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Exploring Academic Advantages: Benefits of Bachelor of Science in Biology with Specialization in Microbiology

[1]Asnar L. Aloro, [2]Michelle T. Flores, [3]Preachy Mae S. Valmonte, [4]Julie Fe D. Panoy, [5]Glaiza Calubiran, [6]Mark Jhon B. Abela
Laguna State Polytechnic University
[1]asnar.aloro@lspu.edu.ph, [2]michelle.flores@lspu.edu.ph, [3]juliefe.panoy@lspu.edu.ph,
[4]preachymae.sanglay@lspu.edu.ph, [5]glaiza.calubiran@lspu.edu.ph, [6]markjhon.abela@lspu.edu.ph

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Corresponding Email:
asnar.aloro@lspu.edu.ph

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Index Terms:

Microbiology education, career opportunities, academic advantage, skills benefits

Abstract. Microbiology plays a pivotal role in advancing healthcare, environmental sustainability, biotechnology, and scientific industries. This study investigates the academic and career benefits of specializing in microbiology within a Bachelor of Science in Biology program. Using a descriptive-correlational design, data were collected from 140 participants—including senior high school students, biology undergraduates, and alumni—through structured surveys. Key findings revealed that microbiology specialization significantly enhances critical thinking (M = 3.82), research competence (M = 3.72), and laboratory skills (M = 3.78). Respondents indicated strong career readiness in fields like public health, biotechnology, and clinical microbiology. However, they also reported limited access to advanced lab tools and low program visibility.The findings underscore the rising demand for microbiologists in sectors such as public health, food safety, and environmental management. Strengthening microbiology education through improved laboratory training, targeted career guidance, and alignment with industry needs is essential to equip graduates for emerging global challenges.

Introduction

Biology plays a crucial role in understanding living organisms, with microbiology emerging as an essential subfield due to its wide-ranging applications in healthcare, environmental sustainability, and biotechnology. Specializing in microbiology within a Bachelor of Science in Biology program offers students' academic advantages and enhances their employability in rapidly evolving scientific and industrial sectors (Lao et al., 2019).

Specialized programs in microbiology equip students with in-demand skills in areas such as microbial genetics, immunology, and microbial ecology, thereby improving their readiness for careers in pharmaceuticals, clinical research, and environmental management (Friedman et al., 2017; Mendoza et al., 2021). Labor market trends also indicate a growing demand for microbiologists due to ongoing advancements in health and environmental sciences. The U.S. Bureau of Labor Statistics (2021) projects a significant rise in microbiology-related careers, a trend echoed in the Philippines, where increased health threats and technological progress have further emphasized the need for microbiology professionals (PCIEERD, 2020).

In response to these trends, the Commission on Higher Education (CHED, 2022) has encouraged the integration of specialized tracks into undergraduate biology curricula to enhance graduate competitiveness in the job market. This study employs a descriptive-correlational research design to examine the educational benefits and employment prospects of microbiology specialization. It aims to inform students, educators, and policymakers by analyzing the academic outcomes and career pathways of biology graduates.

Objectives

This research seeks to offer a thorough insight into the advantages of specializing in microbiology in the Bachelor of Science in Biology program.

This study specifically aims to:

1. Assess how the microbiology specialization enhances students' preparedness for advanced studies by determining how the program strengthens foundational knowledge and academic readiness.
2. Evaluate the program's impact on critical thinking, problem-solving, laboratory proficiency, and research skills to measure how well it develops competencies essential for scientific and technical fields.
3. Examine the relevance and structure of the microbiology curriculum to evaluate its alignment with educational goals and industry expectations.
4. Identify career opportunities for microbiology graduates across various sectors including research, healthcare, industry, and environmental services.
5. Collect insights from students, alumni, and industry professionals to recommend program enhancements that support both academic development and employability.

Methodology

This study's goal is to investigate the educational benefits and advantages of a Bachelor of Science in Biology, focusing on microbiology. The methodology described covers the research design, selection of participants, data collection tools, and analysis methods to be used.

