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Profiling Scientific Literacy of Biology Education Students in Distance Higher Education

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Abstract

Scientific literacy is a key competence in the 21st century, enabling students to understand scientific concepts, engage in inquiry, reason with evidence, and address socio-scientific issues. However, limited empirical evidence exists on how distance learning environments shape the scientific literacy of pre-service biology teachers. This study aimed to profile the scientific literacy of biology education students in distance higher education by identifying their strengths and weaknesses across four dimensions: conceptual understanding, scientific inquiry, evidence and reasoning, and socio-scientific issues. A quantitative survey design was employed involving 167 students in the Biology Education Study Program of a distance higher education institution. Data were collected using a 15-item Scientific Literacy Survey developed based on Bybee's (2009) framework, rated on a four-point Likert scale (1 = strongly disagree to 4 = strongly agree). Descriptive statistics and Latent Profile Analysis (LPA) were applied to analyze students' competencies. The descriptive results indicated that students possessed moderate scientific literacy, with mean scores ranging from 2.93 to 3.19. Conceptual understanding (M = 3.15) and socioscientific issues (M = 3.08) were the strongest domains, while scientific inquiry (M = 2.97) and evidence and reasoning (M = 3.00) emerged as weaker areas. LPA revealed three distinct groups: High Balanced Literacy (32%), Moderate Conceptual but Weak Inquiry (48%), and Low Across All Aspects (20%). These findings suggest that while students are capable of connecting scientific knowledge to real-world contexts, they face challenges in inquiry and reasoning. The study recommends the integration of virtual laboratories, project-based learning, and socioscientific case discussions to strengthen inquiry skills and foster scientifically literate graduates prepared for 21st-century challenges

Keywords: profiling, scientific literacy, distance higher education, SDGs

1. Introduction

Scientific literacy is a key 21st-century competence that is crucial for individuals to think critically, filter information, and make evidence-based decisions in everyday life. It is no longer regarded merely as an academic skill but as a life skill that enables society to cope with the complexity of the modern world, particularly in addressing global challenges such as climate change, pollution, public health, and the rapid development of digital technologies (OECD, 2019). Consequently, scientific literacy has become a primary goal of science education across all levels, including higher education.

In the theoretical perspective outlined by Bybee et al. (2009), scientific literacy encompasses four interrelated dimensions. The first is Conceptual Comprehension, which refers to the student's capacity to understand and articulate scientific concepts clearly in a relevant context. The second is Scientific Inquiry, which emphasizes the ability to formulate research questions, design procedures, and conduct scientific investigations. The third dimension, Evidence and Reasoning, highlights students' competencies in analyzing data, identifying patterns, and building logical arguments to support conclusions. Finally, Scientific Social Issues involve awareness of, and active engagement with, social, ethical, and environmental issues related to the use of science in everyday life. Collectively, these dimensions provide a holistic representation of scientific literacy, especially significant in the rapidly evolving landscape of distance higher education in the digital age.

The competencies associated with Scientific Inquiry are often hampered by a lack of opportunities to engage with real laboratories, a situation that is particularly evident in distance education programs that largely rely on simulations or virtual laboratory tools (Rahmawati & Irwanto, 2021). many students still have difficulty when asked to critically analyze scientific data and use it as the basis for a strong argument (Anggreani et al., 2023). Concurrently, the dimension of Socioscientific Issues tends to be underemphasized, despite its important role in developing comprehensive scientific literacy that includes awareness and sensitivity to pressing global issues such as energy scarcity, environmental sustainability, and public health issues (Sumarni et al., 2021).

International research reinforces these findings. Levy (2025) corroborates these findings. Levy (2025) emphasizes that distance learning can serve as an important means of "bringing science to the edge, by ensuring access to quality science education for people in remote areas, despite internal resistance and limitations remaining a challenge. Digital literacy is tightly bound to students' readiness for online learning and their self-paced learning skills (Alanoglu et al., 2025). Furthermore, Roy et al. (2025), through a systematic review, highlighted that the implementation of scientific literacy across educational contexts requires ongoing theoretical and practical development to remain responsive to contemporary demands.

