

Integrating Biostatistical Thinking into Undergraduate Students: A Data-Driven Pedagogical Framework

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ABSTRACT

Purpose: In order to enhance the ability of students to develop critical thinking, interpret biological phenomena, and analyze data, the integration of statistics into the biology curriculum is important. Therefore, the purpose of the present research is to explore the integration of statistical concepts in the biology course, students' ability to interpret and apply the concept of biology with the help of statistical tools, and to assess the perception of students about the integration of statistics with biology. **Design/ method/ approach:** This research used a mixed methodology for an in-depth opinion of respondents. Data was collected from students and teachers of different institutions. Moreover, the coursework of the students was compared before and after the inclusion of statistical tools. Semi-structured interviews were collected from teachers and students. The data collected was analysed through content analysis, and a grounded theory approach was used. **Findings:** The results of the study show that the integration of statistical concepts in the course of biology positively improves analytical and critical reasoning, students develop the ability to interpret and apply the concept of biology with the help of statistical tools, the perception of students about the integration of stats with biology shows appreciation regarding its usefulness, and instructional activities are important to develop the learning outcomes of students. **Originality:** Present study add value to the literature by discussing integration of Statistics into curriculum of biology.

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1. Introduction

Integration of biostats in the education of biology is very important because modern education of biology mainly relies on quantitative reasoning and data analysis. Students can easily understand the way biostatistics provides support to the basic concepts of biology with the help of a data-driven pedagogical framework (Mayes et al., 2022). This method enables students to evaluate evidence, analyze experimental results, and interpret biological variation. When different data sets are used by the biology students, they develop deeper understanding and scientific reasoning of the way biological research is shaped through data. Ultimately, adding biology curricula with biostats plays an important role in preparing students to address difficult biological questions by using analytical approaches (Yin et al., 2024). This integration also ensures that students are well equipped of professional roles and advanced studies in rapidly evolving world.

Studies have mentioned that statistics is one of the vital components of different subjects including sciences and medicine. Biostatistics is the field that deals with the applied area of biology, health sciences, and medicine. It is important for healthcare providers to be aware of progress in statistical investigation so they can apply statistical inquest in health and medical related decisions (Sakarna et al., 2025). Therefore, biostatistics is considered as one of the important disciplines that has played a very important role in the growth of medical research. Past studies have mentioned that medical stats is not liked by the students of medical. It is a general perception that there are certain difficulties in the field of biostatistics education. Most of the students of biology are motivated to study medicine, but their motivation to study bio-statistics and research methodology is very low (Conan, 2025). On the other hand, there is a variety of abilities and knowledge regarding mathematics required among students for the growth of bio-statistical knowledge. Some of the medical doctors have mentioned that they did not pay much attention to the subject of statistics while they were studying medicine.

Since the last two decades, the popularity of the term integrated curriculum has grown manifolds, especially in the

field of medical education, thus becoming one of the popular concepts at the international level. The main purpose of integration is to minimize the barriers between clinical sciences and basic sciences that are currently in place because of traditional curricular structures (Husain et al., 2020). The integration of different subjects promotes the acquisition of skills and retention of knowledge through progressive development and repetitive concepts along with their application. In the past, the integration of biology and statistics is recommended by many scholars and associations. Hence, it is key to justify the existing structures and aims of the subjects of Statistics and biology with the purpose to consider the political and social context (Krejikes & Greatorex, 2024). It is also important to minimize the gap between classroom practices and curriculum policy. Integration of curriculum develop connection among different subjects of a field, encourage real world learning, enhance problem solving skills and help students to understand relationship between knowledge of these areas (Kumar & Acharya, 2024).

Integration is developed between data science and the curriculum by using data-driven biology education. It plays a very important role in contributing and guiding students to prepare for a data-rich world. The main focus of the data-driven learning policy is on the development of strategies from different data of biological behavior (Zhang et al., 2023). Moreover, it aims to alter these behavior in-real time. Furthermore, different methods are used to achieve this objective under data driven policy learning approach. It plays important role to reproduce behavior on the basis of behavioral data by focusing on natural human behavior (Wang et al., 2024). The studies regarding life sciences are data-intensive; therefore, education on data-driven biology is vital. Students are equipped with critical thinking skills, computational skills, and analytical skills, all of which are essential in modern research (Ramadani et al., 2025). Thus, data driven biology education plays the role of bridge between required skills and traditional biological knowledge which is necessary in future landscape of science (Nurdin et al., 2025).

The aim of recent efforts in the field of education is the development of competencies among students. There are a number of different active learning techniques being used by educationists to develop competencies. The concept of active learning is very broad and is based on a number of different learning strategies. Studies have suggested that the learning of students who are studying medicine on campus is more compared to those who are studying online. It shows that the experience of educators plays a very important role in the learning process of students (Rezai et al., 2025). The teaching method of the teachers plays vital role in the development of skills among students of biology. Therefore, teachers of biology should work on the effectiveness of their lectures and work on the skills of students (O'Connor, 2021). Thus, the research question that this study needs to address are (1) whether integrating the statistical concepts in the subject of introduction to biology course will improve the critical and analytical reasoning of the students (2) whether the students are able to apply and interpret the biological concepts effectively with the help of statistical tools. (3) what is the perception of the students regarding the challenges and the usefulness of the integrating biology with statistics. (4) How instructional activities effect the learning outcomes.

