teaching type ($\beta=5.12, p<0.001$) were the most significant predictors, followed by prior knowledge ($\beta=4.38$) and class participation ($\beta=3.25$). This research focuses on one subject (biology), one region, and self-reported learning styles, which can introduce bias.

Final Impact Statement: This model offers a practical, evidence-based strategy for enhancing educational quality and equity in the critical entry points of the health science pipeline. We conclude that medical and health science educators should consider adopting DI principles in their preparatory curricula to maximize comprehension, foster diverse learning, and ultimately contribute to the advancement of high-quality health science education. Future research should look into differentiated instruction in other science areas, as well as bigger and more varied populations, and incorporate technology-driven adaptive methods to validate and expand on these results.

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