



INTEGRATING INDIGENOUS ETHNOBOTANICAL AND PHYTOCHEMICAL KNOWLEDGE INTO A BIOINFORMATICS MODULE FOR SUSTAINABLE BIOLOGY EDUCATION

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ABSTRACT

This study aims to develop a bioinformatics module for pre-service biology teachers by integrating indigenous ethnobotanical knowledge and phytochemical information from medicinal and cosmetic plants traditionally used by the Baduy community. The study used a Research and Development (R&D) design based on a modified 4D model comprising the Define, Design, and Develop stages. The module was developed based on 23 plant species, including 17 medicinal and six cosmetic plants, and incorporated GBIF for taxonomic verification, PubChem for phytochemical and molecular exploration, and Google Colab-supported activities for molecular analysis and phylogenetic reconstruction. Seven experts (three bioinformatics experts, two ethnobotany experts, and two learning-media experts) and 16 pre-service biology teachers (eight Indonesian and eight Thai students) evaluated the module. Expert and student responses were analyzed qualitatively using thematic analysis. The findings showed that the module was perceived as relevant to bioinformatics, genetics, and biotechnology learning, and that its sequential learning activities helped students engage with complex bioinformatics content. Participants also perceived potential benefits for digital literacy, bioinformatics skills, computational thinking, research skills, and pedagogical competence. However, the study was limited to developmental evaluation with a relatively small sample and did not test instructional effectiveness. Overall, the module showed preliminary relevance and usability as a contextual learning resource that integrates indigenous plant knowledge with contemporary bioinformatics learning.

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Keywords: Baduy tribe; bioinformatics module; ethnobotanical; phytochemical; Biology education

INTRODUCTION

Indigenous knowledge and biodiversity conservation are increasingly relevant to sustainable development because traditional communities maintain valuable knowledge regarding the use and management of biological resources. This is closely related to SDG 4 (Quality Educa-

tion), particularly education for sustainable development, and SDG 15 (Life on Land), which emphasizes biodiversity conservation and sustainable use of terrestrial resources (Arora & Mishra, 2019). The Baduy community in Banten, Indonesia, preserves extensive traditional knowledge of plants used for food, medicine, body care, and household purposes, which is transmitted orally across generations (Habiyaemye & Korina, 2021; Hariyadi et al., 2024; Daman-

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huri et al., 2025; Hendrawati & Saepudin, 2026). However, such indigenous knowledge has rarely been connected with contemporary biological databases and computational approaches that could strengthen its scientific interpretation and educational value (Li et al., 2025a; Tiwari, 2026). A preliminary study through interviews with a Baduy community leader indicated that medicinal and cosmetic plants remain an important part of daily life, including plants used for traditional medicines, cosmetics, soaps, shampoos, and toothpaste. In parallel, a needs analysis in bioinformatics learning indicated the need for locally contextualized learning resources that allow pre-service biology teachers to connect biological databases with authentic biological phenomena. Earlier research studies found various difficulties in teaching bioinformatics. Magana et al. (2014) revealed that bioinformatics education needs to combine competencies in biology, computing, and data analysis. Thus, bioinformatics' interdisciplinary nature makes it an ongoing instructional challenge. In more recent research, Mello et al. (2025) outlined obstacles in terms of complexity of data, infrastructure, and preparation of teachers, and thus the presence of bioinformatics tools is not enough to assure the successful implementation of these tools in science education. Sari et al. (2024) proved the possibility of using NCBI-BLAST and sequence analysis tools for genetics instruction, yet the main emphasis was on the introduction of the tools themselves instead of embedding them in a certain context of learning. The same can be said about recent bioinformatics learning research, where researchers introduced digital and computational elements, yet the research did not offer a sufficient integration of indigenous ethnobotanical knowledge as a basis for exploring biological data.

These conditions indicate a need for learning materials that make bioinformatics more meaningful by connecting computational biological analysis with indigenous biodiversity and locally relevant biological resources.

Previous studies have provided important but still fragmented foundations. Ethnobotany-based learning modules and booklets have successfully contextualized biology learning and received positive validation and student responses (Khastini et al., 2019; Nurjanah & Laguatan, 2025; Muhammad et al., 2026; Suleman et al., 2026; Yani & Sapriati, 2026), while Atmojo et al. (2025) have emphasized the role of ethnoscience and local wisdom in bridging scientific and cultural knowledge. Conversely, bioinformatics learning modules have introduced students to

computational analysis of natural products, such as predicting active compounds (Dhaniaputri et al., 2024), but generally do not integrate ethnobotanical documentation, taxonomic verification, phytochemical exploration, molecular analysis, phylogenetic reconstruction, and pedagogical reflection into a single learning pathway. Thus, the research gap lies in the limited integration of indigenous ethnobotanical knowledge, phytochemical information, and bioinformatics learning for pre-service biology teachers. This study's novelty is the development of an ethnobotanical-phytochemical-bioinformatics learning pathway in which indigenous plant knowledge serves as the starting point for evidence-based computational biological investigation.

