

Bioindicator literacy in Indonesian higher education: Instructors' teaching practices and students' literacy levels

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Abstract: Bioindicator literacy supports students' ability to understand, use, and interpret bioindicator organisms in environmental quality assessments. However, research on bioindicator learning practices and students' bioindicator literacy levels is still relatively limited. Therefore, this study aims to explore bioindicator learning practices in higher education and identify students' bioindicator literacy levels. A quantitative descriptive approach was chosen in this study, involving 167 biology education students who have taken Ecology courses and 9 lecturers who teach courses related to ecology, taxonomy, or the environment. Two instruments were developed: the first for lecturers to explore bioindicator learning. The second instrument for students to determine the level of student bioindicator literacy. The results showed that students' bioindicator literacy was in the low category with an average score of 50.33. The dimension with the lowest achievement was practical implementation at 36.34, while the highest achievement was in sustainability awareness at 61.45. These findings indicate that students are relatively aware of the importance of bioindicators for environmental sustainability, but still struggle with the direct identification of bioindicators in the field. Bioindicator education at the university level has included theoretical lectures and field projects utilizing digital technology, but remains constrained by limited laboratory facilities and the accuracy of organism identification applications. The development of various innovative learning technologies in bioindicator education is expected to enhance students' bioindicator literacy.

Keywords: Bioindicator literacy, ecology course, higher education

Abstrak: Literasi bioindikator mendukung kemampuan mahasiswa dalam memahami, menggunakan, dan menafsirkan organisme bioindikator dalam penilaian kualitas lingkungan. Namun, penelitian mengenai praktik pembelajaran bioindikator dan tingkat literasi bioindikator mahasiswa masih relatif terbatas. Oleh karena itu, penelitian ini bertujuan untuk mengeksplorasi praktik pembelajaran bioindikator di perguruan tinggi dan mengidentifikasi tingkat literasi bioindikator mahasiswa. Pendekatan deskriptif kuantitatif dipilih dalam penelitian ini, yang melibatkan 167 mahasiswa pendidikan biologi yang telah mengambil mata kuliah Ekologi serta 9 dosen yang mengajar mata kuliah terkait ekologi, taksonomi, atau lingkungan. Dua instrumen dikembangkan: yang pertama untuk dosen guna mengeksplorasi pembelajaran bioindikator; sedangkan instrumen kedua untuk mahasiswa guna menentukan tingkat literasi bioindikator mahasiswa. Hasil penelitian menunjukkan bahwa literasi bioindikator mahasiswa berada pada kategori rendah dengan skor rata-rata 50,33. Dimensi dengan pencapaian terendah adalah penerapan praktis dengan skor 36,34, sedangkan pencapaian tertinggi terdapat pada kesadaran akan keberlanjutan dengan skor 61,45. Temuan ini menunjukkan bahwa mahasiswa relatif menyadari pentingnya bioindikator bagi kelestarian lingkungan, namun masih mengalami kesulitan dalam mengidentifikasi bioindikator secara langsung di lapangan. Pendidikan bioindikator di tingkat perguruan tinggi telah mencakup kuliah teori dan proyek lapangan yang memanfaatkan teknologi digital, namun masih terhambat oleh keterbatasan fasilitas laboratorium dan akurasi aplikasi identifikasi organisme. Pengembangan berbagai teknologi pembelajaran inovatif dalam pendidikan bioindikator diharapkan dapat meningkatkan literasi bioindikator mahasiswa.

Kata kunci: Literasi bioindikator, mata kuliah ekologi, pendidikan tinggi

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INTRODUCTION

Among global environmental issues that still increase with human activities and industrial development are water pollution, degradation of ecosystems, and changes in habitat quality, which pose a threat to the balance of ecosystems and human health (Gavrilaş et al., 2025; Lemgoha et al., 2025; Singh et al., 2025). These conditions demand competencies to monitor environmental changes accurately, sensitively, and sustainably. To this end, bioindicators organisms or biological responses that reveal environmental conditions and changes, including the presence of pollutants or specific ecological stresses have become a widely adopted approach (Lyche et al., 2025; Taurozzi et al., 2024). Microorganisms, macroinvertebrates, plants and algae are commonly used as bioindicators since they are sensitive to environmental change. They record cumulative and long-term ecosystem impacts, which gives a more comprehensive image of environmental quality than physical or chemical measurements alone (Bahranipour et al., 2024; Parmar et al., 2016).

