Global Research in Higher Education
ISSN 2576-196X (Print) ISSN 2576-1951 (Online)
Vol. 9, No. 1, 2026
www.scholink.org/ojs/index.php/grhe

Original Paper

Construction and Practice of a Teaching Model for the Bacterial Gram Staining Experiment from a Project-Based Perspective

Huixia Zhang[1], Xin Zhong[2*], Xiaohong Chen[1], Chang Guo[1] & Binxiu Liao[3]

[1] College of Life Sciences, Longyan University, Longyan, China

[2] College of Physics and Mechanical & Electrical Engineering, Longyan University, Longyan, China

[3] College of Chemistry and Materials Science, Longyan University, Longyan, China

Received: December 20, 2025 Accepted: December 25, 2025 Online Published: January 8, 2026

doi:10.22158/grhe.v9n1p15 URL:http://dx.doi.org/10.22158/grhe.v9n1p15

Abstract

In alignment with the talent development goals of Environmental Engineering under the framework of Emerging Engineering Education, this study aims to improve the practical relevance and overall effectiveness of microbiology laboratory teaching. Using the bacterial Gram staining experiment as a representative case, an integrated teaching model was designed and implemented by combining project-based learning, experimental inquiry, result presentation, and feedback-oriented evaluation. The model was applied to second-year undergraduate students majoring in Environmental Engineering within an authentic project context related to soil microbial analysis. Students completed a structured sequence of tasks, including soil sample collection, microbial isolation and cultivation, Gram staining, and microscopic observation. A multi-dimensional assessment system was established to evaluate students' experimental operation skills, the quality of laboratory reports and group presentations, and learning attitudes, enabling a comprehensive evaluation of teaching outcomes. The results indicate that the proposed model standardized experimental procedures and enhanced the clarity, coherence, and rigor of laboratory records and reports. Compared with traditional teaching methods, both pass rates and excellence rates in experimental assessments improved. Students reported higher motivation, stronger problem-solving ability, better teamwork, and clearer understanding of engineering applications.

Keywords

New engineering education, Project-based learning, Bacterial gram staining, Engineering practice

1. Introduction

With the continuous advancement of emerging engineering education, cultivating interdisciplinary talents with engineering innovation capabilities and strong practical competence has become a crucial task in the reform of higher education in China (Li, M. Q., Xi, P., Wang, Q. S. et al., 2025, pp. 139-143). The Ministry of Education has clearly stated that engineering education should shift from the traditional "knowledge-transmission-oriented" model to "competency-oriented" and "innovation-driven" models, to respond to the practical needs of national scientific and technological innovation and the strategy of strengthening the nation through talent development (Ji, W. Y., Liu, Z. S., & Yang, L., 2025, pp. 76-80). Under this context, experimental teaching is regarded as a key component of the engineering education system for enhancing students' scientific research thinking and engineering awareness. The integration of theory and experimentation characterizes the microbiology course, and its teaching effectiveness directly affects the quality of talent cultivation under the framework of emerging engineering education. The Gram staining experiment is a core component of the "Morphological Observation of Microorganisms" course. It not only serves as the starting point for students to master basic experimental skills, but also plays an important role as a bridge connecting biological theory with engineering applications. However, in current experimental teaching at universities, problems such as weak hands-on ability among students, a disconnect between teaching content and real engineering contexts, and insufficient cultivation of innovative awareness are still widespread (Li, M. Q., Xi, P., Wang, Q. S. et al., 2025, pp. 139-143; Ji, W. Y., Liu, Z. S., & Yang, L., 2025, pp. 76-80). Therefore, constructing an experimental teaching model aligned with the concept of emerging engineering education has become a key breakthrough for improving teaching quality and the level of innovative talent cultivation.

Traditional microbiology experimental teaching often relies on teacher explanations and procedural training, with students remaining largely passive recipients in the classroom and lacking opportunities for active exploration and independent thinking (Bian, S. Q., Liu, Y. F., Wang, L. N. et al., 2025, pp. 75-80). Especially in bacterial morphology teaching, instructional content frequently focuses on the repetitive execution of operational procedures, without guiding students to recognize the practical value of experimental outcomes in engineering applications (Du, L. N., Wu, M., Yang, J. et al., 2020, pp. 1278-1285; Tian, Y. H., 2017, pp. 44-46). This single teaching approach weakens students' learning interest and innovative potential, and limits the development of their interdisciplinary thinking ability (Tang, X. F., & Chen, X. D., 2024, pp. 1051-1054; Gong, S. F., Fang, Y. Y., Hu, H. H. et al., 2025, pp. 1-8). To address these shortcomings, this study introduces the Project-Based Learning (PBL) approach, utilizing "soil microbial difference analysis" as a real-world task to construct a task-oriented learning process. Students work in teams to complete experimental design, sample processing, cultivation and observation, and result analysis. Under teacher guidance and feedback, a learning cycle of "problem-driven inquiry—exploratory research—reflective reinforcement" is formed. Through this process, students deepen their understanding of theory through practice, stimulate innovative thinking, and achieve a transformation from knowledge acquisition to competence construction (Bian, S. Q., Liu, Y. F., Wang, L. N. et al., 2025, pp. 75-80; Du, L. N., Wu, M., Yang, J. et al., 2020, pp. 1278-1285; Tian, Y. H., 2017, pp. 44-46).