Previous ethnobotany-based modules provide contextual and culturally relevant biology learning but generally remain focused on descriptive plant use, biodiversity, or local wisdom without incorporating computational biological analysis. In contrast, bioinformatics-based modules introduce students to biological databases, molecular analysis, and computational tools, but often use decontextualized or general biological datasets and rarely draw on systematically documented indigenous knowledge. Therefore, this study's novelty lies not merely in combining ethnobotany and bioinformatics, but in constructing a sequential learning pathway in which indigenous plant knowledge becomes the starting point for taxonomic verification, phytochemical exploration, molecular data analysis, and pedagogical reflection. Theoretically, integrating indigenous knowledge and bioinformatics learning bridges culturally embedded biological knowledge and contemporary data-driven science. Indigenous knowledge offers authentic biological contexts shaped by long-term interactions between communities and biodiversity, while bioinformatics provides scientific tools to verify, interpret, and extend this knowledge through taxonomic, molecular, and phytochemical databases.

Accordingly, this study aims to develop and establish the preliminary feasibility of a bioinformatics module integrating ethnobotanical and phytochemical knowledge of medicinal and cosmetic plants for pre-service biology teachers using a modified 4D framework. Specifically, the study aims to: (1) identify learning needs, relevant ethnobotanical contexts, and module learning objectives at the Define stage; (2) design a sequential bioinformatics learning pathway integrating biological databases and computational activities at the Design stage; and (3) develop and preliminarily evaluate the module through expert

review and pre-service biology teachers' responses at the Develop stage. Through these stages, the study provides an integrative framework connecting indigenous knowledge, biodiversity, digital biological data, and computational practices in biology teacher education.

METHODS

This study employed Research and Development (R&D) using the Four-D (4D) instructional development model introduced by Thiagarajan, as cited in Lawhon (1977), consisting of Define, Design, Develop, and Disseminate stages. The model was modified into three stages—Define, Design, and Develop—because the present study focused on developing and establishing the module's preliminary feasibility rather than its large-scale dissemination. The developed product was a bioinformatics module integrating ethnobotanical and phytochemical information on medicinal and cosmetic plants traditionally used by the Baduy community.

The module content was based on 23 plants, consisting of 17 medicinal and six cosmetic plants identified from the Baduy community in Banten, Indonesia. Participants involved in the development stage included experts in bioinformatics, ethnobotany, and learning media, as well as pre-service biology teachers from public universities in Indonesia and Thailand. Experts were selected using purposive sampling based on their academic expertise, teaching or research experience, and relevance to the content of the developed module. The 16 student participants were also selected using purposive sampling based on their status as pre-service biology teachers, their relevance as intended users of the module, and their willingness to participate in the module evaluation.

The development procedures consisted of three stages. The Define stage involved curriculum and needs analyses to determine relevant learning outcomes, student characteristics, and the potential integration of indigenous plant knowledge into bioinformatics learning. The team analyzed curriculum documents from a biology education program and obtained preliminary information on medicinal and cosmetic plant use from the Baduy community. The findings informed the module's learning objectives and content scope.

Design involved constructing the module structure and sequential learning activities. Ethnobotanical information was transformed into bioinformatics learning activities involving taxo-

nomic verification, phytochemical exploration, molecular data analysis, and pedagogical reflection. GBIF supported taxonomic exploration (Robertson et al., 2019; El-Gabbas, 2026), PubChem supported phytochemical and molecular information (Bultum et al., 2019; Kim et al., 2025), and Google Colab supported molecular data processing and phylogenetic learning (Vallejo et al., 2022).

The Develop stage involved producing the module prototype, conducting expert evaluation, collecting pre-service biology teachers' responses, and revising the module. Bioinformatics, ethnobotany, and learning-media experts used feedback to evaluate scientific accuracy, curriculum relevance, learning systematics, presentation, and potential skill development. The module was implemented over approximately 90 minutes and included module orientation, guided database exploration, discussion, and completion of an open-ended evaluation questionnaire. Student responses were used to assess the module's clarity, practicality, and perceived learning potential. Revisions were conducted based on recurring suggestions and identified weaknesses.