2. Literature Review

2.1 Biostatistics

Studies has used term biostatistics to refer the statistics linked to biological science like public health, medicine and biology. Therefore, biostatistics is referred as linkage of biology with data that arise out side biological sciences or linkage of science with application of statistical methods with data developed from non-medical field (Daniel & Cross, 2018). In other words, biostatistics is the application of stats to medical data and biology with focus on interpretation, analysis and collection of data from different fields like biology, public health, and medicine. Biostatistics involves usage of different statistical techniques to derive meaningful conclusions on the basis of data, test hypothesis and design experiments to human health (Mishra & Khan, 2024). It is one of very important field to create public health policies, develop treatment, diagnose diseases and make discoveries (Afzal & Rizwi, 2013).

In the field of biomedical research, role of biostatistics is very important as it lays the foundation for basic study design and hypothesis testing. Additionally, it is also indispensable to interpret and manage the ever growing complexity and scale of biological data (Sultan, 2025). Scholars notes that evolving role of biostatistics in the research of medicine shows its vital contribution to ensure reproducibility, validity and precision in order to develop inference that is important in population and minimize the chances of bias. Additionally, in biostatistics is also important to translate findings into actionable knowledge, analyze different data sets, and refine measurements, therefore, promoting medical science. The importance of biostatistical methods have increased with the advancement of different genomic technologies. Through integration of computational approaches and statistical inference, the synthesis of clinical data has become possible which is important for advancement of public health and medicine (Olushola et al., 2024).

2.2 Active Learning

In literature, there are contrasting definitions of term active learning. The study by Doolittle et al. (2023) defined active

learning as opposite of passive learning. Similarly, researchers asserted that students just not learn by only sitting in classes, answering different questions, and memorizing different terms (Bernstein, 2018). Whereas, active learning focuses on the participation of students in the learning process where content must be possessed by the students by using different learning strategies including usage of case studies, role playing, laboratory work, peer tutoring and service learning (Dzaiy & Abdullah, 2024). Active learning is also linked to learning activities based in technology such as smartphone or mobile devices usage in classes, usage of games or simulation (Wibowo et al., 2023).

There are a number of different forms of active learning including synonymous and experiential learning. Studies have linked active learning with different theories of learning where students learn through critiquing and challenging concepts that are developed on the basis of their own experience along with experiences of others (Al Shloul et al., 2024). Sometimes teachers also provide guidance to these students who encourage cognitive learning among students. Active learning is linked to process of learning that involves interaction of students with different stakeholders (Rakha, 2025). Thus, in the process of active learning, power, self-regulation, autonomy and control relationships of students are often perceived as important factor (Forte-Celaya et al., 2021).

2.3 Curriculum Integration

Since last few decades, integration has become a process and concept reflecting combination of administrators, clinicians, professors and students for the modernization and improvement of curriculum (Ayub Ahmad et al., 2016). Uniting and organizing the information that is already available allows its educators to develop curricula more easily. Such curricula help the educators in application of clinical and scientific knowledge. Studies has defined integration as organization of material that is used for teaching to unify or interrelate subjects that are frequently taught in specific departments and academic courses (Allouch et al., 2024). Curriculum integration is the mechanism to create and develop new curriculum that is based on discipline and areas of diverse range. A number of different benefits are reported of curriculum integration including understanding and awareness of risk response and preparedness among community, educators and students (Roehrig et al., 2021). Therefore, curriculum integration is the pre-requisite of sustainable development of education in future. Curricula develops competencies that minimize vulnerabilities and improves resilience. Integration of curriculum develop link among various subjects to develop meaningful experience (Chhatra et al., 2024). It develop connection and knowledge among different disciplines, develop relevancy among various subjects and develop deeper understanding of subjects as well. Collaboration of subjects encourage real world problem solving, collaboration, critical thinking and engagement among different stakeholders (Simanjuntak et al., 2022).

Education regarding data driven biology is the approach that integrates large scale biological data sets, statistics and computational tools within a curriculum with purpose of teaching basic concept of biology (Robeva et al., 2020). It also helps students to be equipped with key skills of data literacy. This strategy is one of the new way to engage students in problem solving methods and authentic research experience using data gathered from around the world. Education of data driven biology develop a culture of inclusion, and accountable team building (Donovan et al., 2022). Students get diversified knowledge with this type of integration of diversified discipline with depth pf answers of biological questions with scientific knowledge. Biology students get knowledge and experience of other subjects with this integration. The aim of data driven biology training program is to train biology students to have knowledge of other subjects and research fields (Wilton et al., 2022).

3. Methodology

3.1 Design of Research

Mixed method approach was used by the researcher to in depth understand the impact of integrating statistics with biological concepts. In qualitative design we compared the scores of the course pre and post levels, while in qualitative design we collected the data by conducting interviews with instructors and the students. Both data sets were analyzed separately and then merged for the triangulation and interpretation. With the help of such research design, we can measure the changes in the learning performance and how the faculty and the students perceive this change. We focused on the following questions 1) whether integrating the statistical concepts in the subject of introduction to biology course will improve the critical and analytical reasoning of the students 2) whether the students are able to apply and the interpret the biological concepts effectively with the help of statistical tools 3) what is the perception of the students regarding the challenges and the usefulness of the integrating biology with statistics. 4) How instructional activities affect the learning outcomes.