To further enhance teaching effectiveness, this study integrates hierarchical teaching, multimedia instruction, and virtual simulation experimental teaching into the project-driven teaching model, making experimental teaching more visualized and intelligent (Guo, H., Jin, Y., Li, Z. R. et al., 2022, pp. 75-78; Xu, Y. Y., Li, W. R., & Wang, X. S., 2021, pp. 125-128). The overall process of project-driven teaching is shown in **Fig. 1**, which divides teaching into four stages: project design, experimental exploration, presentation, and evaluation of results, forming a closed-loop system. Teachers use virtual simulation technology to demonstrate bacterial morphology, structure, and experimental procedures, while students conduct simulated experiments through virtual platforms to operate, learn, understand, and master the content. Multimedia tools are applied to virtually educate students on engineering applications of bacteria in environmental pollution remediation, food science, and clinical practice, enabling students to emphasize knowledge transfer and application internalization during the integrated process of "learning" and "practice" (Gong, S. F., Fang, Y. Y., Hu, H. H. et al., 2025, pp. 1-8; Guo, H., Jin, Y., Li, Z. R. et al., 2022, pp. 75-78; Xu, Y. Y., Li, W. R., & Wang, X. S., 2021, pp. 125-128). In the teaching evaluation stage, the evaluation system in this study mainly consists of experimental skills, experimental reports, teamwork, and innovative solutions. By combining formative and summative assessments, students' entire learning process and innovative learning abilities are comprehensively evaluated (Hu, Q., Wang, C., Huang, Y. P. et al., 2021, pp. 223-227; Xie, Y. X., Bi, M. X., Sun, Y. H. et al., 2025, pp. 134-137). This evaluation approach emphasizes the main role of students in learning, objectively reflects learning outcomes, and provides a basis for teaching improvement and adjustment.

The analysis shows that the implementation of a project-driven teaching model based on Gram staining is conducive to improving students' abilities in experimental design, result analysis, and expression, enhancing active participation and creativity in experiments, and promoting a high degree of integration between theory and practice in experimental teaching. It effectively improves students' ability to solve complex engineering problems and embodies the principles of emerging engineering education: "student-centered, problem-oriented, and practice-based." As a replicable and referential teaching model, it provides a valuable approach for reforming microbiology experimental teaching and plays a positive demonstrative role in cultivating modern scientific and technological talents with an innovative spirit and practical ability.

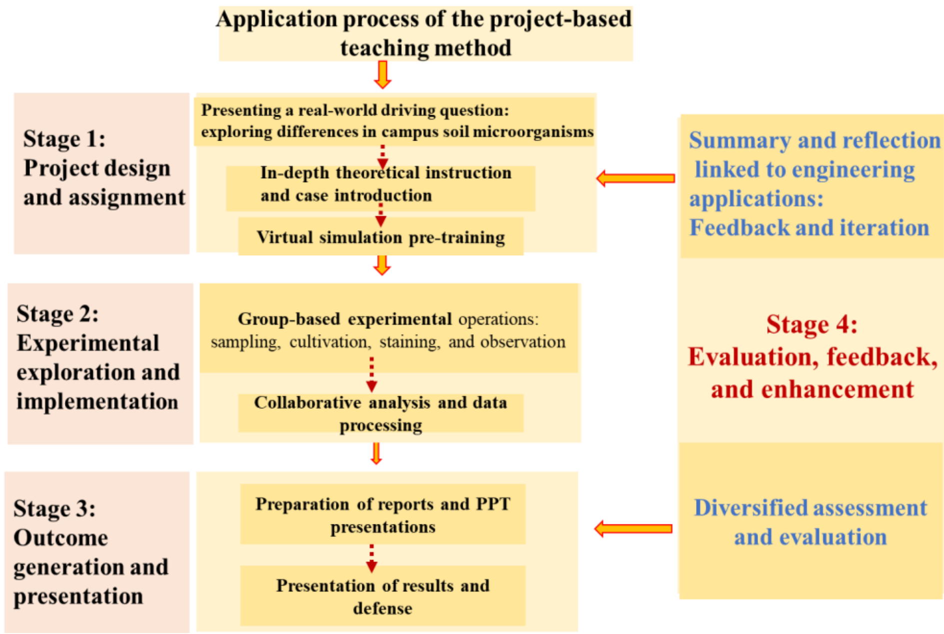


Figure 1. Optimization of the Bacterial Gram Staining Experiment through Project-Based Teaching