Data were collected using document-analysis sheets, preliminary interview guidelines, and an open-ended module evaluation questionnaire. The expert and student evaluation instrument covered five dimensions: (1) curriculum relevance, (2) learning content, (3) systematic learning stages, (4) appearance and design, and (5) potential skill development. Each dimension included questions concerning strengths, weaknesses, applicability, and recommendations for improvement. For example, responses indicating that the module was "difficult at the beginning" were coded as initial complexity and grouped under the theme learning-stage difficulty, while requests for additional tutorials were coded as need for guidance and grouped under required scaffolding. Three validators with relevant expertise in biology education and instrument development qualitatively validated the evaluation instrument. No quantitative content-validity index was calculated because the validation was conducted qualitatively. The validation focused on content relevance and language clarity, and the instrument was revised based on their feedback before use. The module and evaluation questionnaire were provided in English to ensure consistency across Indonesian and Thai participants. Participants could provide clarification in their preferred language when needed. Responses provided in Indonesian or Thai were translated into English before analysis. Bilingual members of the research team

checked the translations to preserve the intended meaning of the responses. Informed consent was obtained from all participants prior to data collection. Permission to document ethnobotanical information was obtained from the relevant Baduy community representative. Only information voluntarily shared for educational and research purposes was documented, while culturally sensitive or restricted indigenous knowledge was excluded.

All subjects were informed of the study objectives and procedures and gave informed consent before participating. Permission was sought to record any ethnobotanical data from the proper representative of the Baduy community. Information not freely offered for educational and research purposes was not considered, and culturally sensitive or restricted indigenous knowledge was excluded. We used source triangulation by comparing feedback from experts in bioinformatics, ethnobotany, learning media, Indonesian students, and Thai students.

Curriculum documents and preliminary interview data were analyzed descriptively to

identify learning needs and relevant indigenous plant contexts. Expert evaluations and pre-service biology teachers' open-ended responses were analyzed qualitatively using thematic analysis adapted from Braun & Clarke (2012). The analysis involved six steps: (1) familiarization with the responses, (2) generation of initial codes, (3) grouping related codes into preliminary themes, (4) reviewing themes against the original responses, (5) defining and naming the final themes, and (6) reporting the themes according to the five evaluation dimensions. Coding focused on recurring strengths, weaknesses, usability issues, and recommendations for module improvement (Saunders et al., 2023). The results were summarized by the five evaluation dimensions, using representative responses to explain major strengths, weaknesses, and recommendations. This qualitative analysis guided iterative revisions of the developed module rather than determining instructional effectiveness. Table 1 presents the components of the bioinformatics module.

Table 1. Bioinformatics Module Assessment Components

Aspects assessed	Evaluation focus
Curriculum	Alignment with learning outcomes and applicability to related courses
Learning Content	Scientific relevance and integration of ethnobotany, phytochemistry, and bioinformatics
Systematics of Learning Stages	Sequence, clarity, and coherence of learning activities
Appearance and Design	Readability, visualization, and usability of the module
Skill development	Potential contribution to bioinformatics, digital, computational, research, and pedagogical skills

RESULTS AND DISCUSSION

A bioinformatics module needs analysis was conducted by examining the undergraduate biology curriculum at a state university in Banten, Indonesia. The university's department has a scientific vision: to develop superior biology education oriented toward the sustainable development of local tropical potential to support an Integrated, Smart & Green University with character and global competitiveness. This is Banten University's distinctive feature: emphasizing the potential of tropical localities in line with their characteristics and natural conditions. Based on document analysis and exploration of medicinal and cosmetic plants used by the Baduy community, we identified a need for learning materials that leverage local potential, including integrating ethnobotanical content with phytochemical insights on Baduy medicinal and cosmetic plants.

The document analysis showed that the biology education curriculum emphasizes the sustainable development of local tropical potential. Accordingly, the integration of Baduy medicinal and cosmetic plants was identified as a relevant context for developing bioinformatics learning materials. Based on these findings, four learning objectives were formulated: 1) explaining the scope and role of bioinformatics in everyday life, specifically related to medicinal and cosmetic plants from the Baduy Tribe; 2) exploring various biological databases such as GBIF and PubChem to ensure and verify that the medicinal and cosmetic plant content aligns with the traditional knowledge of the Baduy people. 3) applying BLAST to construct phylogenetic trees, and 4) applying bioinformatics in biology learning activities. Figure 1 presents the resulting conceptual framework.