3.2 Sample and Population

Target population was all the students enrolled in the course of introduction to biology during current semesters at

the higher educational institute. Quantitative component of the study are the students who have given the consent for participation in the research. We have used single group pre-post design for the selection of data. For the qualitative section purposive sampling technique was used for the interviews and focus group. 20 students selected having diversity in the quantitative background, performance (low-medium-high) and gender to capture the variation in perspectives. Researchers also included 5 instructors in interviews.

3.3 Instructional Intervention and Materials

Subject: Bio-statistical approach with Introductory biology (modified, BIO-101)

3.4 Modules Interventions (Spread Across Semesters)

Three modules for two weeks are integrated into regular labs and lectures. First module constitutes the data and variability, in which descriptive statistics and standard deviation are added in the course. In second module the graphics and interpretations were added like Histogram, scatterplots and trend analysis. In third module hypothesis testing was added, and the assessing the p-values for the significance of the effects.

Material of teaching: Short videos (micro-lectures), worksheets, data collection templates and lab protocol, Graded lab manual rubrics were analyzed.

3.5 Training of Instructors

Two-week training workshops were organized for the teachers for the effective delivery of the modified course.

4. Instruments and Measures

4.1 Quantitative and Quantitative Instruments

Course performance was compared before and after the inclusion of statistical concepts in biology. We have compared the grades of the students before and after the inclusion of statistics.

For the selection of qualitative data semi-structured interviews were conducted and an interview key was used including open ended questions and then researcher used the response guided approach for the collection of the data.

For the analysis of quantitative data content analysis technique was used based on the grounded theory approach.

4.2 Procedure for Data Collection

Researchers prepare the material before the start of the semester and completed the instructors training workshop, obtained the written consent of the respondents, Administred the semi-structured interviews. In the interviews with the students and the faculty we recorded all the responses.

Activities Designed for the Evaluation of the integration of Biology and Statistical Concepts.

First Phase

Concept: Understanding quantitative description and the biological variation

Activity 1: Biological Variation Measurement

Topic: Cell structure and size

Instructions: microscopic observe of onion cells. By the use of ocular micro-meter measure the diameters of 5 cells
Record your data below.

Cell No.	Diameter (mm)
1	0.2
2	0.1
3	0.5
4	0.4
5	0.3

Concept based Questions:

1. Why do similar type of cells show different sizes?
2. How can we reduce experimental errors by measuring several cells ?

Analytical

1. Calculate the arithmetic mean, range and median of the diameters of cell.
2. Plot the bar graph for the trend analysis
3. Interpret the graph to analyses the variability of size of cell

Second activity: Enzyme Reaction Analysis of Enzyme

Topic: Effect of temperature on enzyme activity

Temperature (°C)	Reaction Rate (units)
5	25
10	35
15	55
20	60
25	48

Concept base Questions:

1. Why does the enzyme activity increase and then decrease with temperature?
2. What is the concept of an 'optimum temperature'?

Analytical Questions:

1. Plot graph of the data
2. highlight the maximum activity point
3. Estimate the average rate of reaction

Second Phase

Concept: integrating biological conception with statistical interpretation

Third Activity

Beetle count in a grass field, select randomly 7 quadrants for the record of the count of beetles found.

Quadrat	Number of Beetles
1	10
2	15
3	8
4	7
5	12

Concept based Questions:

1. Why sampling was used by biologists instead of calculating the population?
2. Which factor factors could cause variation in beetle counts between quadrant?

Analytical

1. Estimate standard deviation and mean of beetle counts.
2. Estimate the total number of beetles in a 100-quadrat area.
3. If 2 quadrat had 10 beetles instead of 15, how mean will be effected ? Explain.

5. Data Analysis

5.1 We Designed a Pre/Post course Outcome Assessment to Measure Student Gains in Course Learning Outcomes

After the establishment of the bio-stat learning outcome of the particular course, we designed an instrument for the measurement of gain of the students. Assessment items based on the four basic topics of cellular and molecular biology including genetics, and inheritance, meiosis, function and structure of nucleic acid, energy enzymes, and life's reaction, central dogma and gene regular and application of two quantitative skills. Researcher investigated the 5 students of the BS class with respect to the selected areas of the research. From Table 1 it is evident that the students' scores of the relevant areas' genetics, and inheritance, meiosis, function and structure of nucleic acid, energy enzymes, and life's reaction, central dogma and gene regular and application of two quantitative skills, improves as we added the statistical skills. When the students investigated after knowledge delivered regarding the probability and the quantitative skills, we can see that the students' scores improved significantly. Scores with respect to Inheritance, meiosis, genetics, it is demonstrated that the students scored 10, 11, 20,26,30 respectively improved to 12,14,28,32,35. After guiding the teachers and delivering the knowledge related to graphical analysis like linear regression, trend analysis, and the histogram plots, scores of the students improved to 13,15,30,45,50. In Structure and function of Nucleic acid without statistical knowledge score of the selected group was 4,6,8,10,13, that improved with the knowledge of probability and accounting 6,8,10,12,17 respectively. When the knowledge of graphical understanding of the students enhanced by the addition of statistical knowledge with the biology scores of the students increased to 10,12,15,18,21. In the section of Energy, Enzymes, and life's reactions scores of the students was 2, 22, 23,25,31 that increased when the probability and the accounting knowledge added the scores of the students were 10,30,35,36,39. Moreover, after having knowledge about the graphical concepts the scores improved to 15,31,36,39,40. In the central dogma and Gene regulation the scores of the students were 12 ,16, 23,26,30, when the students were given with the knowledge about probability and counting , the scores moved to 10,30,35,36,39. After having

knowledge about the graphical analysis , scores of the selected group moved to 19,27,32,30,35 respectively. The results showed that integration of statistics with biology improved the student analytical and critical thinking skills and enhanced the overall performance of the students.