2. Research Content

2.1 Project Design and Assignment

(1) Project Conception and Problem-Driven Design

This experiment was conducted in accordance with the project-oriented teaching philosophy, emphasizing students' central role in the learning process. By setting real and open-ended driving questions, students' learning initiative is stimulated, thereby cultivating their abilities in comprehensive analysis and innovative practice (Ashiq, K., 2023, p. 2). In this study, "comparing differences in soil microorganisms across different areas of the campus" was selected as the core task. Combined with the bacterial Gram staining experiment, students were guided to analyze the morphological characteristics and survival conditions of microorganisms in different soil types.

The topic selection was grounded in real campus scenarios, such as flowerbeds, playgrounds, and tree-lined pathways, which are convenient for sampling and observation, thus enhancing the learning experience. Moreover, it aligns with the goals of ecological civilization construction, fully demonstrating the role of microorganisms in agricultural production, pollution remediation, and ecological protection, and strengthening students' sense of social responsibility. In terms of problem design, openness was emphasized, and students were encouraged to propose and verify hypotheses based on environmental parameters such as soil moisture and vegetation cover, thereby fostering scientific inquiry and critical thinking skills.

The teaching team integrated relevant policy contexts, including the “14th Five-Year Plan,” to ensure that the project was both scientifically sound and regionally distinctive. Through the use of heuristic questioning, such as asking “Why do microbial communities differ among different soil environments?”, students’ curiosity and desire for exploration were stimulated, helping them develop practical competencies that align with the objectives of emerging engineering education.

(2) Theoretical Instruction and Case Introduction

To strengthen theoretical support and enhance students’ learning motivation, the course carefully constructed a systematic teaching framework following the model of “in-depth theoretical instruction—case analysis—skills training,” with a particular emphasis on improving microscopic observation skills (**Fig. 2**). The teaching content focused on the principles and procedures of Gram staining, supplemented by animations and three-dimensional models to demonstrate differences in cell wall structures, thereby helping students gain a more intuitive understanding of the staining mechanism.

Teachers provided step-by-step instruction on techniques such as microscope light source adjustment, objective lens selection, and focusing control, ensuring that students mastered the 规范 procedures for microscopic observation. Classroom interaction was mainly conducted through question-and-answer sessions and group discussions (e.g., discussions on “staining errors and improvement methods”), fostering students’ abilities to analyze and solve problems.

The selected cases combined scientific rigor with practical relevance, including typical application examples such as the degradation of petroleum hydrocarbons by Pseudomonas and nitrogen fixation by Rhizobium. These cases were further integrated with research on local soil samples to demonstrate the value of microbiology in green development and ecological restoration. By introducing achievements made by domestic research teams in areas such as biofertilizers and desertification control, students’ enthusiasm for contributing to national scientific and technological advancement was stimulated. These cases were presented in the form of videos and images, further enhancing their visual impact and student engagement, and guiding students to closely link experimental learning with the practical needs of societal development.

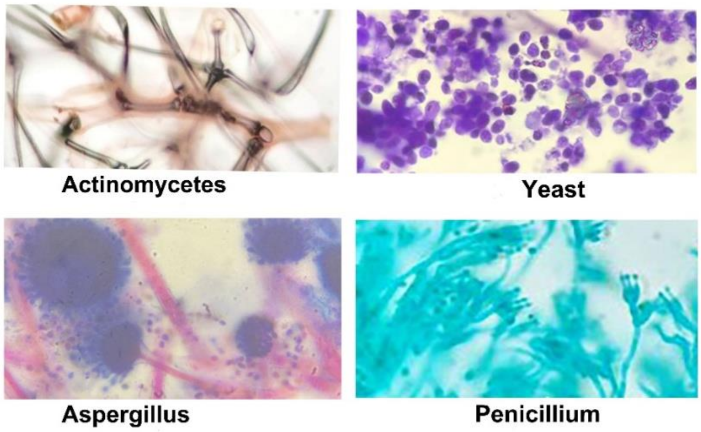


Figure 2. Guidance for Students on Using a Microscope to Observe Microorganisms

(3) Virtual Simulation Rehearsal

As the Gram staining experiment involves relatively complex procedures and high operational requirements, a virtual simulation platform was introduced to help students become familiar with the experimental steps before conducting the actual experiment, thereby reducing potential errors. The system simulates key procedures such as smear preparation, staining, and microscopic observation. Students can identify and correct operational problems in real time, such as false-negative results caused by excessive decolorization time, and gradually develop correct experimental thinking.