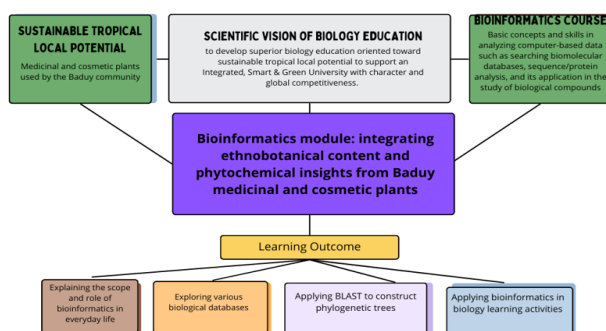


Figure 1. Concept Map of Integrating Ethnobotanical and Phytochemical Insights of Baduy Medicinal and Cosmetic Plants into a Bioinformatics Module for Pre-Service Biology Teachers

Designing a bioinformatics module that integrates ethnobotanical and phytochemical insights regarding Baduy medicinal and cosmetic plants using Canva, featuring a blue cover that in-

cludes the title, illustrations of DNA chains, molecules, and nucleotide bases, as well as images of the Baduy people and examples of medicinal and cosmetic plants (Figure 2).

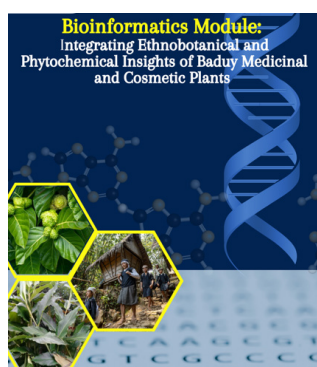


Figure 2. Cover of Bioinformatics Module

The module begins with a description of the Baduy people, their way of life, and the medicinal plants and cosmetics they commonly use, then moves into high technology through bioinformatics, as scientists bring these practices into the modern scientific realm. The section is entitled “Finding Science in Local Wisdom: From Baduy Plants to Modern Bioinformatics,” with subtitles “Background: Local Potential of

Baduy Medicinal and Cosmetic Plants” and “Integration of Bioinformatics in Modern Biology”. Next is the Objectives and Benefits of Learning Through This Module section. The core section of the title is “The Triggering Problem: Molecular Traces from the Baduy Forest,” the initial part of the investigation, with the module page displayed in Figure 3. It includes a brief case presentation and ends with 2 trigger questions.

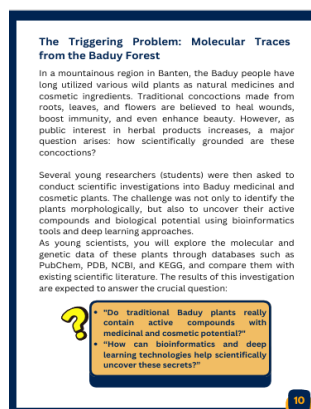


Figure 3. Initial Case in the Bioinformatics Module

The next component is the exploration and plant identification stage using GBIF. The appearance of this section can be seen in Figure 4.



Figure 4. Initial Exploration and Plant Identification View Using GBIF and PubChem

We provided local names, GBIF-confirmed scientific names, traditional claims of benefits, morphological documentation, compounds identified in PubChem, and biological benefits.

This process was repeated for 17 medicinal plants and 6 cosmetic plants sampled from interviews with Baduy people, as presented in Tables 2 and 3.

Table 2. Summary of Baduy Medicinal and Cosmetic Plants Included in the Bioinformatics Module

Plant category	Number of species	Example species	Traditional uses	Bioinformatics exploration
Medicinal plants	17	<i>Piper sarmentosum</i> , <i>Blumea balsamifera</i> , <i>Physalis angulata</i>	Fever, stomach disorders, wounds, respiratory conditions	GBIF verification and PubChem phytochemical exploration
Cosmetic plants	6	<i>Ayapana triplinervis</i> , <i>Pogostemon cablin</i> , <i>Etlingera elatior</i>	Perfume, hair care, soap, skin care	GBIF verification and PubChem phytochemical exploration

***Note:** Detailed ethnobotanical and phytochemical data for all 23 plant species are provided in the Supplementary Material

The initial version of the bioinformatics module in this study was delivered as an electronic module (e-module) and assessed using the components listed in Table 1. Bioinformatics experts, ethnobotanists, learning media experts, and pre-service biology teachers from Indonesia and Thailand provided their assessments using the same components to ensure equal assessment rights across aspects from their perspectives. The experts included three bioinformatics experts, two ethnobotanists, and two learning media experts. Participant anonymity was maintained by assigning consistent codes: BE1–BE3 for bioinformatics experts, EE1–EE2 for ethnobotany experts, ME1–ME2 for media experts, IDN-S1–IDN-S8 for Indonesian students, and THA-S1–THA-S8 for Thai students.

Table 3 presents the results of the thematic analysis of the bioinformatics module assessment by experts. Experts indicated that the module

needs to explicitly specify its difficulty level and target audience, clarifying whether it is suitable for the undergraduate or graduate level. Additionally, learning media experts suggested adjusting the illustrations to avoid appearing too childish and incorporating interactive multimedia.