In higher education, bioindicator education is focused on the theoretical understanding of bioindicators and the application of this knowledge by students in interdisciplinary project-based activities that combine environmental education with practical ecosystem monitoring techniques (Fioramonti et al., 2021; Karl et al., 2024). In this line, the International Union for Conservation of Nature (IUCN) also recommends the use of bioindicators as an educational instrument for comprehending the dynamics of environmental change. These activities expose students to conceptual material and to authentic learning experiences where students can directly observe, sample and interpret biological responses to environmental conditions. This experiential approach is one component of a broader trend in higher education pedagogy that intentionally links theory with practice in the field to improve students' contextual understanding of ecological phenomena. Through these activities, students acquire not only a theoretical knowledge but also analytical skills to interpret biotic and abiotic data in a contextual and applicable way (Leite, 2024). This type of pedagogical integration is considered crucial because a firm understanding of bioindicators enhances the students' ability to understand, analyze and evaluate the environmental conditions in a more general context (Nali & Lorenzini, 2007; Urabe et al., 2018).

The measurement of bioindicators-related competencies has evolved along two complementary lines with a large potential for integration. The first stems from ecological and methodological research, in which tools such as biotic indices have been developed to assess environmental quality based on the presence and composition of indicator organisms, providing a solid scientific basis to the interpretation of biological data (Fossi et al., 2018; Fusaro et al., 2018; Mateu-Vicens et al., 2014). The second line is from education research, where general instruments for ecological and environmental literacy have been designed to measure students' conceptual understanding and environmental awareness, providing useful frameworks for assessing student learning (Ginting et al., 2023; Hanafi et al., 2023; Sigit et al., 2024). The intersection of these two lines provides a significant opportunity, an instrument for measuring bioindicator learning and literacy as a separate construct, capable of identifying competencies such as interpreting the responses of organisms, integrating biotic and physicochemical data, and applying biomonitoring procedures in an educational context.

Biology and environmental science students need a specific competency that directly relates ecological relationships and biological concepts to interpreting the responses of organisms as indicators of environmental quality. Bioindicator learning intersects with ecological literacy (related to ecological relationships and environmental awareness) and biological literacy (related to general biological concepts and scientific reasoning (Markert et al., 2019; Peffer et al., 2020; Saboe et al., 2021). In addition to these two literacies, students need to be able to synthesize biotic and physicochemical data, utilize bioindicator based evidence for environmental decision making and to practice ethical awareness in organism collection, procedural scientific skills and field-based critical reasoning that links biological and physicochemical data to real world environmental decisions (Kaplan et al., 2024; Markert et al., 2019; Xie et al., 2025). A tool to measure this competency would provide instructors with an empirical basis to assess their teaching practices, and researchers with a reliable tool to track the development of bioindicator competence under different conditions (Clark et al., 2022; Hampton et al., 2017). Based on this rationale, bioindicator literacy in this study is operationalized as the ability of an individual to understand bioindicator concepts, ethically apply bioindicator concepts in environmental analysis, and critically interpret biological data to support sustainability-oriented environmental decision-making.

The research on bioindicators has greatly aided in the development of biotic indices and environmental quality assessments. This information can be transferred to higher education to support students in understanding the concept of bioindicators, identify organisms, analyze data, and interpret environmental conditions. Based on this premise, this study has two foci: to investigate teaching practices on bioindicators in higher education and to evaluate students' levels of bioindicator literacy. The aim of this study is to describe students' understanding of bioindicator concepts and the use of biological information to critically and contextually evaluate environmental conditions. The research findings are anticipated to be a basis for developing more relevant learning strategies with the data-driven and field-experience-based approach (Alditia et al., 2025; Ramchunder & Ziegler, 2021; Sholihah & Malahayati, 2025).

METHOD

Research design

This study employs a quantitative descriptive approach to systematically describe the bioindicator learning process in higher education institutions as well as students' levels of bioindicator literacy. This approach was chosen because it allows for the presentation of an objective empirical picture of the teaching practices employed by instructors and students' literacy achievements (Creswell, 2012). Data were collected from faculty members teaching courses in ecology, taxonomy, or environmental studies related to bioindicator learning. Subsequently, bioindicator literacy achievements were assessed among students who had completed an ecology course. The selection of subjects was based on their relevance to bioindicator learning, so that the data obtained could describe the learning conditions and the students' level of bioindicator literacy.

