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EXPLORING FUTURE BIOLOGY TEACHERS' LITERACY: A PATHWAY TO CONTEXTUAL CURRICULUM INNOVATION IN ARCHIPELAGIC EDUCATION

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ABSTRACT

The development of students' scientific competence is closely tied to the literacy skills of those who teach them. Consequently, pre-service teachers' mastery of biotechnology concepts becomes a key foundation for nurturing scientific literacy in future classrooms. This study aims to describe the biotechnology literacy profile of pre-service biology teachers regarding both conventional and modern biotechnology within the context of the Maluku Archipelago. Employing a quantitative descriptive approach, the research involved 20 students enrolled in the Biology Education Program at Pattimura University. The instrument, in the form of open-ended tests, was developed based on three dimensions of biotechnology literacy (conceptual, procedural, and socio-scientific) adapted to the local insular context. Data were analyzed using descriptive statistics to classify levels of competence. The findings revealed that the overall level of biotechnology literacy among participants was categorized as good (mean score = 72.88), with the highest achievement in conceptual literacy (86.25%), followed by procedural (70.31%) and socio-scientific literacy (68.75%). These results indicate that while the understanding of fundamental biotechnological concepts is relatively strong, the application and reflective competencies related to social, ethical, and environmental issues require further reinforcement. The study recommends the integration of coastal local contexts, authentic project-based practices, and socio-scientific issue training to enhance the biotechnology literacy of pre-service teachers in island regions.
Keywords: Island-based Science Education, Literacy, Pre-service Biology Teachers

INTRODUCTION

Teachers play a strategic role in national development, not only as transmitters of knowledge but also as key agents in fostering students' scientific literacy. A teacher's level of scientific literacy is a critical prerequisite for ensuring that the learning process produces graduates capable of critical thinking, problem-solving, and understanding the impact of science on everyday life. Research indicates that many preservice biology or science teachers still demonstrate scientific literacy skills within the moderate range, which calls for specific attention (Adi et al., 2020). Therefore, strengthening scientific literacy among preservice teachers is essential so that they can effectively transfer these competencies to their future students.

As prospective biology teachers, students in biology education programs must possess adequate literacy capacity to design, implement, and evaluate meaningful learning experiences. In the context of preservice teachers, scientific literacy encompasses not only conceptual understanding but also mastery of scientific procedures and the ability to relate science to socio-cultural and environmental aspects. Studies have shown that learning models integrating contextual elements with scientific literacy can enhance preservice teachers' competencies (Ramadani & Lestari, 2024). Therefore, as part of their professional development, preservice teachers need to be equipped with strong scientific literacy skills.

Within the field of biology, one of the most relevant areas for fostering scientific literacy is biotechnology (both conventional and modern). As a learning topic, biotechnology offers a rich context for developing both conceptual and procedural literacy, as it encompasses microbiological processes, genetics, molecular techniques, and their applications in everyday life. Research has shown that biotechnology learning grounded in project-based or locally contextualized approaches can enhance students' literacy on biotechnology-related topics (Sobach et al., 2023). Therefore, positioning biotechnology as a focal area of literacy development for preservice biology teachers is both relevant and strategic.

The context of island and coastal regions, such as the Maluku Archipelago, presents both unique challenges and opportunities in biology education and scientific literacy. In island settings, socio-cultural, economic, and environmental conditions possess distinctive characteristics, for instance, marine ecosystems, seagrass beds, local food fermentation practices, and the utilization of indigenous microbes, which can serve as authentic sources for biotechnology learning. Research on education in coastal environments indicates that learning grounded in local ecological contexts can strengthen students' scientific literacy and enhance the relevance of instruction (Rusly et al., 2025). Thus, integrating biotechnology topics with the local context of the Maluku Islands can enrich preservice biology teachers' scientific literacy while supporting regional educational autonomy.