Table 1: Pre/Post Assessment Questions by Biology Concept and Quantitative Skill

Statistics Skill	Inheritance, Meiosis, Genetics	Structure and Function of Nucleic Acid	Energy, Enzymes, and Life's Reactions	Central Dogma and Gene Regulation
Non	10, 11, 20,26,30	4,6,8,10,13	2, 22, 23,25,31	12 ,16, 23,26,30
Probability and Counting	12,14,28,32,35	6,8,10,12,17	10,30,35,36,39	15,18,30,29,34
Graphical Analysis	13,15,30,45,50	10,12,15,18,21	15,31,36,39,40	19,27,32,30,35

Researcher collected the data about the performance of the students from two sections of the BS biology students, in first section teacher integrated the statistical concepts with the biological concepts while in second section simple biological concepts were taught. During the semester above-mentioned activities were performed in the classes, and at the end semester students were evaluated in the traditional way. It was analyzed that the grade points of the section with the bio-statistical concepts scored high as compared to the section without integration of statistical concepts.

Table 2: Performance of Group 1

Students	Section A	Section B
1	90	70
2	80	65
3	76	58
4	87	49
5	68	59
6	78	63
7	88	83
8	63	57
9	59	48
10	68	55

From Table 2 we can see that the students of section A performed well as compared to the students of section B. Students of section A had clearer understanding about the biological concepts and the interpretation of the biological concepts with the support of statistical concepts. On the other hand, the students of section B could not perform well because of the lack of understanding about the statistical concepts.

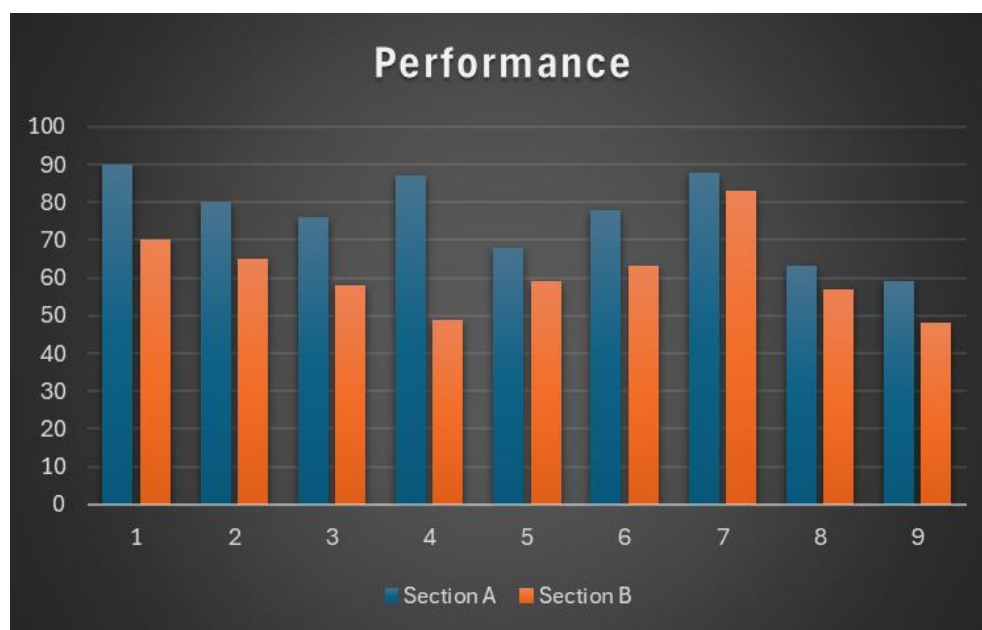


Figure 1: Comparison of Performance (Section A and B) Group 1

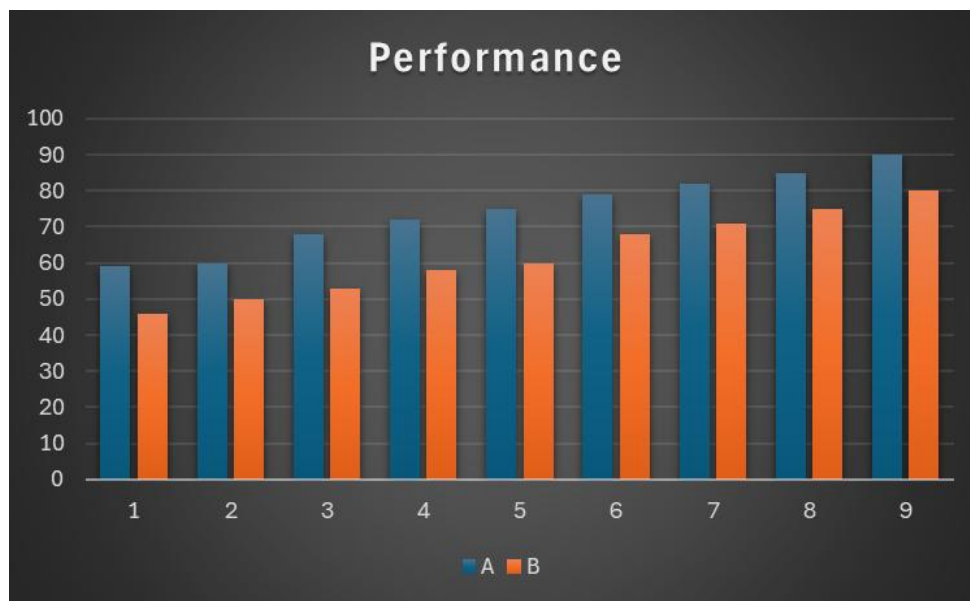
Figure 1 shows the higher performance of section A group as compared to section B group of students.