This study began with the identification of the problem and the formulation of objectives, followed by a literature review to serve as the foundation for instrument development. Two instruments were used in this study. The first was a bioindicator learning

questionnaire for lecturers, and the second was a bioindicator literacy instrument for students. Both instruments were used to collect data on teaching practices and students' levels of bioindicator literacy. The overall research stages are presented in Figure 1.

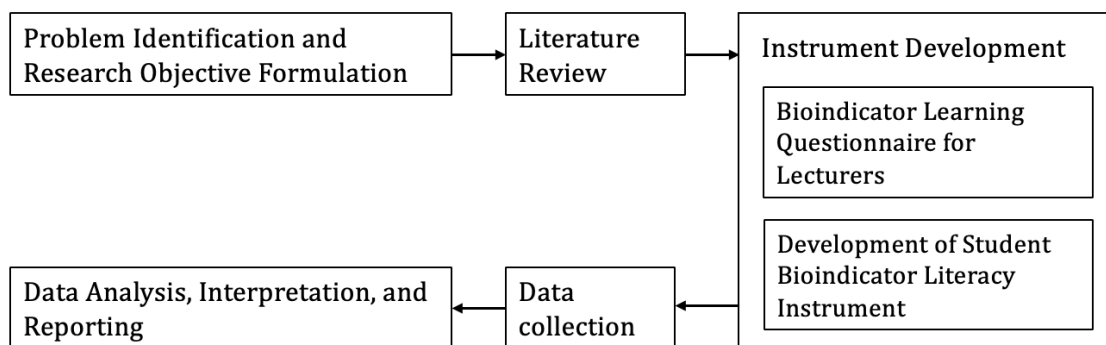


Fig 1. Research design

Population and sample

The population in this study was students of the Biology Education Program at the State University of Malang, the University of Muhammadiyah Malang, and Budi Utomo University who took the Ecology course and lecturers who taught courses related to ecology, taxonomy, or the environment that discussed bioindicators in the three universities. The research was conducted on a sample of 167 students and 9 lecturers, selected by purposive sampling. The students chosen were those who had taken the Ecology course. Meanwhile, lecturers were chosen based on their involvement in teaching courses on bioindicators.

Ethical issues related to research were carefully addressed during data collection. All participants gave their informed consent through an online survey via Google Forms. Before completing the survey, participants were informed about the research objectives, use of research data, confidentiality of respondent data, and the right of participants to participate voluntarily and to withdraw at any time without academic consequences.

Instruments

Based on the research objectives, two instruments were developed for this study. The first instrument was designed for lecturers, while the second was designed for students. This study used two types of instruments developed in accordance with the research objectives, namely one for faculty members and one for students. These instruments were developed because no standardized and validated measurement tools specifically designed to explore bioindicator learning and assess students' bioindicator literacy were yet available. The instrument for lecturers is a bioindicator learning questionnaire used to gather information regarding bioindicator learning practices in higher education institutions. This questionnaire covers several key aspects, namely (1) learning approaches; (2) assessment approaches; (3) field learning media; (4) field activities; (5) learning challenges. Each aspect is represented by 3 items, resulting in a total of 12 questionnaire items. The development of the instrument was based on the latest literature review, which explains that bioindicator literacy focuses not only on theoretical aspects but also on contextual skills.

We explored seven dimensions of bioindicator literacy, comprising the cognitive, psychomotor, and affective domains. These dimensions of bioindicator literacy include, namely (1) conceptual knowledge, which encompasses students' understanding of the concepts, functions, and types of bioindicators; (2) practical implementation, namely students' skills in using bioindicators to monitor and assess environmental health; (3) critical evaluation, which refers to students' ability to critically evaluate bioindicator data and responses; (4) ethical consideration, namely how students apply ethical values in the use of bioindicators; (5) sustainability awareness, which involves awareness of sustainable environmental practices through the use of bioindicators; (6) policy and management integration, which involves understanding environmental policies and being able to use bioindicator data to support decision-making and environmental management; and (7) interdisciplinary connections, which reflects the ability to link bioindicator concepts with other disciplines, as well as utilizing technology to enhance bioindicator studies. These dimensions were then developed into a bioindicator literacy instrument consisting of 25 multiple-choice items and 15 Likert-scale items. The multiple-choice questions were used to measure students' conceptual understanding, while the survey questions were used to explore students' skills and attitudes toward the use of bioindicators in environmental quality monitoring. The bioindicator literacy instrument is detailed in Table 1.