Design of research

A descriptive-correlational research design was employed to assess the relationship between microbiology specialization and various academic and professional outcomes (Creswell & Creswell, 2017). This non-experimental method allows for the systematic analysis of variables without manipulation. The study targeted three groups of participants: (1) senior high school students intending to pursue biology with a microbiology focus, (2) current Bachelor of Science in Biology students, and (3) alumni who graduated within the last five years. These groups were surveyed to capture both prospective and retrospective insights into the academic and career impacts of the specialization.

Instruments for gathering data

A structured survey questionnaire was developed, comprising three sections: demographic information (e.g., age, gender, academic level), academic perception items (e.g., knowledge acquisition, skill development), and career relevance items (e.g., employment type, industry preparedness). Items were rated using a 5-point Likert scale.
To ensure reliability and validity, the instrument underwent pre-testing with a small sample ($n = 15$) representing the target population. Cronbach's Alpha was computed to assess internal consistency, yielding an acceptable reliability coefficient ($\alpha = 0.87$). Content validity was established through expert review by three faculty members with backgrounds in microbiology and educational research.

Data Analysis

Data were encoded and analyzed using IBM SPSS Statistics version 25 (Field, 2018). Descriptive statistics (frequencies, means, SDs), cross-tabulations, and comparative mean analyses were applied to interpret trends across demographic groups and academic levels. Content validity was confirmed via expert review, and instrument reliability was validated through Cronbach's Alpha ($\alpha = 0.87$) from pre-test data ($n = 15$).

Ethical Consideration

This study adheres to established ethical standards in research involving human participants. Informed consent was obtained from all respondents, who were fully briefed on the study's purpose, procedures, and their voluntary participation. Participants were assured of the confidentiality and anonymity of their responses, and were informed of their right to withdraw from the study at any stage without penalty or consequence.

Significance of the Study

The study investigates how specialized education in microbiology prepares graduates with knowledge and skills to address critical issues in healthcare, environmental conservation, and biotechnology. With an emphasis on disease prevention and sustainable practices, this specialization enhances career opportunities. Graduates play vital roles in public health and food security, promoting economic stability and societal well-being through targeted education that fosters innovation and sustainability.

Results and Discussion

This section presents the result, the analysis, and the interpretation of data gathered from the experiment conducted by the researcher. The said data were presented in tabular form in accordance with the specific data the researchers gathered.

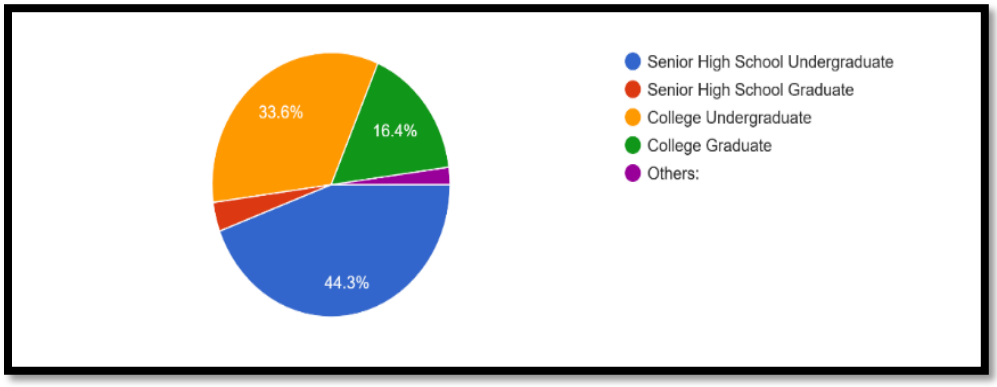

Figure 1: Distribution of Respondents by Educational Level (n = 140)

Figure 1 shows that out of 140 respondents, 44.3% (n = 62) were senior high school students, 33.6% (n = 47) were college undergraduates, and 16.4% (n = 23) were college graduates, while the remaining 5.7% (n = 8) identified as "others." The high proportion of senior high school participants emphasizes the importance of evaluating how early exposure to microbiology can support preparedness for higher education. As most are still at the beginning of their academic paths, understanding how microbiology specialization fosters relevant competencies is essential.