Each of the answers could have been categorized under several themes since there were more than one competency involved. Frequencies of the themes, therefore, indicate how many respondents used each of the themes and hence are not exclusive of each other. Quotations representative of the themes were chosen from the interviews, including codes for anonymity purposes. Quotes from Indonesian respondents were translated into English without altering the meaning.

The experts generally considered the module relevant and interdisciplinary, although they emphasized the need to clarify its level of difficul-

ty and provide additional guidance for complex activities. For example, one bioinformatics expert stated, “*The steps are clear but difficult at the beginning*” (BE2), while a learning-media expert noted, “*The Baduy context makes the topic more interesting*”

(ME1). An ethnobotany expert also emphasized the value of connecting local plant knowledge with modern biological analysis: “*More tutorials are needed for database use*” (EE1).

Table 3. Thematic Analysis of Bioinformatics Module Assessment by Experts

Aspect Assessed	Bioinformatics Experts	Ethnobotanists	Learning Media Experts
Curriculum	The module is considered relevant to OBE and 21st-century demands because it trains in biological data analysis and computational thinking. However, it needs to strengthen the scientific background and clarify the level of difficulty in accordance with the CPMK.	Appreciate the integration of Baduy local wisdom into the curriculum and the modules’ flexibility for various biology courses. Assess the module’s contextual nature and support for multidisciplinary learning.	The module’s alignment with the curriculum is assessed in terms of the integration of objectives, materials, and activities, but it emphasizes the need for more explicit objectives and a clearer flow to support student follow-up.
Learning Content	The content is considered rich because it uses NCBI, PubChem, KEGG, and BLAST to analyze compounds and biological targets. It is recommended to select cases for which data are actually available in databases.	Assess the strength of the content in linking traditional knowledge of medicinal/cosmetic plants with modern scientific analysis. Suggest deepening the phytochemistry material to make it more representative.	The content is relevant but needs simpler language and illustrations to support independent understanding of complex material.
Systematics of Learning Stages	The data exploration-analysis-interpretation flow across the learning stages is consistent with the bioinformatics workflow, but some steps are too complex for beginners.	Appreciate the contextual flow from local exploration to modern science, but suggest clearer explanations of the transitions at each stage.	The systematics are sufficiently coherent and well structured, but recommend adding a communication stage for results and visual guidance to support follow-through.
Appearance and Design	The visuals are adequate for data exploration, but the team would like more informative visuals to explain molecular concepts.	The design is attractive, but add visuals of plants, maps, or Baduy culture to strengthen the local context.	The e-module is modern, user-friendly, and communicative, but the visual style needs adjustment to avoid being overly childish, and interactive multimedia should be added.
Skill Development	The module emphasizes data analysis skills, pattern recognition, and algorithmic thinking as key strengths.	Viewing the module fosters an appreciation for biodiversity and local wisdom while also fostering scientific thinking.	The module supports digital literacy, independent learning, scientific communication, and 21st-century skills for pre-service biology teachers.

Based on the expert evaluation, several revisions were made to address the identified issues related to learning level, scaffolding, visualizati-

on, multimedia support, and database accessibility. Table 4 summarizes the specific expert concerns and corresponding revisions to the module.

Table 4. Expert-Identified Issues and Corresponding Revisions to the Bioinformatics Module

Expert-identified issue	Evidence from expert feedback	Revision made to the module
Learning level and difficulty were unclear.	"There should be clear boundaries according to the educational level..." (EE1, translated)	The module was explicitly designated for undergraduate Biology Education students, and the expected learning level was clarified.
Beginners require more guidance.	"...students, especially those with limited prior experience, may find the tools and associated terminology overwhelming." (BE1)	Additional guidance and step-by-step instructions for database exploration were incorporated.
Molecular concepts require visualization.	"3D model of DNA" (EE2, translated)	Added supporting 3D DNA/protein visualization materials.
Baduy context required stronger visualization.	"A video about Baduy could be added..." (EE1, translated)	Added supporting Baduy cultural videos and contextual visual materials.
Multimedia should be strengthened.	"...interactive multimedia (videos or direct simulations)..." (ME1, translated)	Supporting bioinformatics explanation videos and multimedia links were incorporated.
Database information may be unavailable in some cases.	"As the example cases, some information cannot be found in the database." (BE3)	Example cases were reviewed, and activities were directed toward plants and compounds with accessible database information.