Table 1. Indicators, number, and examples of items in the bioindicator literacy instrument

Indicator	Number of Items	Example Item
Conceptual Knowledge	4	Students are able to explain the relationship between bioindicator abundance and organic pollution conditions in river waters.
Practical Implementation	5	Students are able to conduct sampling of bioindicators (diatoms, plankton, or macrozoobenthos) according to established procedures.
Critical Evaluation	4	Students are able to critically evaluate changes in bioindicator composition based on physicochemical data from river water samples.
Policy and Management Integration	4	Students are able to use bioindicator data to provide recommendations for water quality management in accordance with environmental quality standards and regulations.
Interdisciplinary Connections	4	Students are able to integrate digital technology into water quality analysis using bioindicators.
Sustainability Awareness	5	Students are aware that the use of bioindicators is important for supporting sustainable environmental management.
Ethical Consideration	5	Students are able to apply ethical principles and maintain environmental sustainability during field-based bioindicator sampling activities.

The seven dimensions of bioindicator literacy were grouped into three domains. The cognitive domain comprises four dimensions, namely conceptual knowledge, drawing on studies of bioindicator organism understanding and biological literacy foundations (Anderle et al., 2024; Lewinsohn et al., 2015), critical evaluation, drawing on studies of data interpretation and diatom-based water quality indices (Celades et al., 2021; Xue et al., 2023), policy and management integration, drawing on studies linking bioindicator evidence to environmental regulation (Celades et al., 2021; Ivanova et al., 2022; Xue et al., 2023), and interdisciplinary connections, drawing on studies of cross-disciplinary and technology-supported biomonitoring (Bórquez-Sánchez, 2025; O'Neil et al., 2020; Saboe et al., 2021). The affective domain comprises two dimensions, namely ethical consideration, drawing on studies of research ethics and environmental responsibility (Gardner et al., 2016; Koyama & Watanabe, 2023), and sustainability awareness, drawing on studies of ecological literacy and sustainable practice (Durmus & Kinaci, 2021; Koyama & Watanabe, 2023; Toomey et al., 2023). The psychomotor domain is represented by practical implementation, drawing on studies of field-based application and hands-on bioindicator skills (Celades et al., 2021; Hsu et al., 2024). This tripartite structure is a reflection of integration of knowledge, attitude and skills required for bioindicator based environmental analysis.

Validity and reliability

For the lecturer questionnaire, content and face validity were assessed because the instrument was designed to describe teaching practices rather than measure a latent psychological construct (Mokkink et al., 2010). Face validity was established through several rounds of review and revision to improve the clarity, relevance, and readability of the items. A pilot review was conducted in July 2025 with two ecology professors and two assessment professors. Their feedback was used to further refine the questionnaire.

The student bioindicator literacy instrument was assessed for content validity by three experts in ecology and biology education. The Content Validity Index (CVI) showed S-CVI/Ave values of 0.92 to 0.99 among biology education experts and 0.92 to 0.98 among ecology experts. These results indicate that the items were considered relevant to the dimensions being measured.

Table 2. Nilai correlation coefficients dan cronbach's α

Indicator	Correlation Coefficients Categories	Cronbach's α
Conceptual Knowledge	0.840-0.861	0.81
Practical Implementation	0.836-0.947	0.89
Critical Evaluation	0.825- 0.941	0.88
Policy and Management Integration	0.855-0.895	0.87
Interdisciplinary Connections	0.836-0.870	0.91
Sustainability Awareness	0.815-0.922	0.90
Ethical Consideration	0.813-0.892	0.93

Empirical validity was assessed using corrected item-total correlations for each dimension of the bioindicator literacy instrument. All items met the acceptable correlation

criteria, indicating that the items adequately represented their respective dimensions. Reliability was then assessed through a pilot test involving 60 students before the main data collection. Cronbach's alpha values ranged from 0.81 to 0.93 across the dimensions, indicating good to excellent internal consistency. Overall, the results indicate that the bioindicator literacy instrument had adequate validity and reliability for assessing students' bioindicator literacy. The corrected item-total correlation and Cronbach's alpha results are presented in Table 2.