This finding supports the work of Savoca et al. (2023), who emphasized that early exposure to specialized science education significantly enhances students' interest in STEM careers and their preparedness for advanced academic pathways. In parallel, the insights of college-level students and alumni offer valuable evidence on how microbiology education cultivates essential competencies such as critical thinking, problem-solving, laboratory proficiency, and research skills—core elements that are effectively developed through inquiry-based learning models (Dah et al., 2024).

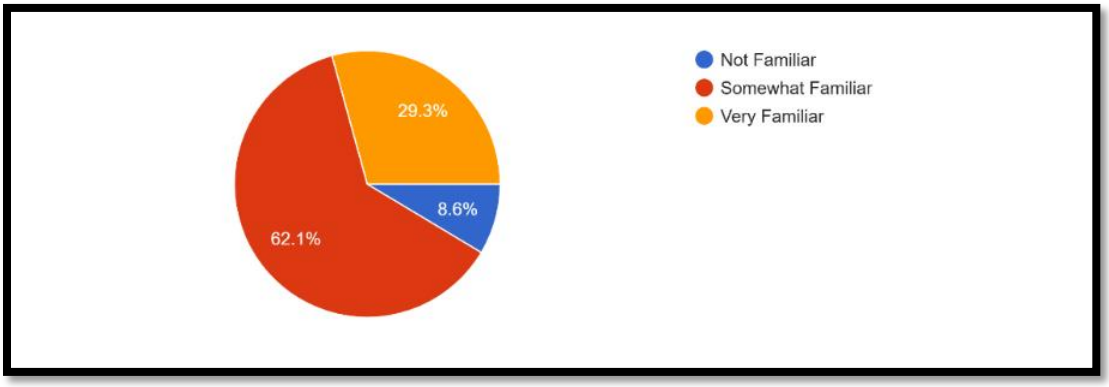

Figure 2: Familiarity of the program

According to Figure 2, 62.1% (n = 87) of respondents reported being "somewhat familiar" with the microbiology specialization, 29.3% (n = 41) were "very familiar," and 8.6% (n = 12) indicated no familiarity. While the majority have at least some knowledge of the program, a relatively low percentage fully understand its academic and professional scope.

These findings suggest a need for targeted science communication, academic advising, and practical exposure opportunities (e.g., orientation sessions or lab immersion) to help bridge the knowledge gap. Doing so may encourage more students to consider microbiology as a specialization and career path; ultimately cultivating a more scientifically engaged and prepared student population.

The evidence shows that while a considerable proportion of respondents have some degree of awareness regarding the Bachelor of Science in Biology specializing in Microbiology program, an overall lack of understanding remained. Efforts in science communication, career counseling, and offering hands-on opportunities may be undertaken to mitigate this prevailing climate and consequently inform students of the program's advantages and possible careers. Recognizing this shift could help boost enrollment and cultivate a more enlightened student body, better prepared for careers in Microbiology and related fields. This limited familiarity may restrict students' capacity to make well-informed decisions about pursuing microbiology as a specialization. As noted by Chen et al. (2024), awareness and comprehension of academic pathways play a critical role in shaping students' self-efficacy and career planning. Similarly, Amalina et al. (2025) underscore that early, purposeful exposure to STEM disciplines significantly increases the likelihood of students engaging in related academic and professional fields.

	MEAN	**SD**
It is encouraging to critically analyze and discuss scientific articles or research papers in microbiology courses.	**3.56**	**0.603**
It is challenging to apply microbiological concepts to novel or real-world problems.	**3.04**	**0.864**
I believe the program will help develop the ability to approach biological problems from multiple perspectives (e.g., ecological, molecular, evolutionary).	**3.76**	**0.507**
I often work on solving open-ended problems or case studies in microbiology courses.	**2.93**	**0.828**
I develop a work plan that would prepare me to approach problems that require interdisciplinary knowledge.	**3.04**	**0.817**
I frequently have the opportunity to work with advanced laboratory equipment and technologies, such as spectrophotometers, gel electrophoresis, chromatography, PCR, microscopy, and bacterial culturing.	**2.58**	**0.997**
I can independently design and conduct experiments in laboratory courses.	**2.67**	**0.963**
I believe that the program provides opportunities to present research findings (e.g., posters, presentations, reports)	**3.64**	**0.578**
Average Mean	**3.15**	