The Indonesian context also offers relevant insights. Ariyatun (2024) reported that the scientific literacy profile of senior high school students in Central Java was at a moderate level, both in terms of competence and attitudes toward online learning. These findings indicate the need for mapping scientific literacy at the higher education level so that instructional strategies can be designed to be more contextual and aligned with the reinforcement of 21st-century skills. Rahayu et al. (2025), found that project-based learning is effective in enhancing students' creative thinking skills and engagement in online classes. This finding aligns with Bybee et al.'s (2009) scientific literacy framework, particularly in the aspects of Scientific Inquiry and Evidence and Reasoning. Previous research, such as Students' Practicum During COVID-19 Pandemic at Universitas Terbuka (Rahayu et al., 2021), highlighted the limitations of access to real laboratory experiences and the urgent need to develop alternative, technology-based learning media for distance learners. Similarly, De Jong, Linn, and Zacharia (2013) emphasized that both physical and virtual laboratories play a critical role in developing inquiry and reasoning skills, yet access inequality often constrains students in open and distance learning settings. Furthermore, Chang, Hsu, and Wu (2020) demonstrated that virtual laboratories can enhance conceptual understanding and inquiry skills, although their effectiveness depends on students' scientific literacy levels and engagement with digital tools.

However, most of these studies have primarily focused on identifying learning barriers or designing alternative media, without comprehensively examining how these limitations affect students' scientific literacy profiles in higher education, especially within distance learning contexts (Makransky & Petersen, 2021; Tytler & Osborne, 2012). Therefore, the present study addresses this gap by investigating the dimensions of scientific literacy among university students in distance education settings, focusing on how limited laboratory experiences and digital learning environments influence students' inquiry skills, reasoning, and evidence-based understanding. This mapping is essential to inform curriculum design, strengthen digital pedagogical innovation, and support the development of adaptive laboratory alternatives that foster scientific literacy in open and distance learning institutions.

Thus, research on profiling the scientific literacy of students in distance higher education is highly important. It provides an in-depth understanding of students' strengths and weaknesses across various aspects of scientific literacy. The findings also can serve as a foundation for lecturers and institutions to design more innovative, contextual learning strategies oriented toward the development of 21st-century skills. Meanwhile, it supports the achievement of *Sustainable Development Goal (SDG) 4*, which promotes inclusive, equitable, and quality education and lifelong learning opportunities for all. Therefore, this study aims to profile the scientific literacy of biology education students in distance higher education by identifying their strengths and weaknesses across four key dimensions—conceptual understanding, scientific inquiry, evidence and reasoning, and socioscientific issues. Specifically, it seeks to classify students into latent profiles based on their scientific literacy patterns and to provide insights for designing innovative, contextual, and sustainable learning strategies that support the achievement of 21st-century skills and SDG 4 goals.

2. Methods

2.1 Type of Research

This study employed a quantitative survey design to map students' scientific literacy skills in distance higher education. The survey approach was chosen for its efficiency in collecting data from a relatively large sample and for its ability to describe the distribution of students' competencies across the four dimensions of scientific literacy proposed by Bybee et al. (2009): *Conceptual Understanding, Scientific Inquiry, Evidence and Reasoning,* and *Socio-scientific Issues*.

2.2 Respondents or Participants

The research involved 167 active students enrolled in the Biology Education Study Program at a distance higher education institution in Indonesia. Participants were selected using a random sampling technique to ensure that the sample represented students from various regional learning centers. Participation was voluntary, and all respondents provided informed consent before completing the survey.