Nevertheless, there remains a noticeable gap in biotechnology literacy among preservice biology teachers, particularly in the eastern and archipelagic regions of Indonesia, which have been underexplored empirically. The limited number of studies in these areas has resulted in a lack of baseline data regarding preservice teachers' literacy profiles in both conventional and modern biotechnology. Consequently, efforts or programs aimed at strengthening literacy in this context cannot yet be designed based on strong empirical evidence. Since biotechnology literacy encompasses not only cognitive aspects but also procedural and socio-scientific dimensions, research that provides an empirical overview is crucial.

Recent studies indicate that preservice teachers' levels of biotechnology literacy remain in the low to moderate range, particularly in the procedural and socio-scientific dimensions that require further strengthening. For instance, a study of preservice science teachers in Sweden revealed a significant gap in their conceptual understanding of basic biotechnology despite their generally positive attitudes toward its applications (De La Hoz et al., 2022). Several module-based interventions have been developed to enhance biotechnology literacy; for example, online modules for preservice science teachers have been shown to significantly improve eco-literacy skills within biotechnology contexts (Wulandari et al., 2024). Therefore, in archipelagic regions characterized by strong local wisdom and limited technological access, it is crucial to conduct empirical studies that describe preservice teachers' biotechnology literacy profiles to inform the design of contextually relevant and effective interventions.

Considering these aspects, this study aims to identify the biotechnology literacy profiles of preservice biology teachers, focusing on both conventional and modern biotechnology within the context of the Maluku Archipelago. The findings are expected to provide empirical input for the development of curricula, instructional modules, and biotechnology literacy enhancement programs in teacher education institutions, particularly in island regions. Moreover, this research is significant in supporting national self-reliance through the utilization of local and global biotechnological potentials fostered by scientifically literate teacher education. Thus, the study offers a meaningful contribution to improving the quality of preservice biology teachers and the relevance of science education in archipelagic areas.

RESEARCH METHOD

This study employed a quantitative descriptive approach to portray the biotechnology literacy profile of prospective biology teachers in coastal and island-based regions of the Maluku Archipelago, a methodological choice aligned with previous studies that used quantitative description to analyze science literacy competencies through test-based instruments (Indasa & Jauhariyah, 2024). This approach was chosen to map literacy competence without manipulating variables, emphasizing the depiction of factual conditions in the field. The research involved 20 students of the Biology Education Study Program, Pattimura University, who were enrolled in the Biotechnology course. The sample was selected using a purposive sampling technique, based on the consideration that these students had acquired fundamental knowledge of biotechnology and represented the profile of future biology teachers in island regions.

The research instrument consisted of a biotechnology literacy essay test developed based on three core dimensions proposed by Busch & Rajwade, (2024): conceptual, procedural, and socio-scientific literacy. The test comprised five items contextualized to local settings, such as food fermentation, bioethanol, and reproductive cloning. The instrument was validated by three expert validators through assessments of content, construct, and readability, with all items deemed feasible after minor revisions. The instrument's reliability was examined using the Intraclass Correlation Coefficient (ICC), yielding a value of 0.89, indicating a very high level of inter-rater consistency.

Data were collected during regular face-to-face sessions, with a 90-minute time allocation for individual completion. Students' responses were analyzed using descriptive statistics, including mean scores, percentage attainment, and ability categorization following Prihatiningtyas et al. (2025): low (0–40), moderate (41–60), good (61–80), and very good (81–100). The analyses were conducted using IBM SPSS Statistics, which facilitated the calculation of descriptive statistics and categorization of students' literacy levels. The findings were interpreted contextually by examining the relationship between students' biotechnology literacy and the socio-ecological characteristics of the Maluku Archipelago. This approach not only provides a quantitative overview but also highlights the relevance of biotechnology education in strengthening scientific literacy within Indonesia's eastern island regions. This study was conducted with approval from the Head of the Biology Education Study Program, who authorized data collection as part of academic research involving pre-service biology teachers. All participants were informed about the study's purpose, voluntary participation, confidentiality, and the use of anonymized data for research purposes. No personal or identifying information was collected.

FINDINGS AND DISCUSSION

1. Findings

This section presents the results of data analysis on the biotechnology literacy of prospective biology teachers, including an overview of general statistical findings and achievements in each literacy dimension. The results are presented quantitatively to illustrate students' performance trends, followed by a discussion that interprets these findings within the context of biotechnology education in the archipelagic region.