The simulation platform also integrates parameters of various soil types, enabling students to analyze the influence of different environmental factors on microbial distribution and to preliminarily construct experimental hypotheses. This approach reduces experimental risks and reagent consumption, shortens the learning curve, and effectively reflects the developmental trend of integrating information technology with engineering education. The virtual simulation sessions were arranged for 1–2 class hours after the completion of theoretical instruction, and each student was required to complete at least three simulation operations.

(4) Group Role Assignment, Task Implementation, and Summary

The project was implemented through group-based collaboration, with each group consisting of 4–6 students. Roles were assigned according to individual interests and strengths, such as sampling leader, operator, recorder, report writer, and coordinator, forming a clear division of labor. Each group collected 3–5 soil samples from different areas of the campus, completed Gram staining and data analysis, explored the relationships between microbial community characteristics and environmental factors, and presented their outcomes through experimental reports and oral presentations.

Task design emphasized autonomous inquiry and collaborative learning, strengthening students' abilities in research design, data analysis, and scientific communication. Through the research process, students deepened their understanding of microbial ecological functions while enhancing their awareness of ecological protection and sustainable development. This project was advanced along the main line of "problem-driven learning—theoretical support—simulation rehearsal—collaborative inquiry," thereby establishing a student-centered teaching model that equally emphasizes theory and practice. This model not only improves students' research and engineering competencies but also integrates ecological civilization and patriotic education throughout the implementation process, providing a practical example for the reform of emerging engineering education.

2.2 Experimental Exploration and Implementation

(1) Soil Sampling and Environmental Observation

Soil sampling is a critical initial step in microbiological experiments. Students were required to work in groups to collect surface soil samples from different areas of the campus (such as flowerbeds, lawns, and woodland areas). Samples were taken from a depth of 0–10 cm, with an approximate weight of 50 g each, using sterile shovels and sealed bags to prevent cross-contamination.

Before sampling, relevant environmental parameters were recorded, including soil moisture measured with a hygrometer, ambient temperature recorded with a thermometer, and soil pH determined using pH test strips or appropriate instruments (typically ranging from 4.5 to 8.0). In addition, the type of vegetation cover (e.g., herbaceous plants, shrubs, or bare ground) was carefully noted (**Fig. 3**). For example, flowerbed soils often contain abundant organic matter (such as decomposed leaves or fertilizers), resulting in relatively higher microbial abundance, whereas lawn soils, due to frequent mowing, tend to exhibit lower community diversity.

This process not only helped students master standardized sampling methods but also trained them to analyze the relationships between environmental factors and microbial distribution. Students also recorded the geographic coordinates of each sampling site, the specific sampling time (September 2, 2025, autumn, sunny), and the prevailing weather conditions, providing solid data support for subsequent experiments and reflecting the systematic and rigorous nature of scientific research.

Figure 3. Group-based Soil Sampling

(2) Microbial Cultivation and Colony Observation

Collected soil samples were homogenized with sterile water at a 1:10 (w/v) ratio to prepare soil suspensions, followed by serial dilution (10^{-3} to 10^{-6}) to obtain appropriate microbial concentrations. Aliquots (0.1 mL) of each dilution were aseptically spread onto nutrient agar plates using sterile pipettes. Plates were incubated at 28–30℃ for 24–48 h under aerobic conditions. All plates were incubated in an inverted position to prevent condensation-related contamination, and colony development was monitored at regular intervals. Following incubation, colony morphology was assessed based on size, color, margin characteristics, surface texture, and colony count. Reference strains, Staphylococcus aureus (Gram-positive) and Escherichia coli (Gram-negative), were included as controls and produced characteristic golden-yellow circular colonies and gray-white opaque colonies, respectively. All procedures were performed adjacent to an alcohol flame to reduce airborne contamination (**Fig. 4**). The resulting cultures provided representative and reproducible microbial isolates suitable for subsequent Gram staining and microscopic analysis.

Figure 4. Microbial Cultivation and Colony Observation

(3) Gram Staining and Microscopic Observation

Representative colonies, including both soil-derived isolates and reference strains, were selected from culture plates for smear preparation and Gram staining (**Fig. 5**). The procedure was performed as follows: (i) a drop of sterile water was placed on a clean glass slide, a thin bacterial smear was prepared, air-dried, and heat-fixed over an alcohol flame; (ii) the smear was stained with crystal violet for approximately 1 min and rinsed with water; (iii) iodine solution was applied as a mordant for about 1 min, followed by rinsing; (iv) decolorization was carried out using 95% ethanol for 5–10 s, a critical step requiring precise control; and (v) the smear was counterstained with safranin for approximately 30 s and air-dried.