Data collection & analysis

Data were collected using Google Forms distributed to lecturers and students who met the inclusion criteria. Lecturer questionnaire data were analyzed descriptively using frequencies and percentages to summarize bioindicator teaching practices. Student bioindicator literacy data were analyzed by calculating the mean score and percentage achievement for each dimension. Multiple-choice items were scored dichotomously, while Likert-scale items were scored according to the response scale used in the questionnaire. The scores for each dimension were converted into percentages and categorized based on adapted literacy biology and literacy ecology criteria (Semilarski & Laius, 2021; Sigit et al., 2024). Each level of bioindicator literacy is presented in detail in Table 3.

Table 3. Bioindicator literacy criteria	
Value	Information
86 ≥	Very high
76 - < 86	High
60 - < 76	Medium
55 - < 60	Low
< 55	Very low

RESULTS AND DISCUSSION

Overview of students' bioindicator literacy

The results of the study indicate that the total bioindicator literacy score of students is 50.33 in the low category. This finding shows that students have a lot of scope to improve their understanding, application and critical use of bioindicator-based evidence in environmental analysis. The total score shows that the students performed differently on the dimensions, not at a similar level. The scores were between 36.34 for practical implementation (very low) and 61.45 for sustainability awareness (medium) with a difference of 25 points. Students performed better in the dimensions of awareness and ethical judgment particularly in sustainability awareness and ethical consideration. The dimensions that need procedural skills and analytical judgment, particularly the practical implementation, conceptual knowledge and critical evaluation, scored lower. The low overall score was thus mainly related to the students' limited ability to apply bioindicator concepts in practice rather than a lack of awareness, suggesting that these findings are not due to unawareness.

This distinction is important because bioindicator literacy in this study encompasses the integration of conceptual understanding, procedural skills, and critical interpretation.

Students with good awareness but limited practical and evaluative skills might be described as having developing bioindicator literacy rather than fully developed bioindicator literacy. Most of the student's participants in this study already know why bioindicators matter for environmental sustainability. What many still need is further support to apply bioindicator procedures independently and interpret bioindicator data critically. This leads us to the next question – which particular competencies are most in need of strengthening, and why? The following section takes each of the seven dimensions to answer this.

Dimensional profile of bioindicator literacy

The bioindicator literacy levels of students vary in each dimension. The average bioindicator literacy scores of the students for each dimension are shown in Figure 2. In the conceptual knowledge dimension, students scored 42.65% which places them in the low category. The results of this study suggest that most students still do not fully understand the basic principles of bioindicators, especially how changes in the abundance, dominance or composition of certain organisms reflect changes in environmental quality (Hsu et al., 2024; Snow, 2020). A solid grasp of the relationships between organisms, habitats and pollution pressures is a prerequisite to enable students to interpret data, evaluate environmental conditions and formulate management recommendations in subsequent stages of the biomonitoring process (Narguizian, 2019; Sigit et al., 2023).