In group 2 of both sections similar evaluation was done and the results of the accumulated scores are given below

Table 3: Performance of Group 2

Students	A	B
1	59	46
2	60	50
3	68	53
4	72	58
5	75	60
6	79	68
7	82	71
8	85	75
9	90	80
10	92	84

From the above table 3 it is evident that the scores of section A students are higher than the scores of section B. for more understanding we have the bar chart showing the higher performance of the section A students.

**Figure 2:** Comparison of Performance (Section A and B) Group 2

From figure 2 the higher understanding of the biological concepts of Section A students integrated study of biology and statistics and the low comparative performance of section B lacks statistical understanding.

To understand the philosophy more deeply about the integration of biological concepts with statistics, researchers used the qualitative research design and conducted interviews from the faculty and the students about their perception of the inclusion of statistical concepts in the biological concepts. The interviews were recorded and after that researcher transcribed the data and after reading the statements line by line researcher found the themes and coded the data. Following are some responses from the respondents about the research questions of the study

(1) Whether integrating the statistical concepts in the subject of introduction to biology course will improve the critical and analytical reasoning of the students

Here are some selected responses from the students and the teachers

"I agree that the integration of biological concepts with statistics will enhance my academic performance because in the experiments of biology data is involved and statistical learning at the same time will support me to understand biological results easily". "I accept that my performance improved as the statistical tools helped me to understand and analyze the processes of biology, interpretation of graphs and in drawing scientific conclusions". "Integration of biology with statistics helped me to develop effective and efficient research skill required for the lab work and result reporting". "Yes of course bio-statistical combination will improve the performance as the statistical techniques will help to understand changes in the biology data and will improve the interpretation"

According to the teachers "Integration of biology with statistics improved the analytical skill of the students and enabled them for the interpretation of experiment data more effectively and for drawing the sound conclusion". "When I taught the statistician techniques and tools with the biological concepts, it improved the understanding of the students regarding the core biology concepts because they immediately applied the tools of statistics to the real problems of biology,

that in turn enhanced their understanding". "Course of integration enhanced the evidence based critical thinking and the ability of the students for designing the experiments and analyzing was improved". "Interdisciplinary competence fostered by combining the biology with statistics, that not only improved prepared students for higher level of science study but also improved academic performance"

(2) Whether the students are able to apply and interpret the biological concepts effectively with the help of statistical tools.

Here are some selected responses from the students and the teachers

According to the students "yes statistics helped me to clearly understand the biological concept, statistical tools helped me to interpret the biological ideas effectively, helped me to create sense of data collection and the lab experiments". "Student: In biology applying statistical tools make the topic easy, particular populations studies, genetics and results experiments". "It makes easy for me to interpret the trends, graphs and the outcome more effectively, that improves my overall performance and understanding of the concepts of biology". I can remember the biological concepts more easily and logically by the integration of biology and statistics, because the graphs and trend analysis helped, me a lot to understand".

According to faculty members "Integration of statistics with biology strengthens the scientific and analytical skills of the students to grasp the biological concepts". Applying statistical methodology in the biology class helped the students to interpret the experimental data and reduced the errors and misconception".

(3) What is the perception of the students regarding the challenges and the usefulness of integrating biology with statistics.

Here are some selected responses from the students and the teachers

With respect to usefulness

According to some students "learning biology with statistics will support me to understand the results of biological experiments, particularly in ecology and genetics" some others "my scientific thinking will improve and instead of memorizing the concepts I can analyze real data. Some students said that inclusion of bio-stat biology will feel more research-based and applied.

With regard to challenges

Some respondents said "sometimes it is difficult to understand the formulas of statistics, as we have not learned them earlier" according to some others "connection of abstract concepts of statistics in biology is challenging but will practice become easier.

According to teachers

Students analytical and critical skill will strengthen by the introduction of biology and statistics and will improve the accuracy of the interpretation". "Merger of biology and statistics will help the students to better design experiments and understand the variability of the biological data.

With respect to challenges

"Sometimes it is difficult for the students to understand the mathematical part requiring additional scaffolding and support". "In curriculum designing and then completing the curriculum it is challenging to complete the contents in limited time apply deeply the statistical techniques effectively"

(4) How instructional activities affect the learning outcomes.

Here are some selected responses from the students and the teachers

"With real-life explanation instructor can guide the students and demonstrate effectively, I remember and understand my topic easily and quickly". "Quizzes, problem-solving sessions, group discussion, motivates for the class participation and enhance performance". Organized lectures, clear instructions and well organized and structured slides helped the students to understand the contents more easily" "provision of timely feedback on classwork, assignments helped to correct the mistakes" "group work, students engagement activities and peer teaching help the students to understand the concept effectively and easily".

According to teachers

Collaborative activities such as group work and peer teaching help students engage with concepts, which positively influences their learning achievements." Thus, the integration of statistical concepts with biology will enhance the understanding of the students with respect to the core concepts of biology.