2.3 Data Collection

Data were collected using a Scientific Literacy Survey instrument consisting of 15 items designed to measure the four dimensions of scientific literacy.

a. Conceptual Understanding, assessed students' ability to explain and apply biological concepts.
b. Scientific Inquiry, measured skills in formulating hypotheses, identifying variables, and understanding experimental design.
c. Evidence and Reasoning, evaluated students' competence in interpreting data, identifying patterns, and drawing logical conclusions.
d. Socio-scientific Issues, explored students' awareness and reasoning regarding ethical, social, and environmental issues related to science.

All items were rated using a 4-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Agree, 4 = Strongly Agree). This format allowed for capturing students' degree of agreement and perceived competence across each literacy aspect. Higher mean scores indicated higher levels of perceived scientific literacy.

2.4 Data Analysis

Before analysis, the collected data were screened for completeness and consistency. **Descriptive statistics** (mean, standard deviation, and frequency) were calculated to describe students' scientific literacy profiles in each dimension. To further identify patterns of scientific literacy among students, **Latent Profile Analysis (LPA)** was conducted using Mplus version 8. LPA enabled the classification of respondents into distinct groups based on their response patterns across the four scientific literacy dimensions, providing deeper insights into variations in students' literacy levels in distance learning contexts.

3. Result and Discussion

An initial descriptive analysis was performed to illustrate the distribution of students' responses across the four dimensions of scientific literacy, encompassing conceptual understanding, scientific inquiry, evidence and reasoning, and socioscientific issues.

Each item in the Scientific Literacy Survey was analyzed using measures of **mean (M)**, **standard deviation (SD)**, and **response distribution**, reflecting both central tendency and variability among respondents. Higher mean scores indicate stronger agreement or higher perceived competence in the respective scientific literacy aspect. These descriptive findings offer an initial understanding of students' literacy profiles before conducting the **Latent Profile Analysis (LPA)** to explore potential groupings based on performance patterns.

Table 1 summarizes the descriptive statistics for all 15 items representing the four dimensions of scientific literacy.

This overview serves as a foundation for interpreting the subsequent statistical findings. The results of the Scientific Literacy Survey, consisting of 15 items rated on a four-point Likert scale (1 = Strongly Disagree, 4 = Strongly Agree), are summarized in Table 1.

Table 1.
Descriptive statistics of scientific literacy items

Item	Mean	SD
1. Impact of ecosystem imbalance on food crisis	**3.14**	0.64
2. Immune system preventing disease spread	**3.19**	0.61
3. Importance of sanitation & hygiene	**3.17**	0.62
4. Role of green organisms in reducing CO_2	**3.10**	0.63
5. Forest destruction and species decline	**3.15**	0.62
6. Designing experiment on natural fertilizer	**2.99**	0.66
7. Identifying variables in research	**2.94**	0.67
8. Evaluating air pollution experiment steps	**2.99**	0.65
9. Formulating questions from marine ecosystem	**3.01**	0.66
10. Explaining experimental steps (energy efficiency)	**2.93**	0.66
11. Reading graphs (temperature vs species migration)	**2.98**	0.69
12. Drawing conclusions from organic waste management	**3.05**	0.61
13. Comparing photosynthesis experiments	**3.11**	0.61
14. Assessing correlation (pollution & biodiversity)	**2.99**	0.60
15. Distinguishing data vs opinion in articles	**3.04**	0.64

The results suggest that students in distance higher education perceive themselves as moderately competent in scientific literacy, with stronger performance in conceptual and socioscientific dimensions compared to inquiry and reasoning skills.

To move beyond descriptive statistics and gain deeper insights into the heterogeneity of students' scientific literacy, this study employed Latent Profile Analysis (LPA). Unlike traditional mean comparisons, LPA allows researchers to classify respondents into distinct subgroups (profiles) based on their response patterns across multiple dimensions. In this case, the four dimensions of Bybee's (2009) framework: Conceptual Understanding, Scientific Inquiry, Evidence and Reasoning, and Socio-scientific Issues were used as input variables.