Based on Table 4, overall, expert feedback led to concrete revisions in learning-level clarity, scaffolding, visualization, multimedia support, and case selection. The team incorporated these revisions before implementing the module with pre-service biology teachers. The implementation activities began by introducing a bioinformatics module that integrates ethnobotanical and phytochemical insights of Baduy medicinal and cosmetic plants, then introducing the Baduy community and the medicinal and cosmetic plants they use, how to use the bioinformatics module, its uses, and stages. In the initial stage, eight Indonesian and eight Thai pre-service biology teachers explored Baduy medicinal plants using GBIF, and in the second stage, searched for content, mo-

lecular structures, and other molecular information through PubChem. They were very excited and found the learning activity interesting. The learning activity concluded with discussions, recording important information, and presenting the results. Finally, they completed a qualitative survey on the use of bioinformatics modules. The researchers further coded student responses into six perceived competency themes. Table 5 presents the frequency and proportion of each theme among the 16 pre-service biology teachers. Since participants could mention more than one competency, the percentages do not total 100%. Table 5 presents the results of the thematic analysis of bioinformatics module feedback on its use.

Table 5. Frequency and Proportion of Perceived Competency Themes Reported by Pre-service Biology Teachers

Perceived competency	Indonesian n/8	Thai n/8	Total n/16 (%)	Representative evidence
Digital literacy/technology use	6	4	10 (62.5%)	"Digital literacy, computational thinking, and scientific literacy" (IDN-S6, translated); "Digital Literacy (Using database tools like PubChem)" (THA-S3)
Bioinformatics skills	0	3	3 (18.8%)	"Data literacy and bioinformatics skills" (THA-S6); "Bio-data analysis skills" (THA-S8)
Computational thinking	3	2	5 (31.3%)	"Science process skills, computational thinking, and scientific literacy" (IDN-S1, translated); "Computational Thinking skills" (THA-S8)

Perceived competency	Indonesian n/8	Thai n/8	Total n/16 (%)	Representative evidence
Science process / scientific inquiry	1	1	2 (12.5%)	"Science process skills..." (IDN-S1, translated); "Scientific inquiry and research skills" (THA-S6)
Research skills	1	4	5 (31.3%)	"...digital literacy, critical thinking, and research ability" (IDN-S7, translated); "Research skills, data manipulation skills" (THA-S5)
Pedagogical competence / TPACK	1	4	5 (31.3%)	"Pedagogical skills" (IDN-S8, translated); "...elevating their Technological Pedagogical Content Knowledge (TPCK)" (THA-S8)

Among the 16 student participants, digital literacy or technology use was the most frequently perceived competency, mentioned by 10 students (62.5%). Computational thinking and research skills were each mentioned by five students (31.3%), and pedagogical competence, or TPACK, was also identified by five students (31.3%). Three students explicitly mentioned bioinformatics-specific skills (18.8%), and two students mentioned science process or scientific inquiry skills (12.5%). These findings represent participants' perceptions of the module's potential rather than measured improvements in competency.

Table 6. Thematic Analysis of Indonesian & Thai Students' Responses to Bioinformatics Modules

Aspect Assessed	Indonesian Students'	Thai Students'
Curriculum	Assessing modules is highly relevant to the digital-age biology curriculum because it links biological concepts with data analysis, scientific databases, and computing.	Assessing modules are highly relevant to the digital-age biology curriculum because they link biological concepts with data analysis, scientific databases, and computing.
Learning Content	The content is strong because it uses PubChem and gene databases for sequence analysis, gene expression, and protein structure. This content supports an analytical understanding of biology, although selecting a more focused research topic is recommended to maintain relevance.	The content is considered strong because it uses PubChem and gene databases for sequence analysis, gene expression, and protein structure. This content supports an analytical understanding of biology, although more focused topic selection is recommended to maintain relevance.
Systematics of Learning Stages	The learning flow is perceived as consistent and logical, from information gathering to practical application. Inquiry and project models are considered challenging yet meaningful, although initial complexity and limited interaction require additional guidance and tutorials.	The learning flow is perceived as consistent and logical, from information gathering to practical application. Inquiry and project models are considered challenging yet meaningful, although initial complexity and limited interaction require additional guidance and tutorials.
Appearance and Design	The e-module is considered modern, professional, and user-friendly, with clear navigation and supportive visuals.	The e-module is considered modern, professional, and user-friendly, with clear navigation and supportive visuals.
Skill Development	The module was found to be strong in developing digital literacy, computational thinking, research, TPACK, critical thinking, and independent learning. While it still needs more detailed guidance, the module is considered relevant for preparing pre-service biology teachers for the 21st century.	The module was found to be strong in developing digital literacy, computational thinking, research, TPACK, critical thinking, and independent learning. While it still needs more detailed guidance, the module is considered relevant for preparing pre-service biology teachers for the 21st century.