Microscopic examination was conducted under oil immersion. Gram-positive bacteria appeared purple due to their thick peptidoglycan cell walls (e.g., Staphylococcus aureus, typically coccoid and arranged in clusters), whereas Gram-negative bacteria appeared red as a result of their thinner cell walls and the presence of an outer lipopolysaccharide layer (e.g., Escherichia coli, rod-shaped and usually singly distributed). Soil-derived samples frequently exhibited a diversity of bacterial morphotypes, including cocci, bacilli, and spirilla, and their Gram reactions were determined based on staining characteristics. Because excessive decolorization can lead to misclassification, careful control of this step and repeated practice were essential to ensure staining accuracy and to reinforce understanding of the structural distinctions between Gram-positive and Gram-negative bacteria. Overall, this stage effectively integrated theoretical principles with practical microscopy skills, providing a robust basis for subsequent analyses.

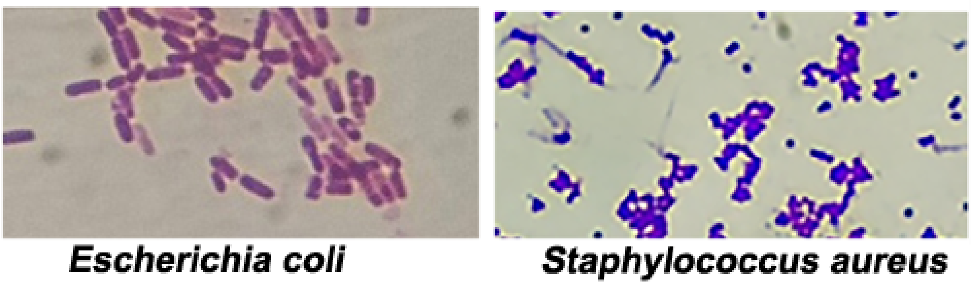


Figure 5. Gram-positive and Gram-negative Bacteria

(4) Collaborative Analysis and Data Visualization

During data analysis, students quantified the proportions of Gram-positive and Gram-negative bacteria in different soil samples. For example, Gram-positive bacteria accounted for approximately 60% of the microbial population in flowerbed soils, whereas Gram-negative bacteria represented about 55% in lawn soils. Environmental parameters, including pH, organic matter content, and soil moisture, were also incorporated into the analysis to enable comparative evaluation. For instance, in flowerbed soils with near-neutral pH and relatively high organic matter content, Gram-positive bacteria tended to be dominant, whereas in more acidic woodland soils, Gram-negative bacteria were present at higher proportions.

Students organized and analyzed the data using tools such as Excel or SPSS. Bar charts were used to clearly display the proportions of microbial groups, while line graphs were employed to illustrate correlations between pH values and microbial distribution. During group discussions, students proposed hypotheses—such as “soils rich in organic matter are more favorable for the growth of Gram-positive bacteria”—and verified the reliability of their results by incorporating control comparisons. Instructors provided analytical templates and guidance, encouraging students to use data-driven approaches to explore interactions between environmental factors and microbial communities. This stage not only strengthened students'collaborative communication skills but also enhanced their abilities in data analysis and scientific reasoning, highlighting the scientific value of data-driven teaching.

(5) Problem Solving and Development of Scientific Thinking

During the experimental process, students encountered various challenges, such as overly thick or thin smears, excessive decolorization time, contamination by extraneous microorganisms, and improper microscope focusing. Instructors provided on-site guidance through observation and employed heuristic questioning—for example, "How does smear thickness affect staining outcomes?" and "How can the optimal decolorization time be determined?"—to guide students in analyzing the causes of these problems and formulating appropriate solutions.

For instance, optimizing smear uniformity could be achieved by adjusting suspension dilution; performing operations near an alcohol lamp reduced contamination; and maintaining clean lenses and proper use of immersion oil improved image quality. Students further verified experimental accuracy by comparing their results with those obtained from standard reference strains (Staphylococcus aureus and Escherichia coli). This iterative process of troubleshooting and refinement enabled students to accumulate practical experience, cultivate patience, attention to detail, and independent thinking, and develop a strong foundation in scientific inquiry. Through continuous reflection and correction, students gained a deeper appreciation of the logic and rigor inherent in scientific research, laying a solid groundwork for future research training.

2.3 Outcome Generation and Presentation

(1) Experimental Report Writing

Each group was required to present its experimental outcomes in a scientifically rigorous and precise written report. The report included the objectives of the experimental design, materials and methods, results analysis, discussion, and conclusions. Reports were expected to be concise, well-structured, and data-driven, clearly presenting experimental findings such as the distribution of Gram-positive and Gram-negative bacteria in different soil samples. Further analysis focused on how environmental factors (e.g., soil pH and organic matter content) influenced differences in microbial community composition.

Standardized report templates were provided by instructors to guide students in adhering to academic conventions and ensuring scientific accuracy and logical coherence. In the discussion section, students were encouraged to interpret the ecological implications of their findings. For example, a higher proportion of Gram-positive bacteria may be associated with elevated organic matter content, suggesting their potential role in soil improvement. To enhance data visualization, students were required to include bar charts or pie charts to illustrate bacterial composition or community structure differences. Instructors further guided students to contextualize their findings within the broader framework of national ecological civilization initiatives, prompting reflection on the potential applications of their results in environmental management and agricultural production, and fostering a sense of scientific responsibility and academic pride.