Legend: 0-1.0 = Strongly Disagree; 1.01 - 2.0 = Disagree; 2.01-3.0 = Agree; 3.01-4.0 = Strongly Agree

Table 1: Student Perceptions of the Academic Impact of the Microbiology Program

The Bachelor of Science in Biology with specialization in Microbiology impacts most and least students in the learning experiences captured in Table 1. The statement with the highest rating, as can be seen from the score (M = 3.76, SD = 0.507), has a strong indication that students perceive the program to have helped them approach biological problems from various perspectives, such as ecological, molecular, or evolutionary viewpoints. This confirms from Amanda et al. (2024) in the sense that interdisciplinary approaches should accompany biology education for the best critical thinking and problem-solving skills.

On the contrary, the lowest rated statement (M = 2.58, SD = 0.997) proves that students have been limited from working with sophisticated laboratory equipment and technologies like spectrophotometry, gel electrophoresis, chromatography, PCR, and bacterial isolation and identification, implied that, very little hands-on experience had been practiced by the students. Concern for this was brought into light by Rafanan and De Guzman (2020), who defined this limitation: "A significant challenge for STEM education is that minimal opportunities to engage in hands-on laboratory activities may diminish students' technical abilities in readiness for their future careers".
Thus, the program has an average mean of 3.15, a representation of the general strong agreement of students toward the favorable impacts of such a program, yet with some areas needing further development, most especially in laboratory accessibility. These hands-on experiences alongside advanced tools in the laboratory may add to strengthening the students' practical skills and overall career preparation for becoming microbiologists.

ANOVA[a]

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	29.605	8	3.701	7.809	.000[b]

Residual	62.081	131	.474
Total	91.686	139	

Dependent Variable: Educational Level
Predictors: (Constant), Student Perceptions of the Academic Impact of the Microbiology Program

Table 2. Statistical Analysis to Predict Student Perceptions of the Academic Impact of the Microbiology Program Based on Educational Level

Table 2 shows the ANOVA results on how students' educational level shapes their views on the Microbiology program. The analysis emphasizes that differences in educational level significantly impact students' perceptions, with a strong predictive relationship reflected in an F-value of 7.809 and a significance level of 0.000, meaning this connection is highly reliable. The model accounts for a meaningful portion of the variance (29.605) across different levels, while some variation (62.081) remains unexplained. Overall, the findings highlight the role education plays in shaping students' experiences and perspectives, offering valuable insights for refining academic programs to better meet their needs.

		MEAN	SD
1.	It will provide strong career prospects, research interest, desire for healthcare, gain knowledge, specialized courses, and expert faculty	**3.70**	**0.864**
2.	I believe that a microbiology specialization would enhance readiness for professional careers (e.g., in medical microbiology, public health, environmental science)	**3.76**	**0.507**
3.	It is vital to have the choice to focus on microbiology in my undergraduate studies.	**3.46**	**0.828**
4.	It will provide me with an understanding of microbiology concepts (e.g., microbial cell structure, microbial metabolism, genetic recombination)	**3.70**	**0.817**
5.	It is vital in order to understand how to conduct laboratory techniques utilized in microbiology, such as culturing, microscopy, PCR, and ELISA.	**3.67**	**0.997**
6.	Microbiology can be pursued through a track, an elective pathway, double specialization, or a full major. *(General microbiology, medical microbiology, Environmental microbiology, Virology, Microbial genetics, Immunology, Microbial biotechnology, Industrial microbiology)*	**3.60**	**0.963**
7.	I prefer to have an opportunity for hands-on research or laboratory-based internships as part of the microbiology specialization.	**3.63**	**0.578**
8.	Microbiology specialization would enhance the ability to pursue these career paths and increase the interest in pursuing a Bachelor of Science in Biology.	**3.69**	**0.535**
Average Mean		**3.65**	

Legend: 0-1.0 = Not Important; 1.01 - 2.0 = Somewhat Important 2.01-3.0 = Important; 3.01-4.0 = Very Important

Table 3: Perceived Benefits of Offering a Microbiology Specialization among Students

From the data presented in Table 3, students' perceptions of the value and benefits of having a specialized microbiology track in a Bachelor of Science in Biology program are analyzed. The overall average mean of 3.65 suggests that nearly all the respondents strongly agree on the value of a microbiology specialization for career advancement, practical laboratory skills, and academic engagement.