Table 1. Descriptive Statistics of Biotechnology Literacy

Statistic	Value
Number of Students	20
Highest Score	92.5
Lowest Score	52.5
Mean	72.88
Median	75.00
Standard Deviation	11.79

Source: Authors' analysis based on field data (2025)

Overall, the biotechnology literacy ability of the prospective teachers was categorized as "good" (mean = 72.88). The distribution value (SD = 11.79) indicates a moderate variation among participants, suggesting that some demonstrated relatively high mastery, while others still required reinforcement, particularly in certain dimensions. The following table (Table 2) presents the average scores for each dimension of biotechnology literacy assessed in this study.

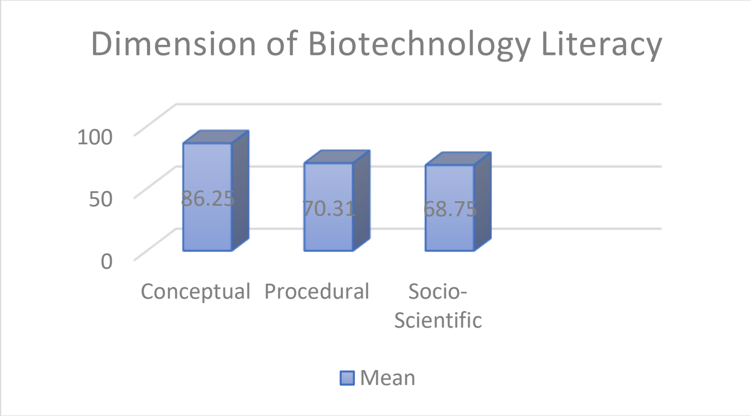
Table 2. Average Scores per Dimension of Biotechnology Literacy

Literacy Dimension	Mean Score (0–4)	Mean (%)	Category
Conceptual Literacy	3.45	86.25	Very Good
Procedural Literacy	2.81	70.31	Good
Socio-Scientific Literacy	2.75	68.75	Good
Overall Mean		**75.10**	**Good**

Source: Authors' analysis based on field data (2025)

Table 2 shows that the findings indicate the prospective teachers demonstrated a solid understanding of fundamental biotechnology concepts, such as PCR and the principles of recombinant DNA. However, the procedural (70.31%) and socio-scientific (68.75%) dimensions, while categorized as good, remained below the conceptual level. This suggests that their grasp of scientific processes and their ability to connect scientific knowledge with social contexts still require further strengthening. To provide a clearer visual representation, Figure 1 presents the comparison of average scores across the three dimensions of biotechnology literacy, highlighting the dominance of conceptual understanding over procedural and socio-scientific aspects.

Figure 1. Dimension of Biotechnology Literacy



Source: Authors' analysis based on field data (2025)

2. Discussions

The descriptive statistical analysis revealed that the biotechnology literacy level of the prospective biology teachers in this sample was generally categorized as good (overall mean score = 72.88; median = 75.0; SD = 11.79), with the highest score reaching 92.5 and the lowest 52.5. This score distribution suggests that although most participants achieved a good category, there was a notable degree of individual variation that warrants further consideration in designing follow-up learning interventions. These findings align with previous reports indicating that prospective biology teachers exhibit diverse levels of biotechnology literacy, particularly between conceptual and applied aspects, emphasizing the need for adaptive pedagogical strategies that accommodate learners' varying needs.

In terms of literacy dimensions, the highest achievement was observed in conceptual literacy (mean = 86.25%), indicating a relatively strong mastery of fundamental biotechnology concepts such as the principles of PCR and the mechanisms of recombinant DNA. This finding suggests that formal instruction during coursework has been effective in conveying conceptual knowledge, which is generally more accessible to measure and internalize through lectures, readings, and conceptual exercises. Although students demonstrate strong conceptual understanding, this does not necessarily translate directly into practical skills or ethical reasoning. Therefore, the implementation of differentiated instruction, accompanied by continuous monitoring, is essential to ensure the effective transfer of knowledge into procedural competence and socio-scientific argumentation (Amalia et al., 2023). Several reviews on biotechnology education emphasize that conceptual understanding should be enriched through contextual learning activities to enable its application in real-world decision-making (Horniaková, 2024).