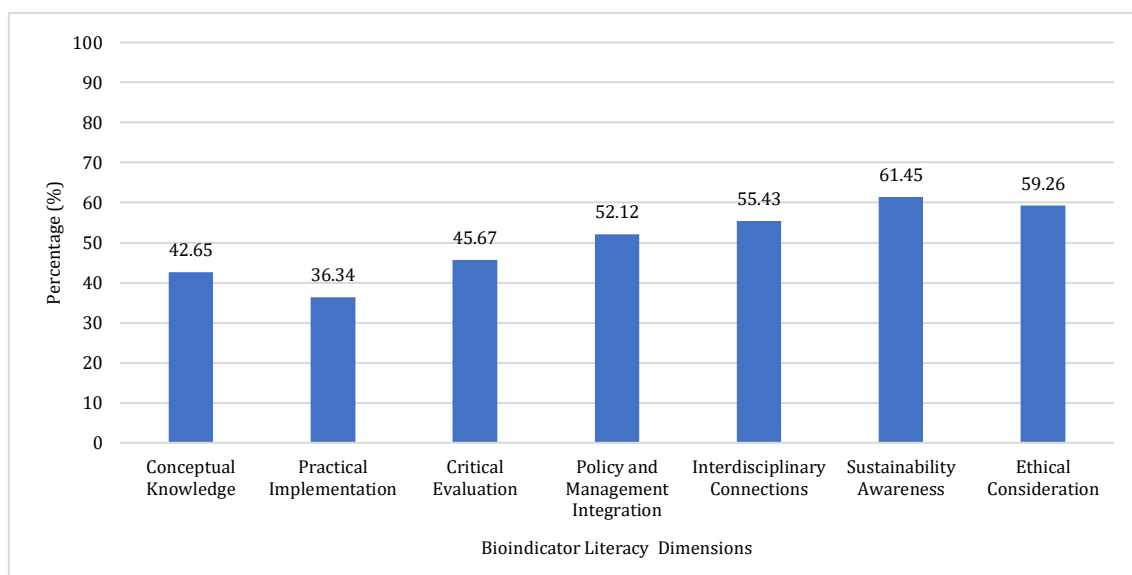


Fig 2. Dimensional profile of students' bioindicator literacy

The lowest dimension was the practical implementation with a mean achievement of 36.34% which is in the very low category. In general students had difficulty translating what they knew conceptually into sound field procedure. The most likely reason is limited field experience. Few students had field experience in working with sampling equipment, selecting sampling points, preserving organisms and following a systematic protocol in the field (Hanafi et al., 2023; Pitman & Daniels, 2016). The gap between conceptual knowledge (42.65%) and practical implementation (36.34%) is telling. Bioindicator literacy does not

come from classroom explanations alone. It is based on structured procedure-based fieldwork that cannot be replaced by conceptual teaching (Hsu et al., 2024; Sigit et al., 2019).

Critical evaluation was 45.67% which also is a very low figure. Most students could not consistently link changes in bioindicator communities to physicochemical parameters such as pH, temperature, dissolved oxygen, BOD, COD, nitrate, phosphate or turbidity. This fits with the low frequency of students practicing combining environmental datasets and making arguments from evidence (Persson et al., 2024). This weakness is analytically relevant. The presence of one organism does not inform us about water quality. It must be judged from biological, physicochemical and ecological evidence taken together (Koyama & Watanabe, 2023; Wells et al., 2021). If a student cannot make that connection, then they have not met the evaluative standard as set by the construct, no matter how well they do on conceptual items.

Integration of policy and management received 52.12 percent, the fourth lowest of the seven dimensions. Scores are above conceptual, practical and critical evaluation but still too low to indicate that students can link biomonitoring results to environmental regulation, management policy or conservation principles with any consistency (Lewinsohn et al., 2015). Students at this level are not yet ready to determine whether a site has crossed a regulatory threshold or to identify the management failures that underlie a pollution problem (Hogan & O'flaherty, 2021). Thus, the present teaching of bioindicators seems to end with identification of organisms and interpretation of water quality. It seldom succeeds in getting students to use biological data in policy and management decisions (Toomey et al., 2023).

Medium category, 55.43% of interdisciplinary connections. The score is on the higher end of the profile, but a value just above the midpoint indicates a moderate rather than strong interdisciplinary ability. Students have a poor ability to transfer bioindicator concepts to other fields, such as electronic instruments for environmental analysis (Fioramonti et al., 2021). Instructors do use digital resources in their teaching (Clark et al., 2022; Hampton et al., 2017), but the result suggests that interdisciplinary integration has not been intentionally built into bioindicator courses..

The most powerful dimension was sustainability awareness with 61.45% in the medium category. Students were relatively better at recognizing what bioindicators contribute to pollution detection, monitoring of ecosystem health and conservation (Durmus & Kinaci, 2021; Karl et al., 2024). This should not be read as an indicator of strong literacy overall. Conceptually and empirically, knowing why bioindicators matter is a different thing than being able to use or critically interpret bioindicator data. This difference is the biggest in the profile, between the practical implementation (36.34%) and this dimension (61.45%).