The most positive statement received the highest rating (M = 3.76, SD = 0.507), which says that a microbiology specialization prepares students for professional careers in medical microbiology, public health, and environmental sciences. Reid and Greene (2025) affirm what we have stated; that is, training in specialized areas of microbiology makes the students competent for research, healthcare, or industry with appropriate skills and knowledge related to those areas. Furthermore, Wang et al (2022) supports this idea by stating that there is increasing demand for microbiology professionals and the necessity for career-based training in biotechnology, epidemiology, and clinical diagnostics.

While the statement about the importance of having the option of focusing on microbiology in their undergraduate studies attracted the lowest rating overall (M = 3.46, SD = 0.828), one possible explanation is that although this statement still lies in the strongly agree range, it indicates slightly less priority regarding career readiness. One interpretation that might arise is that while students value specialization, they also recognize that it is critical to develop a broad biology background before focusing on specialization. According to Miller et al. (2024), undergraduate students benefit instead from exposure to several biological disciplines before committing to a specialization, which could help explain the lower mean.

An overall average mean of 3.65 shows that the students strongly urge the introduction of a microbiology specialization as a good idea. Galvex et al. (2024) show a similar idea that students enrolled in specialized scientific programs reported

greater motivation, skill development, and clarity in their career options. This result further highlights the necessity of practical exposure through research work, laboratory internships, and professional career preparation to maximize student engagement and employability in microbiology areas.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	21.658	8	2.707	5.064	.000[b]
	Residual	70.028	131	.535		
	Total	91.686	139			

a. Dependent Variable: Educational Level

b. Predictors: (Constant), Perceived Benefits of Offering a Microbiology Specialization among Students

Table 4. Statistical Analysis to Predict the Perceived Benefits of Offering a Microbiology Specialization among Students Based on Educational Level

The table 4 presents the results of an ANOVA (Analysis of Variance) test, which examines the relationship between educational level and students' perceptions of the benefits of a microbiology specialization. The regression statistics indicate that the model explains a sum of squares of 21.658, with a mean square value of 2.707 derived from dividing the sum by the degrees of freedom (df = 8). Meanwhile, the residual sum of squares is 70.028, representing unexplained variance. The F-statistic, calculated at 5.064, assesses the significance of the regression model, suggesting a notable relationship between the variables. Most importantly, the significance level (p-value = 0.000) confirms that the results are statistically significant, implying that educational level plays a crucial role in shaping students' views on microbiology specialization. These findings provide valuable insights for institutions aiming to refine their curriculum based on academic backgrounds.

	MEAN	**SD**
Detailed understanding of microbiology principles	**3.80**	**0.507**
Proficiency in the laboratory and hands-on practice	**3.78**	**0.828**
Have a chance to conduct research and try out new ideas.	**3.71**	**0.817**
Use specialized equipment and advanced technologies	**3.76**	**0.997**
Getting ready for higher education	**3.76**	**0.963**
Enhance skills in analyzing, thinking critically, comprehension, and utilization of methods in microbiology	**3.82**	**0.578**
Capability to carry out research independently	**3.72**	**0.496**
Getting ready for advanced studies at the graduate level.	**3.79**	**0.505**
Average Mean	**3.77**	

Legend: 0-1.0 = Not Important; 1.01 - 2.0 = Somewhat Important 2.01-3.0 = Important; 3.01-4.0 = Very Important

Table 5: Academic Advantages of Choosing a Specialization in Microbiology

Table 5 shows the perceived importance, contribution, and academic benefits of choosing a specialization in microbiology. The overall average mean of 3.77 suggests that respondents strongly recognize the academic value of microbiology specialization, particularly in enhancing knowledge, research skills, and preparation for higher education.