The procedural dimension obtained an average score of 70.31%, categorized as good but lower than the conceptual dimension. This condition reflects a common gap between knowing and being able to perform or explain technical steps in detail, a phenomenon that often arises when laboratory practice opportunities are limited or when skill exercises lack sufficient repetition. In the context of prospective teachers, procedural competence encompasses the mastery of instructional steps, the ability to interpret learning outcomes, and the skill to design structured and meaningful learning activities. Without adequate reinforcement of such procedural competence, future teachers may encounter difficulties in implementing effective teaching methods, such as the cooperative learning model of the Jigsaw type, which requires precision at every stage of its execution, from the formation of core groups and expert groups to the presentation and integration of learning outcomes within the original teams. Therefore, a procedural orientation in learning serves as a fundamental principle that enables prospective teachers to facilitate collaborative and meaningful learning experiences for their students (Readi, 2024). Without sufficient procedural reinforcement, prospective teachers may struggle to facilitate effective laboratory experiences for their students. Literature on contemporary biology education recommends integrating real-world scenario–based laboratory practices and simulation technologies to address this procedural gap (Nurdin et al., 2025).

The socio-scientific literacy dimension obtained the lowest average score among the three dimensions (68.75%), although it still fell within the good category. This dimension requires critical ability to connect biotechnology knowledge with ethical, policy, economic, and cultural issues-skills that typically develop more gradually, as they demand repeated practice in argumentation, case analysis, and value-based discussion. The relative decline in this dimension serves as an important consideration for teacher education, as socio-scientific competence plays a central role in preparing teachers to guide students through biotechnology-related dilemmas in coastal communities, such as the utilization of local resources and the ethical implications of cloning or GMOs. Such competence not only fosters teachers' capacity to integrate scientific understanding with ethical reasoning, but also equips them to contextualize biotechnological issues within the socio-cultural and environmental realities of their communities. In doing so, it enables the cultivation of science education that is more ethically grounded, socially responsible, and oriented toward the collective well-being of society (Putrini R Harahap, 2024). Recent studies on socio-scientific issue (SSI)-based learning have demonstrated the effectiveness of this approach in enhancing argumentative competence and evidence-based cs, conceptual content and written assessments tend to dominate, while opportunities for laboratory practice and structured ethical discussions remain limited. Moreover, in island or coastal regions such as Maluku, constraints related to laboratory facilities, availability of experimental materials, and geographical challenges often reduce the frequency of hands-on activities that foster procedural competence. Local educational studies have noted that such infrastructural and accessibility limitations affect the depth of practical skills and the contextual application of science learning. Therefore, reinforcement strategies should address infrastructural barriers while simultaneously leveraging local potentials as contextual learning resources (Yanti et al., 2025).

From the perspective of teacher competence, these findings indicate that pre-service teachers need reinforcement not only in conceptual understanding but also in the ability to design feasible laboratory activities, develop valid assessment rubrics, and facilitate socio-scientific discussions that are sensitive to local values. Such pedagogical competencies include the capacity to design contextualized problem-based learning, moderate ethical debates, and assess students' scientific process skills. The teacher education literature emphasizes that programs should integrate modules for practical competence and socio-scientific issue (SSI) development through microteaching, field practice, and community collaboration, enabling pre-service teachers to gain authentic experiences. This approach is particularly relevant for strengthening teacher capacity in coastal regions, where local contexts serve as rich sources of learning (De La Hoz et al., 2022).

Specifically, in the coastal context of Maluku, integrating ocean literacy and local potentials (fish fermentation, sago processing, or bioethanol production from local waste) can serve as an effective pedagogical bridge to combine the three dimensions of biotechnology literacy. A locally contextualized approach allows students to practice simple experimental procedures while engaging in discussions on real socio-economic implications, thereby strengthening procedural and socio-scientific literacy without relying entirely on well-equipped laboratories. Research on ocean literacy has shown that enhancing teachers' understanding of marine ecosystems and local issues improves their ability to integrate marine content into integrated science teaching. Therefore, developing learning modules that link biotechnology with coastal case studies would be highly relevant (Arwan & Ali, 2025).