(2) Presentation of Results and Defense

Each group prepared a PowerPoint presentation and delivered a 5–10-minute oral report summarizing the research background, methodology, key findings, and significance of the study, thereby strengthening students'scientific communication and logical presentation skills (**Fig. 6**). Instructors provided clear guidelines for PPT preparation, emphasizing concise content, effective integration of text and visuals, and clear highlighting of key data and conclusions.

Following the presentations, instructors and peers engaged in a question-and-answer session, posing questions such as "Why do bacterial proportions differ among soil samples?" or "What practical implications do these findings have in real-world contexts?" Students were required to respond clearly and logically, demonstrating a thorough understanding of the experimental data and sound scientific reasoning. During the defense, instructors adopted a facilitative rather than critical approach, using open-ended questions to help students refine their interpretations and presentation. This process enhanced students' oral communication and on-the-spot response abilities, increased confidence in their research outcomes, and strengthened their sense of teamwork and commitment to scientific inquiry.

Figure 6. Student Presentations and Defense of Experimental Results

(3) Significance of Outcome Presentation

The presentation of project outcomes extends experimental teaching from individual activities to collective, group-based engagement. Through formal public presentations, students experience the meaning and value of scientific research practice, further strengthening their awareness of scientific and technological innovation as well as their sense of responsibility to serve national development. Public presentation of outcomes significantly enhances students' sense of competition and stimulates innovative thinking, motivating each group to proactively refine their results and improve the quality of their presentations in order to showcase their academic achievements at the highest level.

This teaching process implicitly promotes the development of students' comprehensive competencies, including scientific thinking, logical expression, collaborative awareness, and innovative capacity. Such instructional practice aligns closely with the core principles of emerging engineering education, which emphasize "enhancing innovation through practice and strengthening thinking through expression." By encouraging students to integrate experimental processes and scientific questions with real-world challenges—such as ecological civilization construction and environmental governance—this approach enables students to gradually appreciate the social dimensions of scientific exploration. Consequently, students develop a positive and responsible research mindset and a strong sense of mission to contribute to national scientific and technological advancement, thereby laying a solid foundation for their future engagement in innovation-driven research and development.

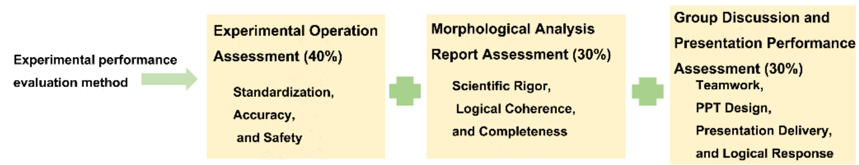
2.4 Evaluation, Feedback, and Enhancement

(1) Multidimensional Assessment Mechanism

To comprehensively evaluate the effectiveness of experimental teaching, the course established a multidimensional assessment system in which student performance was divided into three components: experimental operation assessment, morphological analysis report assessment, and group discussion and presentation performance assessment, weighted at 40%, 30%, and 30%, respectively. The experimental operation assessment focused on students' procedural compliance, accuracy, and safety awareness during the Gram staining experiment, including criteria such as uniformity of smear preparation, clarity of staining results, and adherence to laboratory safety practices.

The morphological analysis report assessment emphasized scientific rigor and logical coherence, with particular attention to the depth of data analysis and the quality of interpretation, especially the ability to reasonably explain results in relation to the ecological significance of soil microorganisms. The group discussion and presentation performance assessment provided a comprehensive evaluation of teamwork, presentation design quality, clarity of expression, and logical reasoning demonstrated during the defense.

Final grades were classified into five categories: excellent (90–100), good (80–89), satisfactory (70–79), pass (60–69), and fail (<60), providing an objective reflection of students' overall performance. This diversified assessment mechanism effectively overcomes the limitations of traditional single-evaluation approaches, ensuring fairness and transparency in grading while allowing students' competencies in experimental skills, analytical ability, and scientific communication to be fully and systematically assessed. Moreover, this mechanism motivates students to pursue excellence in scientific research and engineering practice, thereby supporting the cultivation of high-quality innovative talents dedicated to serving national ecological civilization development goals (**Fig. 7**).