With an average M of 3.82 and an SD of 0.578, the highest-rated statement asserts that microbiology specialization will help develop skills of analysis, critical thinking, and application of microbiological methods. This is congruent with Puig & Jimenez-Aleixandre (2022), who noted that biology education, particularly that of microbiology, engenders critical thinking when students are asked to interpret experimental results, troubleshoot scientific problems, and apply theoretical concepts to real-world scenarios. Kotsis (2024), too, underlines that inquiry-based learning in microbiology courses allows students to develop problem-solving abilities and analytical reasoning relevant to research and professional practice.

The lowest-rated statement (M = 3.71, SD = 0.817) pertains to having the chance to conduct research and try new ideas. While still very important, the slightly lower mean seems to indicate that students value having research opportunities, but their perceptions are limited in terms of access to independent research projects. Buffalari et al. (2020) also found that students engaged in undergraduate research experiences reported increased confidence in their scientific reasoning skills and a deeper appreciation of scientific methodologies. Such endeavors would strengthen students' abilities to develop and test novel scientific ideas through the greater expansion of undergraduate research in microbiology.
In general, with an overall average of 3.77, these findings suggest that students consider microbiology specialization to be of great advantage, especially for knowledge acquisition, research ability, laboratory skills, and preparation for graduate

school. This corroborates Fatton et al. (2021), who contend that specialized microbiology programs afford students hands-on experiences that promote scientific literacy, technical skills, and preparedness for advanced study. This suggests that expanding research opportunities and hands-on laboratory training may maximize the academic benefits accruing from microbiology specialization.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	19.946	8	2.493	4.553	.000[b]
	Residual	71.739	131	.548		
	Total	91.686	139			

a. Dependent Variable: Educational Level

b. Predictors: (Constant), Academic Advantages of Choosing a Specialization in Microbiology

Table 6. Statistical Analysis to Predict Academic Advantages of Choosing a Specialization in Microbiology Based on Educational Level

The ANOVA test in Table 6 shows whether specializing in microbiology leads to significant academic differences based on educational level. The regression sum of squares (19.946) represents the variation explained by the model, showing that educational level plays a measurable role in academic advantages. The F-value (4.553) indicates the strength of the relationship between specialization and academic success, while the significance level (Sig. = 0.000) confirms that the differences are statistically meaningful and not due to chance. Meanwhile, the residual sum of squares (71.739) represents unexplained variation, capturing other influencing factors outside the model. The total sum of squares (91.686) combines both explained and unexplained variations, reinforcing the conclusion that microbiology specialization impacts academic performance differently based on educational background.

	MEAN	**SD**
The most readily available position is as a Research Scientist.	**3.24**	**0.828**
Easiest to reach as a Clinical Microbiologist.	**3.32**	**0.817**
Highly available as an Environmental Consultant	**3.20**	**0.997**
Most reachable as a Public Health Specialist.	**3.26**	**0.963**
Mainly available in Academic/Teaching Roles.	**3.38**	**0.578**
Competitive nature of the job market.	**3.21**	**0.774**
Opportunities for advancing in one's career and moving up in position.	**3.41**	**0.505**
Potential to earn a salary increase.	**3.49**	**0.469**
Average Mean	**3.31**	

Legend: 0-1.0 = Unlikely; 1.01 - 2.0 = Somewhat Likely; 2.01-3.0 = Likely; 3.01-4.0 = Very Likely

Table 7: Perceived Career Opportunities and Advancement in Microbiology-related Fields

The Table 7 data reflect how students perceive career opportunities in microbiology. The overall average mean of 3.31 indicates that respondents think careers associated with microbiology are very likely to be attainable, although some may be considered easier to access than others. The highest-rated statement (M = 3.49, SD = 0.469) emphasizes that students may feel that pursuing microbiology as a field of specialization is highly likely to lead to higher earnings and salary growth. This is according to labor market trends; Putnam and Johnson (2023) reported that careers in clinical microbiology and biotechnology, public health call on an increasing number of professionals who have demonstrated skills in infections, laboratory diagnostics, and research, potentially bringing about competitive salaries. Similarly, Heggeness et al. (2023) showed that microbiologists who belong to pharmaceutical and industrial microbiology sections sometimes accumulate much higher compensation than their counterparts in other specialties within the same section, because they require very specialized skills.