Beyond curriculum interventions, educational technologies such as laboratory simulations, instructional videos, and virtual labs offer pragmatic solutions to address the limitations of hands-on practice in island regions. Recent studies indicate that appropriately selected technologies can enhance procedural understanding and reduce the gap between theory and practice, provided they are accompanied by sufficient pedagogical guidance and opportunities for reflective practice. Nevertheless, in coastal areas, such innovations must be complemented by improved digital access and literacy training for prospective teachers to ensure optimal utilization. This underscores the need for coherent educational policies that align infrastructure provision with adaptive curriculum design (Nurdin et al., 2025).

To support the enhancement of all three literacy dimensions—particularly the procedural and socio-scientific, it is recommended that teacher education programs adopt authentic project-based learning approaches that utilize local coastal resources, such as fish fermentation, macroalgae cultivation, or sago waste conversion into bioethanol. This approach enables prospective teachers to conduct structured small-scale experiments while exploring real socio-ecological contexts, thereby strengthening the linkage between theory, practice, and social values. Recent studies have shown that project-based learning grounded in local contexts significantly improves procedural and socio-scientific competencies compared to traditional lecture-based instruction. Thus, the integration of coastal contexts into biotechnology curricula holds strategic potential to align strong conceptual mastery with the development of applied and reflective competencies.

Unstructured exploratory interviews with several student participants were conducted to complement and contextualize the quantitative results. Most students reported that understanding fundamental biotechnology concepts was relatively easy to achieve through lectures and digital learning resources; however, applying these concepts in laboratory practice was often constrained by limited equipment and materials. They also acknowledged that biotechnology topics related to social or ethical issues were seldom discussed in depth during class sessions, resulting in suboptimal development of their ability to evaluate the social and environmental impacts of biotechnological innovations. Nevertheless, students noted that case-based discussions grounded in local context, such as fishery waste management, traditional food fermentation, and sago-based bioenergy, helped them grasp the interconnectedness of science, technology, and society. These interviews indicate that students possess critical awareness of the importance of contextualizing biotechnology education within coastal community life, while also recognizing the need to expand opportunities for practical engagement and ethical dialogue as priorities in biology teacher education across the archipelagic region.

Based on the findings and literature review, several actionable recommendations can be proposed to strengthen biotechnology education for prospective teachers in coastal regions: (a) integrating locally contextualized modules, such as ocean literacy and local food resource utilization, into the curriculum; (b) increasing the frequency of practice through mini laboratories, portable experiment kits, and digital simulations; (c) embedding SSI training and ethical discussion facilitation within teacher education programs; (d) establishing campus–community or local industry partnerships for field-based learning; and (e) enhancing digital literacy and infrastructure accessibility. These policy implications align with studies emphasizing the importance of integrating local contexts and leveraging technology to improve the quality of science education in remote areas. Implementing these recommendations may help narrow the gap between conceptual mastery and applied competencies among prospective teachers in coastal regions (Fikriyah et al., 2024).

CONCLUSION

The study revealed that prospective biology teachers in the Maluku Archipelago demonstrated a good level of biotechnology literacy, characterized by strong conceptual understanding but relatively weaker procedural and socio-scientific competencies. These findings indicate that biotechnology education in teacher preparation programs remains predominantly concept-oriented, with limited emphasis on developing practical scientific skills and ethical-social awareness relevant to coastal community contexts. This study provides the first empirical profile of biotechnology literacy among pre-service biology teachers in Indonesia's eastern archipelagic region, offering a clear foundation for developing contextually relevant curriculum and locally grounded learning modules. Although limited by its small sample size and single institutional scope, this research establishes directions for future studies to investigate the effectiveness of authentic project-based learning and socioscientific issue-based instruction in strengthening procedural and socio-scientific competencies among prospective biology teachers in coastal regions.

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