Through LPA, students were grouped into profiles that represent meaningful patterns of scientific literacy rather than assuming a uniform distribution of competencies across the sample. This method provides a nuanced understanding of how strengths and weaknesses cluster within the student population and offers practical implications for designing differentiated instructional strategies in distance higher education.

The analysis identified three unique student profiles. The first, High Balanced Literacy, reflects learners who demonstrate consistently high abilities across all four dimensions. The second, Moderate Conceptual, Weak Inquiry, denotes the largest group, made up of students with sufficient conceptual understanding but limited inquiry skills. The third, Low Across All Aspects, potray students who are experiencing difficulties in every area of scientific literacy. An overview of these profiles, along with the average scores for each dimension, is presented in Figure 1.

Figure 1.
Scientific literacy profile

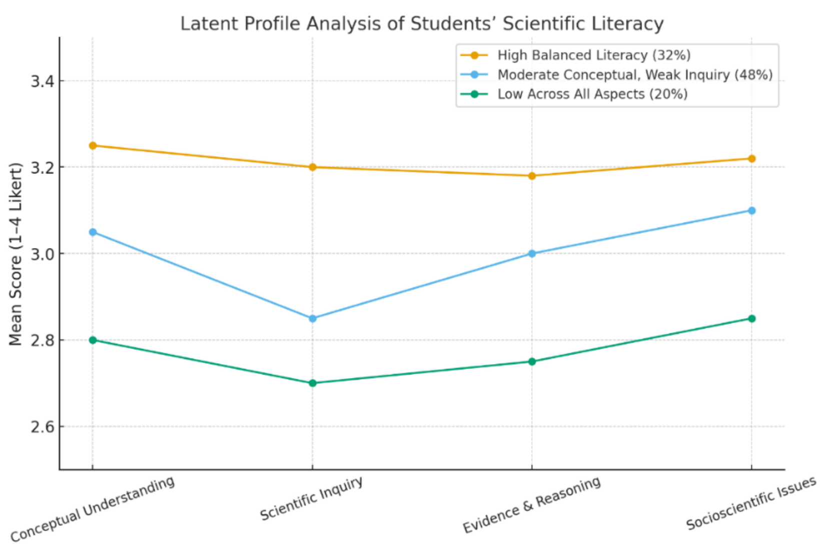

Figure 1 presents the results of the Latent Profile Analysis (LPA), which classified students into three distinct profiles of scientific literacy based on their performance across the four dimensions of science literacy, such as conceptual understanding, The first profile, High Balanced Literacy (32%), illustrated by the orange line, consists of students who achieved relatively high results in all four dimensions. Their mean scores, which exceeded 3.2, reflect solid mastery of scientific concepts, scientific inquiry, evidence and reasoning, and socio-scientific issues, sufficient inquiry abilities, and a well-established awareness of socio-scientific issues. The second profile, Moderate Conceptual, Weak Inquiry (48%), illustrated by the blue line, constitutes the largest proportion of the sample. Students in this category obtained average scores in conceptual understanding and sociocentric issues (around 3.0–3.1), yet performed lower in scientific inquiry (approximately 2.85). This indicates that although they are able to comprehend and link scientific knowledge to everyday and global contexts, they encounter challenges in inquiry-related skills, particularly in designing experiments and determining research variables. The third profile, Low Across All Aspects (20%), depicted by the green line, represents students with the lowest achievement across the four dimensions (approximately 2.7–2.8). This subgroup highlights learners who need considerable help, not only to strengthen their basic conceptual understanding but also to enhance their inquiry skills and reasoning competence.

3.1. Strength in Conceptual Understanding and Socio-scientific Awareness

The findings from this study show that Items 1–5, which discovered themes such as ecological disproportion, the immune system, hygiene and sanitation, deforestation, and the role of photosynthetic organisms in reducing carbon emissions, obtained comparatively higher scores. This result suggests that students demonstrate a solid grasp of biological concepts and can connect them with urgent real-world challenges. According to Bybee et al. (2009), this reflects the essential component of scientific literacy that links disciplinary knowledge with its societal applications.