Based on this expert's feedback, we made improvements to the module and the final dissemination. The improvements included adding a sentence encouraging students to analyze medicinal or cosmetic plants by answering scientific questions and completing the activity using a bioinformatics database. The cover states that this module is designed for biology education students, meaning it is intended for students majoring in biology. Supporting materials such as 3D DNA/protein models, bioinformatics explanation videos, and Baduy culture videos were added to facilitate visualization and context.

The module was generally perceived as relevant and meaningful, but both expert and student responses also revealed an important instructional challenge: several bioinformatics activities were technically demanding for beginners. Tasks involving database navigation, molecular information, sequence analysis, and interpretation require not only biological knowledge but also digital and computational familiarity. Therefore, the module should not be implemented as a fully independent learning resource without adequate scaffolding. Step-by-step tutorials, worked examples, guided database exploration, visual explanations of molecular concepts, and gradual progression from simple data retrieval to more complex analysis are needed, particularly during the initial stages of learning. This finding suggests that the effectiveness of contextual bioinformatics learning depends not only on the authenticity of the biological context but also on the level of instructional support provided to learners. This contextualization is particularly relevant because bioinformatics databases and tools have become important components of contemporary biology education (Sari et al., 2025; Ebbs et al., 2026). In the developed module, GBIF supports taxonomic and distributional verification of traditionally used plants, whereas PubChem provides access to chemical compounds and associated biological information (Kim et al., 2016; Smith et al., 2016; Pandey et al., 2022; El-Gabbas, 2026). Therefore, the module connects indigenous knowledge with data-driven biological investigation rather than presenting local wisdom merely as contextual information.

The identification of 17 medicinal and six cosmetic plants further demonstrates the richness of biological knowledge maintained by the Baduy community. Their traditional uses cover health-related purposes such as fever, digestive disorders, respiratory problems, wounds, and body aches, as well as personal-care purposes including skin care, fragrances, and natural cleansing. This di-

versity reflects the close relationship between indigenous communities and their surrounding ecosystems, where plant functions are recognized through knowledge accumulated and transmitted across generations. Similar patterns have been reported in global ethnobotanical studies showing that indigenous communities possess extensive ecological knowledge adapted to health, subsistence, and everyday needs (Brondízio et al., 2021). This study extends this ethnobotanical information into a learning pathway in which traditional plant claims can be examined using taxonomic, phytochemical, and molecular data.

Expert evaluations indicate that the module is relevant to contemporary biology education because it combines bioinformatics, genetics, biotechnology, ethnobotany, and computational approaches within a contextual learning environment. Its multidisciplinary character is consistent with previous studies describing bioinformatics education as an interdisciplinary field connecting biological science with computational and data-analysis practices (Aron et al., 2021; Johnston et al., 2022; Wang, 2024). The experts also valued databases such as NCBI, PubChem, KEGG, and BLAST, but emphasized selecting database-accessible cases and adjusting activity complexity to learners' level. This finding supports previous reports that bioinformatics content can be contextualized through authentic biological problems and data-driven investigations (Hu et al., 2019; Karim et al., 2021; Tang et al., 2024). The sequential progression from local exploration to data retrieval, analysis, and interpretation therefore represents an important instructional feature, although appropriate scaffolding remains necessary for beginners.

The findings suggest that the module's value lies not only in introducing bioinformatics tools but also in providing a culturally meaningful entry point for data-driven biological inquiry. By beginning with indigenous plant knowledge, students can connect ethnobotanical information with taxonomic, phytochemical, and molecular databases. This approach may support biology teacher education by linking local biological contexts with digital data literacy and evidence-based reasoning. However, the module should be interpreted as a contextual learning resource with preliminary feasibility rather than as evidence of instructional effectiveness (Pertiwi et al., 2024).

Indonesian and Thai students' responses also need to be interpreted within their different cultural and educational contexts. For Indonesian students, the Baduy context represents indigenous knowledge rooted in their national

and regional environment, which may support contextual familiarity and cultural relevance. In contrast, Thai students approached the same material as an unfamiliar indigenous context, making the module function more as a cross-cultural bioinformatics learning experience. Despite this difference, both groups valued integrating biological databases and computational activities. This suggests that local ethnobotanical contexts may support culturally situated learning for domestic students while also offering comparative and intercultural learning opportunities for international learners. However, the small number of participants means that these contextual differences should be interpreted cautiously rather than generalized as national differences.