The second highest score was 59.26 percent for ethical consideration. Students demonstrated a basic understanding of the importance of ethics in biomonitoring, including protection of habitat, workplace safety, welfare of organisms and responsibility to the wider ecosystem (Hogan & O'flaherty, 2021; Koyama & Watanabe, 2023). But even then a score in this range indicates competence, not solid ethical competence. It is unlikely that field ethics will simply transfer from general guidelines. They need explicit teaching, they cannot be left to incidental exposure (Gardner et al., 2016; Hogan & O'flaherty, 2021).

The seven dimensions, in their entirety, confirm the trend seen in the overview. The students performed worst in tasks involving procedural execution or analytical synthesis (practical implementation, conceptual knowledge and critical evaluation). They scored better on tasks that required recognition and judgment, with no hands-on work (sustainability awareness and ethical consideration). The gap is anything but marginal. The spread of approximately 25 percentage points between the highest and lowest dimensions indicates that bioindicator education as taught currently is more effective in creating awareness than in developing the procedural and analytical skills required by the construct.

Teaching bioindicators in higher education

Bioindicator education was carried out in the participating institutions through lectures, class discussions and case-study analysis of pollution of the environment. Hence the teaching is not purely conceptual but it already is a part of the contextual learning. Field projects are especially important here. But students won't get a bioindicator from a definition. They learn it by watching living things, collecting samples, looking at environmental data, and figuring out what that data tells us about the ecosystem. Therefore, in principle, the identified teaching practices are consistent with the character of bioindicators as a topic in applied ecology.

Table 4. Bioindicator education in higher education institutions

Bioindicator Learning Aspects	Frequency (f/9)	Percentage (%)	Key Findings
Learning approaches	9/9	100%	Learning activities were conducted through theoretical lectures and field-based projects.
Assessment approaches	9/9	100%	Assessment was carried out through written examinations, project reports, and project presentations.
Field learning media	9/9	100%	The learning media utilized included applications for organism identification, location mapping, and data analysis.
Field activities	9/9	100%	Learning activities involved environmental observation, including the identification of bioindicators in river, forest, or lake ecosystems.
Learning challenges	9/9	100%	Challenges included limited laboratory facilities, constraints in conducting field activities, difficulties in data analysis, and the limited accuracy of organism identification applications.

Students were evaluated by the instructors through written tests, project reports and project presentations (Table 4). Each format captures a different facet of learning. Written tests assess the conceptual understanding, project reports assess the students' ability to present the data and draw conclusions, and presentations assess whether they can

communicate the results of an environmental analysis (Großschedl et al., 2018; Sigit et al., 2024; Yücel & Özkan, 2015). Thus, instructors already use a diverse array of assessments that cover learning from conceptual mastery to communication. Table 4 also shows that field learning media have entered into bioindicator courses such as organisms identification, site mapping and data analysis. This is a good development. Bioindicator work requires students to identify organisms, record where they are found, process data, and interpret patterns in biological communities, and digital resources can help in each of these steps in the field (Markert et al., 2019; Skliar et al., 2024).

Fieldwork is key to bioindicator education. In field based projects, students collect water samples from rivers or lakes and observe and analyze environmental conditions first hand. Such activities promote bioindicator literacy, as students need real data to grasp the links between organisms, habitats, and environmental pressures (Koyama & Watanabe, 2023; Urabe et al., 2018). Time in the field also teaches students that environmental quality manifests itself both in physicochemical parameters and in the response of organism communities (O'Neil et al., 2020; Zimmerman & Weible, 2017). But to get these benefits, you have to design your field activities carefully, otherwise they're just general observations. Students require well-defined tasks such as selecting sampling locations, recording habitat conditions, recognizing bioindicator organisms, correlating their observations with environmental parameters, and developing interpretations of water quality through evidence (Ha & Choi, 2023; Stanfield et al., 2022).

Instructors also reported several obstacles (Table 4) such as lack of adequate laboratory facilities, limited field activities, difficulty in using data analysis applications, and limited accuracy of identification applications. The latter deserves special attention because the use of such applications by instructors is widely reported. The identifications should be cross-checked with morphological features, taxonomic literature and scientific discussion as the output is not always correct so that students do not just accept what the application tells them (Obolewski, 2025). Digital resources can support learning, but should not replace students' own scientific reasoning (Hu et al., 2026). These barriers also help to explain why students scored the lowest on practical implementation, conceptual knowledge and critical evaluation. Students have few chances to practice sampling, identification, preservation and data analysis due to poor facilities and infrequent fieldwork (Burger & Schwenk, 2021; Heard, 2016; Windschitl et al., 2007). Challenges with analysis software can complicate the translation of observations to meaningful ecological interpretations for students (Bravo et al., 2016; Irish et al., 2019). The constraints on facilities and technology are therefore not incidental. These correspond closely to the dimensions in which students performed worst, suggesting that the bioindicator literacy gap is due not only to how the subject is taught but also to the resources available for teaching it. This link is addressed in the following recommendations.