6. Discussion

This research adopted mixed methodology to reach the objectives of study. On the basis of findings, it is revealed that integration of statistical concepts in the course of biology positively improves analytical and critical reasoning (Johnston et al., 2014). It enables students to make judgments on the basis of data-driven science, evaluate patterns, and interpret evidence. In other words, the integration of the syllabus of statistics into the beginning course of biology develops a cause-and-effect pathway that is very powerful and could strengthen the student's ability of analysis and critical thinking. When

students are exposed to concepts of biology alongside principles of statistics, they start realizing that there exists a correlation between biology and stats in a way that biology is basically a science based on data. Therefore, the usage of statistics by the students helps them to understand and memorize facts of biology while examining different biological evidence. As a result of this integration, students improve their understanding and ability to develop logical interpretations, question basic assumptions, and analyze different patterns of biological data. Another possible reason for these findings is that when statistics is used by students for the quantification of variation in populations, this process also leads to understanding differences in biological traits. Additionally, consistent integration of courses of biology and stats, and their integration in biology classes, plays a very important role in understanding experimental design. Students get more engaged with research methods and patterns. As students of biology start learning and calculating different statistical measures such as levels of significance, correlation, and arithmetic means, a clear understanding of biological conclusions is developed among students. Because of this statistical engagement, critical reasoning of students is improved as they develop the ability to make judgments regarding biological data, whether they are sufficient, valid, and reliable to support scientific claims. Therefore, statistics is one of the most important reasons to improve scientific judgment.

Moreover, the integration of statistics into the courses of biology helps students in the interpretation of real data sets. These students do not need to depend on theoretical explanations in their studies and experiments. If students are exposed to biological data that is authentic, they practice reasoning through probability, variability, and uncertainty skills, which are the base of analytical thinking. Furthermore, students also develop the habit of approaching biological questions by using evidence-oriented and investigative approaches after repeatedly applying statistics to the problems of biology. As a nutshell, the regular usage of statistics in the subject of biology develops cumulative effects where the application of statistics develops capacity within students to make informed decisions, interpret evidence, and evaluate patterns.

The findings also show that students develop ability to interpret and apply the concept of biology with the help of statistical tools ([Hawkins, 2019](#)). The usage and integration of different tools of statistics in the beginning courses of biology allow students to interpret and apply concepts of biology with more clarity and accuracy. When students go through different ideas of biology, including cellular processes, genetic variation, and population growth, the usage of statistical tools gives them authenticated and reliable methods to examine certain data and processes. Usage of different tools of statistics like regression, trends, proportion, and graphs helps students in the development of a clear pathway to transform different observations of biology into meaningful interpretations. By using this approach, students are able to understand biology with the help of measurable evidence. Thus, statistics plays the role of a bridge between concepts of biology and biological data that is based on real-world examples. In the analysis of biological responses and the examination of patterns in data sets of ecology, statistics plays a very important role in the identification of different relationships. Statistical tools are also vital to decode different variables that are common in the field of biology. They improve the ability to explain the reason for the occurrence of different biological results and help in understanding the interaction of different factors of biology. The integration of statistics also provides support in getting accurate interpretations of different biology experiments that are conducted by the students.

Additionally, the integrated usage of stats and biology improves the communication of students regarding scientific ideas. When biological results are produced by the students with the help of numerical indicators, charts, and statistical summaries, the explanation of the tests becomes more scientifically grounded and precise. As a result, their ability to discuss different biological processes with more logic and clarity is improved. Moreover, an investigative environment in the field of biology is fostered with the integration of statistics. In such an environment, students are directly engaged with biological data rather than relying on different theoretical interpretations. With the help of this hands-on engagement, the biological concepts of students become concrete with reasoning based on statistics. The results also show that perception of students about integration of stats with biology shows appreciation regarding its usefulness along with awareness about challenges it reflects in the integrated curriculum as reflected by [Metz \(2008\)](#). From the perspective of students, usefulness can be viewed by the way integration provides strength to the ability to interpret findings of biology in a more effective way. Most of the students are of the view that the combination of statistics and biology allows them to engage with data that is real-time and belongs to different areas like ecology and genetics. This data is used for experimentation and makes the curriculum aligned with actual scientific practice, inquiry-driven, and applied. With the help of this connection, students go beyond memorizing information. They start understanding basic operations of biological concepts and support them with the evidence of quantitative data. Therefore, using the integration approach helps in the development of a more in-depth biological curriculum that enhances the involvement of students in scientific exploration.

On the other hand, challenges are openly acknowledged by the students that are linked to this integration. One of the most obvious difficulties faced by the students of biology is understanding formulas of statistics and procedures that they will not have used before during their academic path. It can be demanding to develop a link between statistics and biology, especially when they are integrated into the curriculum of a single semester. It is perceived by the students that they need repetitive exposure and time to adjust to this shift towards analytical thinking. With the passage of time, these students will get more comfortable. The perception of teachers mirrors this finding as well. Teachers noted that the integration of

statistics and biology strengthens the interpretive and analytical skills of the students, enriching the overall curriculum. Teachers also mentioned that students may need extra time and classes to understand statistical components. This is a big challenge because, in the integrated curriculum, it is one of the major difficulties. Students view this integration as valuable, but it is very challenging for them to adapt to the new curriculum.