These results are in line with previous research that emphasizes the importance of incorporating sociocentric contexts into science education. For example, Sumarni et al. (2021) report that placing learning around sociocentric issues (SSI) encourages important improvements in students' literacy and environmental awareness. Likewise, Sadler et al. (2016) holds SSIs not only strengthen conceptual mastery but also foster students' critical engagement with global challenges such as climate change, sustainable food systems, and public health. Such proof is notably associated in the context of distance higher education, where authentic and contextualized learning experiences get a main role in helping students bridge abstract scientific ideas with their routine realities (Levy, 2025).

In addition, both **conceptual understanding** and **socioscientific awareness** act as crucial foundations for developing sustainability-oriented competencies that align with the Sustainable Development Goals (SDGs), particularly **SDG 4 on Quality Education** and **SDG 13 on Climate Action**. Bybee (2013) emphasizes that science education should not be confined to the delivery of factual content but must also encourage learners to build the capacity to respond responsibly within the complexities of modern society. From this perspective, the students' relatively strong performance in these areas represents a valuable platform upon which more advanced skills, such as scientific inquiry and evidence-based reasoning can be cultivated.

3.2. Challenges in Scientific Inquiry

In contrast to the stronger domains, Items 6–10, which measured abilities such as designing experiments, determining variables, and outlining experimental procedures, obtained the lowest average scores (≤3.00). This pointed out the students experience significant challenges around **scientific inquiry**. Mastery of inquiry not only entails conceptual knowledge but also engage procedural skills in planning, conducting, and evaluating investigations (National Research Council, 2012). Within the context of distance education, limited access to physical laboratories further intensifies these adversities, diminishing odds for authentic, hands-on practice.

Evidence from previous studies solidify this interpretation. Rahmawati and Irwanto (2021) found that learners working with virtual laboratories often featured disparities in experimental design and variable identification when compared with those engaged in traditional laboratory settings. Similarly, inquiry-oriented science instruction in Indonesian higher education remains underdeveloped, largely due to resource constraints and a tendency to prioritize theoretical teaching (Irwanto et al., 2019). Such challenges are particularly prominent in distance learning systems, where laboratory experiences are large overridden with simulations or written case analyses.

It should also be acclaimed inquiry is intrinsically linked with higher-order cognitive skills, including problem-solving, creativity, and decision-making (Kuhn, 2010). Students' relatively low outcomes in this dimension may therefore reflect wider difficulties in fostering critical and creative thinking within online learning environments. Addressing these shortcomings calls for innovative instructional models that embed inquiry into digital platforms, such as online project-based learning, virtual experimentation, and collaborative problem-solving activities.

3.3. Moderate Competence in Evidence and Reasoning

Items 11, 14, and 15, which were designed to assess students' competence in interpreting graphs, analyzing correlations, and distinguishing between empirical data and personal opinions, were scored at a moderate level (≈3.0). From these results, it can be inferred that a foundation in evidence-based reasoning is possessed by the learners, although the capacity for more advanced critical evaluation still needs to be enhanced. As noted by Zimmerman (2007), scientific reasoning is defined as the systematic use of evidence to justify or refute claims, a process in which both analytical skills and metacognitive awareness are required.

This outcome is in line with findings by Anggreani et al. (2023), who showed that many university students continue to face challenges in evaluating evidence, particularly when working with complex datasets or distinguishing objective results from subjective interpretation. Comparable trends have also been noted in international studies, where reasoning abilities often lag behind conceptual understanding (Osborne, 2014). Such a gap may reduce students' capacity to make sound decisions on sociocentric issues, including matters related to climate change policy or biomedical innovation, where evidence-based reasoning is indispensable.

The centrality of evidence and reasoning within scientific literacy also reflects international standards such as PISA (OECD, 2019), which emphasize the necessity of developing students' capacity to critically use data in both daily life and professional contexts. In the setting of distance education, enhancing these competencies calls for deliberate scaffolding, such as structured training in data analysis, the use of argumentation frameworks like Claim Evidence Reasoning, and opportunities for peer evaluation of reasoning processes.