The perceived potential for developing data analysis, pattern recognition, computational thinking, digital literacy, research, scientific communication, and pedagogical skills is consistent with previous studies emphasizing the contribution of bioinformatics learning to computational and professional competencies in biology education (Wilson Sayres et al., 2018; Goller et al., 2021; El Islami et al., 2023; Rafik & Sari, 2023). The novelty of the present module lies in its ethnobotanical–phytochemical–bioinformatics learning pathway: it uses indigenous plant knowledge as the starting point for taxonomic verification, phytochemical exploration, molecular data analysis, and pedagogical reflection. Thus, rather than treating ethnobotany and bioinformatics as separate learning domains, the module connects traditional biological knowledge with contemporary computational practices to support sustainability-oriented biology teacher education.

One major limitation is that bioinformatics databases cannot be used to verify claims about traditional medicine or cosmetics. GBIF may help in providing information regarding taxonomic identification and distribution of the plants, and PubChem contains information regarding chemicals and biological properties of the claimed compounds (Diallo et al., 2021; Perez-Mon et al., 2026); but even if a compound or a biological activity is present, that will not prove its clinical efficacy, dosage, safety, and traditional usage methods for the plants. Database coverage may also differ across plants, and some important local plants may have limited information on their molecular or phytochemical profiles. Thus, database searching in this module should be used only as a research tool to verify evidence, not to verify indigenous medicinal claims.

Several factors may influence the module's effectiveness in future implementation. The technical complexity of database navigation,

molecular-data interpretation, and phylogenetic analysis may create difficulties for students with limited prior bioinformatics experience (Irizarry et al., 2025). Differences in digital competence, biological background, language, and familiarity with the Baduy context may also affect engagement with the learning activities. Therefore, adequate scaffolding is required, including step-by-step tutorials, worked examples, visual support, and gradual progression from basic database exploration to more complex computational analysis. These challenges indicate that future effectiveness studies should examine not only learning outcomes but also learners' prior knowledge, digital readiness, and the level of instructional support provided.

In practice, the module can be applied to bioinformatics, genetics, biotechnology, ethnobotany, or molecular biology classes for training pre-service biology teachers. Instructors may start with indigenous plants as a case study to teach taxonomic identification, chemical database searching, sequence analysis, phylogenetic interpretation, and scientific validation of biological statements. In addition, this module can facilitate tasks in which students compare traditional knowledge with database knowledge and create biology lessons based on the outcomes of the comparison. As a teacher-education strategy, this method offers a pragmatic framework for linking traditional or indigenous biological knowledge with digital literacy and scientific reasoning without treating traditional knowledge as scientifically false or scientifically validated.

Integrating Baduy traditional knowledge into bioinformatics learning also requires careful ethical consideration. Indigenous knowledge should not be treated merely as freely accessible data, because such knowledge is embedded in community ownership, cultural identity, and collective rights. The CARE Principles for Indigenous Data Governance emphasize collective benefit, authority to control, responsibility, and ethical use of Indigenous data and traditional knowledge (Carroll et al., 2020). In addition, the Nagoya Protocol highlights the importance of prior informed consent or community approval and fair and equitable benefit-sharing when accessing and using traditional knowledge associated with genetic resources. Therefore, only knowledge voluntarily shared for educational and research purposes should be included, culturally restricted information should be protected, and the Baduy community should be appropriately acknowledged in the interpretation and educational use of their traditional knowledge.

Furthermore, database-based exploration should not be interpreted as direct scientific validation of traditional medicinal or cosmetic claims (Li et al., 2025b). GBIF can support taxonomic and distributional information, while PubChem provides available chemical and biological information; however, database records cannot establish clinical efficacy, appropriate dosage, safety, or a plant's traditional mode of use. Thus, the module positions bioinformatics databases as tools for evidence exploration and comparison rather than as instruments for confirming indigenous claims. Further phytochemical, pharmacological, toxicological, or clinical investigation would be required to establish such claims.

CONCLUSION

This study developed a bioinformatics module integrating indigenous ethnobotanical knowledge and phytochemical information for pre-service biology teachers. As a preliminary feasibility study, the findings indicate that the module demonstrated relevance and usability based on expert judgment and participant feedback, particularly in linking local biological knowledge with bioinformatics databases and computational activities. Participants also perceived potential benefits for digital literacy, bioinformatics competence, computational thinking, research skills, and pedagogical competence. Theoretically, this study contributes an integrative framework that connects indigenous knowledge, phytochemical information, and bioinformatics learning. Practically, the module provides a contextual learning resource for introducing database exploration and computational biology in biology teacher education. However, these findings should not be interpreted as evidence of instructional effectiveness or actual skill improvement. Further studies using larger samples, validated instruments, and stronger research designs are needed to examine the module's effectiveness, skill-related outcomes, and sustainability-oriented learning outcomes.

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