In the end, results also revealed that instructional activities are important to develop learning outcomes of students (Tullis & Goldstone, 2020) by shaping the environment where biological concepts are easier to retain, more relatable, and clearer. Students can easily develop connection between practical situations and theoretical ideas when teachers provide actual real-life explanations. This situation leads to longer lasting and quicker understanding of the concept. Usage of this approach alter abstract knowledge into meaningful concepts. Moreover, students are engaged in different activities such as group discussion, problem solving and quizzes. It is perceived by students that these tasks are motivating that help them in understanding integrated biology and statistics curriculum.

The learning outcomes of the students are further enhanced with the help of well-structured and organized structure of instructions. The cognitive loading of students is eased in the presence of logically designed slides, systematic lectures and clear instructions. It allows students to focus on understanding the concepts of biology and statistics. Likewise, timely feedback on work delivered by students further refines the learning process of students. Students can identify their mistakes at the beginning of their lectures that help in correction of misunderstandings. Collaborative instructional activities also have major influences. Student engagement exercises, teachers' feedback and group work help the students in understanding different concepts of statistics and biology. It is observed that conceptual understanding of students is deepened by the collective methods of students and teachers. It leads to achievements of higher grades as students learn the way to work in a group. The results suggest that instructional activities in the form of collaboration, feedback, structured teaching and real-life examples play very important role in mastering students.

7. Limitations and Future Directions

This section discusses limitations of this research and propose future directions. Present research used single group pre post design that limits the ability to handle the external factors impacting learning outcomes of study. Therefore, it is proposed that upcoming studies may use comparison groups. Furthermore, the sample collected in this study was collected from very limited institutions that creates difficulties in generalizability of the findings. It is proposed that future studies may collect data from diversified institutes for more generalizability of the outcomes.

Additionally, this study collected data from only 5 instructors and 20 students in the form of interviews that also limit the generalizability of the outcome. It is proposed to expand the number of students and faculty members in future researches. In the end, the quantitative section of the paper was conducted through SPSS and its different tools. It is proposed to use Smart PLS for further similar studies for more in-depth analysis and contribution to the literature of academic world.

8. Theoretical and Managerial Implications

Present research has theoretical as well as managerial contribution that will be discussed in this section. This research adds to the literature of statistics and biology education by discussing the integration of statistical approaches to the courses linked to biology. This research also contributes theoretically by reflecting significance of above-mentioned integration to improve analytical and critical thinking ability of students. This research provided empirical evidence by using mixed method design by the combination of scores linked to pre-post s courses and qualitative interviews of teachers and students. This study also provided empirical evidence that shows the importance of statistical tools to reinforce understanding of biological concepts.

From the perspective of managerial contribution, this study is important for administrators of education, teachers and curriculum designers regarding the value of integration of statistical tools into courses of biology. The results suggests that timely feedback and collaborative learning are important for the improvement of students learning. The results can be used by the policy makers and academicians for the development of integrated curriculum of biology and statistics.

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10. References

Afzal, M., & Rizwi, F. (2013). Biostatistics and data types. *Journal of Islamabad Medical & Dental College*, 2(2), 103.

- Al Shloul, T., Mazhar, T., Abbas, Q., Iqbal, M., Ghadi, Y. Y., Shahzad, T., Mallek, F., & Hamam, H. (2024). Role of activity-based learning and ChatGPT on students' performance in education. *Computers and Education: Artificial Intelligence*, 6, 100219.
- Allouch, S., Ali, R. M., Al-Wattary, N., Nomikos, M., & Abu-Hijleh, M. F. (2024). Tools for measuring curriculum integration in health professions' education: a systematic review. *BMC Medical Education*, 24(1), 635.
- Ayub Ahmad, K., Abid, A., Amina, A., Saad, I., & Nida Ayub, K. (2016). Frame factors for implementation of integrated curriculum in public sector medical college-faculty's perspective.
- Bernstein, D. A. (2018). Does active learning work? A good question, but not the right one. *Scholarship of Teaching and Learning in Psychology*, 4(4), 290.
- Chhatria, S., Pani, B., Digal, A. K., & Sangeeta, M. (2024). Principles and Approaches to Curriculum Development. *Journal of Higher Education Theory and Practice*, 24(1).
- Conan, J.-B. A. (2025). On the Mechanistic Interpretability of Neural Networks for Causality in Bio-statistics. *arXiv preprint arXiv:2505.00555*.
- Daniel, W. W., & Cross, C. L. (2018). *Biostatistics: a foundation for analysis in the health sciences*. John Wiley & Sons.
- Donovan, D., Clemmons, A., & Crowe, A. (2022). Data driven approach to analyze competency teaching in an undergraduate biology program: A case study. *Journal of the Scholarship of Teaching and Learning*, 22(4).
- Doolittle, P., Wojdak, K., & Walters, A. (2023). Defining active learning: A restricted systematic review. *Teaching and Learning Inquiry*, 11.
- Dzaiy, A. H. S., & Abdullah, S. A. (2024). The use of active learning strategies to foster effective teaching in higher education institutions. *Zanco Journal of Human Sciences*, 28(4), 328-351.
- Forte-Celaya, J., Ibarra, L., & Glasserman-Morales, L. D. (2021). Analysis of creative thinking skills development under active learning strategies. *Education Sciences*, 11(10), 621.
- Hawkins, D. (2019). *Biomeasurement: a student's guide to biological statistics*. Oxford University Press.
- Husain, M., Khan, S., & Badyal, D. (2020). Integration in medical education. *Indian Pediatrics*, 57(9), 842-847.
- Johnston, I. G., Rickett, B. C., & Jones, N. S. (2014). Explicit tracking of uncertainty increases the power of quantitative rule-of-thumb reasoning in cell biology. *Biophysical journal*, 107(11), 2612-2617.
- Kreijkes, P., & Greateorex, J. (2024). Differential effects of subject-based and integrated curriculum approaches on students' learning outcomes: A review of reviews. *Review of Education*, 12(1), e3465.
- Kuwar, R., & Acharya, N. H. (2024). Integrated Curriculum: Concept, Characteristics and Consideration for Planning and Designing. *ILAM इलाम*, 20(1), 176-196.
- Mayes, R., Owens, D., Dauer, J., & Rittschof, K. (2022). A quantitative reasoning framework and the importance of quantitative modeling in biology. *ACM*, 11, 1-17.
- Metz, A. M. (2008). Teaching statistics in biology: using inquiry-based learning to strengthen understanding of statistical analysis in biology laboratory courses. *CBE—Life Sciences Education*, 7(3), 317-326.
- Mishra, A., & Khan, M. M. (2024). The science and art of biostatistics: a comprehensive overview. *Asian Journal of Hospital Pharmacy*, 45-51.
- Nuridin, A. M., Gofur, A., & Sari, M. S. (2025). Technology-supported differentiated biology education: Trends, methods, content, and impacts. *EURASIA Journal of Mathematics, Science and Technology Education*, 21(3), em2598.
- O'Connor, L. J. (2021). The distribution of common-variant effect sizes. *Nature genetics*, 53(8), 1243-1249.
- Olushola, A., Adesiyun, A., Ojo, T., & Alao, V. (2024). Bioinformatics and computational biology: Exploring the role of biomathematics in bioinformatics, including the analysis of biological data and the development of computational tools.
- Rakha, A. H. (2025). Promoting online teaching through active learning strategies: Applications and innovations. *Frontiers in Education*,