Recommendations for teaching and strengthening bioindicator literacy

The weaknesses are of different kinds and require different kinds of responses, and the three dimensions with the lowest scores (practical implementation, conceptual knowledge and critical evaluation) require more fundamental changes to teaching than the others. Conceptual instruction should go beyond definitions. Students need concrete examples of how changes in the abundance, dominance, or distribution of organisms are

indicators of environmental change (Anderle et al., 2024; Celades et al., 2021; Khalil et al., 2021). The weakest dimension is the practical implementation and this cannot be dealt with in the classroom alone. Students need more frequent hands-on fieldwork for sample collection, operation of field equipment, and proper specimen preservation (Sholihah & Malahayati, 2025; Stanhope et al., 2017). Instead of addressing organism identification as a standalone task, students should be guided to analyze biological and physicochemical data in conjunction to foster critical evaluation, as no single organism can be representative of the overall water quality (Xue et al., 2023).

Teaching on policy and management should go beyond identification and description of water quality. Students should be trained to use biological data to evaluate the degree of compliance with environmental standards and to propose realistic improvements (Ivanova et al., 2022). Assessment is another thing. The ability of the student to sample correctly, identify organisms correctly or integrate biological and physicochemical evidence is not directly demonstrated by written tests, reports and presentations. Rubrics should be updated to evaluate these skills directly rather than primarily students' written products (Markert et al., 2019; Skliar et al., 2024). In terms of technology, instructors are already using applications for identification, site mapping and data analysis. Because identification applications are not always reliable, the goal is not to develop more applications but to develop tools and routines to help students check automated identifications with morphological characters and taxonomic references (Jansen et al., 2019; Roy et al., 2025; Saboe et al., 2021). Finally, field ethics should be taught explicitly, not through general guidance. Students require explicit guidance on habitat conservation, field safety, conscientious handling of organisms, and their duties to local communities and the environment (Semilarski & Laius, 2021; Stanfield et al., 2022).

There are several limitations to be recognized. The study was primarily descriptive in nature. While it reports on students' bioindicator literacy and current instructional practices, it does not enable causal explanations of the low scores on certain dimensions, and so the links made in the discussion between these scores and instructional or resource constraints should be taken as interpretive rather than causal. Second, bioindicator literacy was assessed using a written instrument, which may not reflect how students actually perform in the field, especially in sampling, specimen preservation, taxonomic identification, and direct analysis of environmental data. Third, it did not examine the differences between institutions in curriculum design, laboratory facilities, or quality of fieldwork. Future research such as direct assessment of performance in the field, analysis of student project reports, and in-depth interviews with instructors and students could fill these gaps. Experimental or longitudinal designs would also be necessary to test whether the teaching strategies recommended here improve bioindicator literacy over time.

CONCLUSION

The results of this study indicate that the students' bioindicator literacy is in the low category. The lowest scores were in the dimensions of practical implementation, conceptual knowledge and critical evaluation. These results indicate that students do not yet possess good skills in understanding basic concepts related to bioindicators, implementing environmental monitoring procedures in the field, and critically interpreting biological and physicochemical data. In fact, bioindicator education at the university level includes

theoretical lectures, discussions, case studies, field observations and digital technology. These practices have been not fully effective, but effectively strengthen students' bioindicator literacy. Constraints to be addressed include limitations in laboratory facilities, restricted field activities, challenges in the use of data analysis applications, and potential inaccuracies in organism identification applications. Thus, bioindicator education should be geared toward more structured, data-driven and field-based learning experiences. Explicit training is needed on sampling, identification of organisms, environmental data analysis, water quality assessment and development of evidence-based management recommendations. Future research should explore the relationship between instructional design, field experience, and increases in bioindicator literacy, and test the ability of AI assisted tools for organism identification verification to meaningfully bolster bioindicator education in higher education institutions.

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