Grade-based performance evaluation criteria

Grade	Percentage-Based Scoring System	Description
A	90-100	Excellent
B	80-89	Good
C	70-79	Pass
D	60-69	Basic Pass
E	<60	Fail

Figure 7. Multidimensional Assessment Mechanism

(2) Feedback and Reflection

The feedback stage plays a crucial role in the project-based teaching approach, serving as a significant driver of both student development and instructional improvement. Instructors provided detailed evaluations of each group's experimental reports and presentations, clearly identifying strengths and areas for improvement. For example, a report with accurate data presentation might require closer integration of the discussion with real engineering contexts, while a presentation with well-designed figures might benefit from more concise text to better highlight key points. In addition, instructors organized group reflection sessions to guide students in critically examining problems encountered during the experiments and exploring optimization strategies, such as how to improve smear preparation to enhance staining quality or how to increase the accuracy of data analysis. Each student was also required to complete an individual reflection report, documenting learning gains, experimental challenges encountered, and directions for further improvement.

In response to student feedback—such as difficulties associated with the operation of the virtual simulation platform—the teaching team introduced additional training sessions focused on platform usage, which significantly improved students' proficiency during pre-laboratory practice. According to course questionnaire results, over 95% of students reported that the objectives of the experimental teaching were clear and well organized, while more than 85% believed that the course content was appropriately challenging, effectively promoted active learning, and that the diversified assessment approach accurately reflected learning outcomes. Most students indicated that the course enhanced their independent thinking and innovative potential and expressed willingness to recommend it to others. This bidirectional feedback and iterative refinement mechanism not only deepened students' understanding of the principles and methods of Gram staining but also continuously improved the teaching content, ensuring closer alignment with students' learning needs. Consequently, it further strengthened students' scientific literacy and sense of responsibility toward contributing to ecological civilization development (**Fig. 8**).

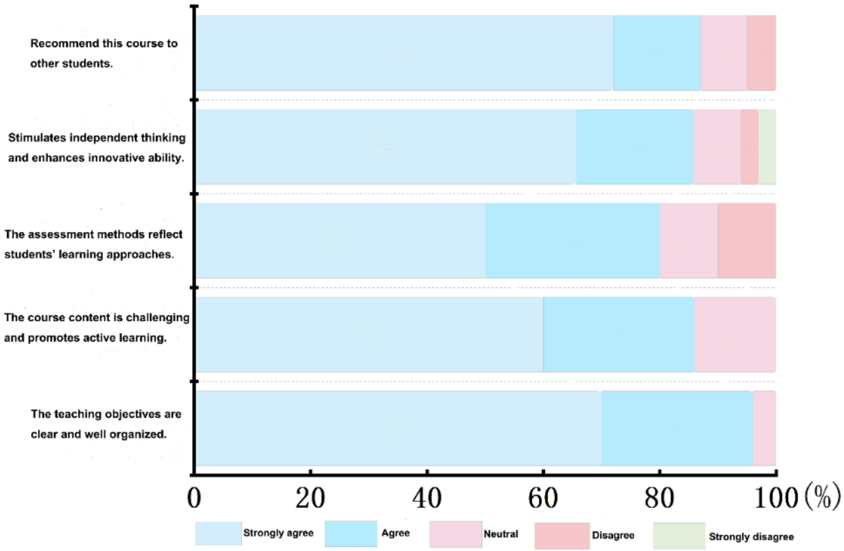


Figure 8. Student Feedback on the Gram Staining Experiment

(3) Engineering Applications and Conceptual Advancement

To highlight the engineering orientation and social value emphasized in emerging engineering education, instructors guided students in a thorough analysis of experimental results and their practical implications, with particular focus on the potential applications of soil microorganisms in areas such as pollution remediation and the development of agricultural microbial fertilizers. For example, soil samples with relatively high proportions of Gram-positive bacteria may exhibit stronger ecological restoration potential. Students were encouraged to analyze their applicability in improving soil quality and to propose feasible solutions aligned with national ecological civilization development strategies.

In addition, instructors introduced successful applications of microbial technologies in major national engineering projects, such as microbial water quality monitoring practices in the South-to-North Water Diversion Project, to stimulate students' enthusiasm for scientific research and foster a sense of responsibility toward contributing to national technological advancement. This instructional approach enabled students to develop a deeper understanding of the critical role of microbiology in technological progress and environmental protection. It not only reinforced their experimental skills and scientific reasoning but also strengthened their ability to translate theoretical knowledge into practical engineering solutions.

Through this advanced stage of learning, students achieved dual enhancement in academic literacy and social responsibility, cultivating a strong sense of mission to engage in scientific and technological innovation in the service of national development. This experience laid a solid foundation for their future participation in research activities and engineering practice.

3. Conclusion

In this study, a project-based teaching approach was innovatively introduced into the bacterial Gram staining laboratory course, facilitating a shift from the traditional lecture-centered model to an inquiry-based learning model that is problem-oriented and practice-centered. This approach established a closed-loop instructional framework consisting of “project design and assignment—experimental exploration and implementation—outcome generation and presentation—evaluation, feedback, and conceptual advancement.” By using driving questions to stimulate learning interest, authentic experiments and collaborative analysis to enhance practical competence, report writing and presentations to strengthen scientific communication skills, and diversified assessment and engineering applications to promote systematic competency development, this teaching model effectively addressed the disconnect between traditional laboratory instruction and real-world engineering applications. As a result, students’ experimental skills, teamwork abilities, and innovative thinking were comprehensively improved.