- Ramadani, S., Sinaga, P., & Liliawati, W. (2025). Critical Thinking in Science Learning: Systematic Literature Review. *Jurnal Pemberdayaan Masyarakat*, 4(1), 183-196.
- Rezai, A., Ahmadi, R., Ashkani, P., & Hosseini, G. H. (2025). Implementing active learning approach to promote motivation, reduce anxiety, and shape positive attitudes: A case study of EFL learners. *Acta Psychologica*, 253, 104704.
- Robeva, R. S., Jungck, J. R., & Gross, L. J. (2020). Changing the nature of quantitative biology education: Data science as a driver. *Bulletin of Mathematical Biology*, 82(10), 127.
- Roehrig, G. H., Dare, E. A., Ring-Whalen, E., & Wieselmann, J. R. (2021). Understanding coherence and integration in integrated STEM curriculum. *International Journal of STEM Education*, 8(1), 2.
- Sakarna, Y., Kalakota, S., Gottipati, A., Kaviandost, P., Chileveru, K., Bhola, R., & Singh, S. (2025). Applications of Biostatistics in Healthcare. *Public Health, Epidemiology, and Beyond. Saudi J Med*, 10(5), 270-276.
- Simanjuntak, M. B., Suseno, M., Setiadi, S., Lustyantje, N., & Barus, I. R. G. R. G. (2022). Integration of curricula (curriculum 2013 and cambridge curriculum for junior high school level in three subjects) in pandemic situation. *Ideas: Jurnal Pendidikan, Sosial, dan Budaya*, 8(1), 77-86.
- Sultan, M. A. (2025). STATISTICAL ANALYSIS ABOUT DETECTING CERTAIN ELEMENTS THAT AFFECT THE STROKE. *JP Journal of Biostatistics*, 25(2), 325-338.
- Tullis, J. G., & Goldstone, R. L. (2020). Why does peer instruction benefit student learning? *Cognitive research: principles and implications*, 5(1), 15.
- Wang, Y., Hayashibe, M., & Owaki, D. (2024). Data-Driven Policy Learning Methods from Biological Behavior: A Systematic Review. *Applied Sciences*, 14(10), 4038.
- Wibowo, G. A., Karim, A. A., Hasan, S. H., & Ruhimat, M. (2023). Use of Technology in Active Learning: Increasing Student Interaction and Engagement. *Al-Hijr: Journal of Adulern World*, 2(4).
- Wilton, M., Vargas, P., Prevost, L., Lo, S. M., Cooke, J. E., Gin, L. E., Imad, M., Tatapudy, S., & Sato, B. (2022). Moving towards more diverse and welcoming conference spaces: data-driven perspectives from biology education research scholars. *Journal of microbiology & biology education*, 23(2), e00048-00022.
- Yin, H., Duo, H., Li, S., Qin, D., Xie, L., Xiao, Y., Sun, J., Tao, J., Zhang, X., & Li, Y. (2024). Unlocking biological insights from differentially expressed genes: Concepts, methods, and future perspectives. *Journal of Advanced Research*.
- Zhang, Y., Wu, D., Hagen, L., Song, I. Y., Mostafa, J., Oh, S., Anderson, T., Shah, C., Bishop, B. W., & Hopfgartner, F. (2023). Data science curriculum in the iField. *Journal of the Association for Information Science and Technology*, 74(6), 641-662.