3.4. Implications for Distance Learning

The overall profile of students' scientific literacy points to the necessity of pedagogical renewal in the context of distance higher education. Although learners demonstrate sufficient conceptual knowledge and an acceptable level of sociocentric awareness, additional reinforcement is still needed in the areas of inquiry and reasoning. This highlights the importance of embedding strategies that emphasize investigative learning and evidence-based reasoning into online science instruction.

One effective option is the use of virtual laboratories, which, when appropriately designed, have been demonstrated to strengthen inquiry-related skills (Herga et al., 2016). Another valuable method is project-based learning, through which opportunities to apply scientific processes to authentic problems are provided to students, and improvements in both inquiry and reasoning skills have been reported, even in online environments (Alanoglu et al., 2025). In addition, when sociocentric issue discussions are incorporated into online learning platforms, learners are encouraged to engage in critical dialogue, to evaluate evidence, to construct arguments, and to reflect on diverse perspectives (Sadler et al., 2016).

These approaches are consistent with global movements in digital education that prioritize active, collaborative, and reflective modes of learning (Levy, 2025). Moreover, they align with the broader educational mission of preparing students with essential 21stcentury competencies such as critical thinking, problem-solving, and digital literacy. By systematically integrating inquiry-based and reasoning-focused practices, distance higher education institutions can ensure that learners become not only conceptually proficient but also capable of responsibly applying scientific knowledge to address real-world challenges.

The novelty of this study lies in its focus on mapping scientific literacy profiles within the context of distance higher education, a domain that remains underexplored in the literature. While previous studies have largely examined students' conceptual understanding or the effectiveness of virtual laboratories, this research uniquely integrates the dimensions of conceptual, inquiry-based, reasoning, and socio-scientific literacy to portray a holistic view of how distance learners engage with science in digitally mediated environments. The findings thus contribute to expanding the discourse on how scientific literacy can be fostered in open and distance learning systems, particularly in developing countries where access to laboratory experiences remains limited.

However, this study has certain limitations. The use of self-reported survey data may not fully capture students' actual performance in scientific literacy, as responses could be influenced by self-perception and contextual factors. Moreover, the study was conducted within a single academic program in one distance higher education institution, which may limit the generalizability of the findings to other contexts or disciplines. Future research should therefore employ mixed-method approaches, combining performance-based assessments, interviews, or classroom observations to provide a more comprehensive understanding of students' scientific literacy development. Comparative studies across multiple distance learning institutions and subject areas are also recommended to explore contextual influences on students' inquiry and reasoning skills. Additionally, longitudinal designs could help track how specific instructional interventions, such as virtual laboratories or inquiry-based modules, contribute to sustained improvements in scientific literacy over time.

4. Conclusion

The results of this research indicate that biology education students in distance learning programs tend to exhibit a moderate degree of scientific literacy. Their strongest competencies lie in conceptual knowledge and awareness of sociocentric issues, whereas their abilities in scientific inquiry and evidence-based reasoning remain comparatively weaker. Descriptive results ($M = 2.93–3.19$) indicate that students can connect scientific concepts with real-world issues such as health, environment, and sustainability, yet struggle with designing experiments, identifying variables, and critically interpreting data. Latent Profile Analysis (LPA) further revealed three distinct groups of learners: High Balanced Literacy (32%), Moderate Conceptual but Weak Inquiry (48%), and Low Across All Aspects (20%), reflecting the heterogeneous nature of students' competencies. These findings emphasize the need for differentiated instructional strategies in distance higher education, including the use of virtual laboratories, project-based learning, and socio-scientific discussions, to strengthen inquiry and reasoning skills while consolidating conceptual knowledge, thereby fostering scientifically literate graduates prepared to address 21st-century challenges.

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