Within the broader context of emerging engineering education, the course guided students to explore the application potential of soil microorganisms in pollution remediation and sustainable agricultural development, thereby fostering a strong sense of mission to contribute scientific expertise to national development. This work provides a replicable and scalable practical model for reforming microbiology laboratory education in higher education and demonstrates the contemporary responsibility of universities in serving national scientific and technological advancement.

The results indicate that this teaching model achieved significant effectiveness: over 90% of students completed the experimental tasks, and marked improvements were observed in both the scientific rigor of experimental reports and the logical coherence of research presentations. Furthermore, several groups proposed innovative concepts related to soil microbial applications, offering new directions for subsequent research. In future work, the research team plans to collaborate with industry, academia, and research institutions to advance application-oriented studies based on real engineering challenges, such as pollution remediation and ecological restoration using soil microorganisms. In addition, emerging technologies, including computer-based image recognition and artificial intelligence–assisted analysis, will be incorporated to further expand the depth and breadth of experimental teaching. Overall, this instructional innovation not only substantially enhances students’ research literacy and engineering practice capabilities but also contributes new momentum to the cultivation of high-quality innovative engineering talents and the advancement of national ecological civilization, highlighting the strategic value and broad prospects of emerging engineering education.

Acknowledgments

This work was supported by the Fujian Provincial Young and Middle-Aged Scientists Fund (JAT241138, JAT241139), the Fujian Provincial Youth Science Foundation (2025J01313087), the Fujian Provincial Natural Science Foundation General Program (2025J011015), and the Longyan University 2025 Educational and Teaching Reform Research Project (2025BJY33).

References

Ashiq, K. (2023). Importance of Project-Based Learning for Pharmacy Education. *Turkish Journal of Pharmaceutical Sciences*, *20*(5), 2. https://doi.org/10.4274/tjps.galenos.2022.69023

Bian, S. Q., Liu, Y. F., Wang, L. N. et al. (2025). A project-driven multi-platform teaching model for network engineering. *Research in Higher Engineering Education*, *2025*(05), 75-80.

Du, L. N., Wu, M., Yang, J. et al. (2020). Application of the project-based teaching method in microbiology teaching. *Microbiology China*, *47*(04), 1278-1285.

Gong, S. F., Fang, Y. Y., Hu, H. H. et al. (2025). Innovation and practice of a blended teaching model for “Environmental Engineering Microbiology.” *Laboratory Research and Exploration*, 1-8 [2025-09-21].

Guo, H., Jin, Y., Li, Z. R. et al. (2022). Exploration of teaching reform for the “Microbiology Experiment” course based on a virtual simulation teaching model. *China Forestry Education*, *40*(01), 75-78.

Hu, Q., Wang, C., Huang, Y. P. et al. (2021). Teaching practice research on innovative design courses for environmental science and engineering majors. *Laboratory Research and Exploration*, *40*(05), 223-227.

Ji, W. Y., Liu, Z. S., & Yang, L. (2025). Innovation of higher engineering practice education models based on emerging engineering construction: A case study of the intelligent construction major. *China Higher Education*, *2025*(Z1), 76-80.

Li, M. Q., Xi, P., Wang, Q. S. et al. (2025). Course development of the “Bioluminescence Imaging Experiment” under the background of emerging engineering education. *Laboratory Research and Exploration*, *44*(07), 139-143.

Liu, L., Miao, L., Man, J. X. et al. (2025). Teaching reform and practice of hydraulic and pneumatic transmission courses under the background of emerging engineering education. *Laboratory Research and Exploration*, *44*(08), 189-192.

Tang, X. F., & Chen, X. D. (2024). Cultivation of new-quality talents: A new benchmark for microbiology teaching in higher education. *Microbiology China*, *51*(04), 1051-1054.

Tian, Y. H. (2017). Application of the project teaching method in microbiological engineering experimental teaching. *Industrial Technology and Vocational Education*, *15*(02), 44-46.

Xie, W. M., Lü, Y. F., Wei, J. P. et al. (2025). Innovative comprehensive design and practice of cell morphology observation experiments. *Chinese Journal of Biology*, 1-5 [2025-09-21].

Xie, Y. X., Bi, M. X., Sun, Y. H. et al. (2025). Research on blended teaching and diversified assessment models in university physics experiments. *Physics and Engineering*, *35*(03), 134-137. https://doi.org/10.26599/PHYS.2025.9320323

Xu, Y. Y., Li, W. R., & Wang, X. S. (2021). Research on virtual simulation technology-assisted experimental teaching of "Food Microbiology." *Education Teaching Forum*, *2021*(46), 125-128.