The lowest-rated statement, on the other hand (M = 3.20, SD = 0.997) pertains to available microbiology roles as Environmental Consultants. Although it is still likely that a below-average score might imply that students see environmental microbiology as a narrower and competitive subject compared to others. According to Qumsani (2024), environmental microbiology is said to play a significant role in climate change, waste management, and ecosystem restoration courses, but it is not as visible or promoted in terms of employment opportunities as much as clinical and industrial microbiology branches are.

As the findings prove, with an average mean of 3.31, the students see microbiology as a field with good career opportunities especially in teaching, research, clinical microbiology, and public health. This reflects the findings of Kumar et al. (2022), who emphasized the rising potential that has been seen for microbiologists in biotechnology and healthcare within academic and industrial contexts, especially concerning global issues like emerging infectious diseases and antimicrobial resistance. Enhanced career guidance and professional training towards specialized areas of microbiology can help students navigate and optimize their career opportunities.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16.969	8	2.121	3.719	.001[b]
	Residual	74.716	131	.570		
	Total	91.686	139			

a . Dependent Variable: Educational Level

b. Predictors: (Constant), Perceived Career Opportunities and Advancement in Microbiology-related Fields

Table 8. Statistical Analysis to Predict the Perceived Career Opportunities and Advancement in Microbiology-related Fields

This table 8 presents a statistical analysis using ANOVA (Analysis of Variance) to predict perceived career opportunities and advancement in microbiology-related fields based on educational level. The model includes regression, which measures the influence of predictors, and residual, which represents unexplained variance. The sum of squares shows the variation in data, where 16.969 is explained by regression, while 74.716 remains unexplained. The mean square represents the average variance per degree of freedom, calculated as 2.121 for regression and 0.570 for residual. The F-value of 3.719 is a crucial statistical measure testing whether the predictors significantly impact the dependent variable. The significance level of 0.001 suggests a strong statistical relationship, meaning career opportunities and advancement perceptions significantly influence educational level choices. This indicates that higher education may correlate with better perceived career prospects in microbiology-related fields, emphasizing the importance of education in shaping career trajectories.

Conclusion and Recommendations

This study concludes that specializing in microbiology within a Bachelor of Science in Biology program offers substantial academic and career-oriented advantages. Based on survey responses from 140 participants—including senior high school students, undergraduates, and alumni—the program was perceived to significantly enhance critical thinking, research competence, and laboratory skills. This study confirms that the Bachelor of Science in Biology with a Microbiology specialization meets its educational and professional objectives. It enhances analytical reasoning, lab and research proficiency, and career readiness—especially in high-demand fields such as biotechnology and public health. These align with the research's goal of evaluating academic advantages, industry relevance, and graduate preparedness.

To fully realize its potential, the program must strengthen laboratory access, expand career guidance initiatives, and foster stronger connections with industry and research sectors. In doing so, it can better support student engagement, academic achievement, and employability in an increasingly science-driven world.

Recommendation

Based on the findings and conclusions of this study, the following suggestions are made to improve the Bachelor of Science in Biology with a focus on Microbiology program:

1. Students may be offered elective courses aligned with their career interests in microbiology (e.g., medical microbiology, environmental microbiology, biotechnology).
2. Career orientation sessions and professional development workshops may be conducted to help students explore diverse career paths in microbiology, including roles in research, clinical settings, and industry.
3. Awareness campaigns, seminars, and information sessions may be launched to inform students about the significance, benefits, and career opportunities associated with a microbiology specialization.
4. For medium strategies, undergraduate research initiatives may be strengthened through project-based learning, internship programs, and thesis opportunities. Faculty-student collaborations on microbiology-related investigations may also be promoted to enhance critical thinking and problem-solving skills.
5. For Long-Term Strategies, stronger collaborations may be established with industries, research organizations, and healthcare institutions to provide internships, mentorship, and job placement support.
6. Laboratory facilities may be upgraded with advanced microbiological equipment and technologies to enhance students' practical experience and professional readiness.

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Competing Interests Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study; all data used were obtained from previously published sources as cited in the reference list.

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Appendices

No appendices are attached to this study.