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Development and Validation of Botani-Co: A Cognitive Botanical Literacy Instrument for University Students

Wiwin Pramita Arif[1,2], Murni Sapta Sari[1], Sri Rahayu Lestari[1]
[1]Universitas Negeri Malang, East Java, Indonesia, [2]Universitas Islam Negeri Alauddin Makassar, South Sulawesi, Indonesia

Corresponding author e-mail: wiwin.pramita@uin-alauddin.ac.id

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Abstract: This study developed Botani-co (*Botanical Literacy Instrument Cognitive*) as an innovative and empirically validated tool to measure university students' botanical literacy. The study aimed to: (1) develop a valid and reliable botanical literacy instrument based on the cognitive dimension, and (2) analyze the characteristics of cognitive test items, including difficulty level, discrimination index, and distractor effectiveness within the cognitive domain of botanical literacy. A Design and Development Research (DDR**)** approach was employed, consisting of two main phases: the *design phase* and the *development phase*. The design phase involved conceptual analysis, indicator formulation, and item construction, whereas the development phase included content validation, empirical testing, and construct analysis. The instrument was administered to 378 university students from various higher education institutions in Indonesia, selected through stratified random sampling based on gender and academic semester. Item analysis for the cognitive dimension produced an overall reliability coefficient (KR-20) of 0.86, indicating high internal consistency. The final instrument comprised 35 multiple-choice items that demonstrated satisfactory validity and reliability across all psychometric criteria. The findings highlight the need to assess botanical literacy through a multidimensional framework, as understanding plants involves cognitive, affective, and psychomotor dimensions. Consequently, *Botani-co* can serve as both a diagnostic and evaluative instrument in biology education to strengthen students' scientific literacy and ecological awareness, aligning with the objectives of Sustainable Development Goal (SDG) 4.7 on education for sustainable development.

Keywords: Botanical Literacy, Cognitive Assessment, Instrument Development

A. Introduction

In school curricula, biology education often emphasizes animal or human organisms, while plants despite their central role in ecosystems, oxygen production, pollination, and other ecosystem services tend to receive less attention. The phenomenon of *plant blindness*, referring to the lack of awareness of the existence and importance of plants,

indicates that many students and members of the public fail to recognize the essential role of plants in daily life and in broader environmental contexts (Achurra, 2022). Therefore, the development of botanical literacy is crucial as a component of comprehensive scientific literacy, enabling students not only to recognize plants superficially but also to understand, appreciate, and apply their knowledge to think critically and act responsibly on environmental and biodiversity issues. Recent studies have shown that botanical literacy supports deeper understanding of ecology, conservation, and the interconnection between humans and plants within a broader environmental framework (Arif et al., 2025). In the Indonesian context where plant diversity is exceptionally high and environmental challenges such as deforestation and climate change are increasingly evident—students' botanical literacy represents a key aspect for developing biological competence and ecological awareness.

Theoretically, botanical literacy can be defined as an individual's ability to recognize, understand, use, and appreciate knowledge about plants, including their biological aspects, classification, diversity, ecology, and relationships with humans and the environment. For instance, a systematic review by Arif et al., (2025) identified that the cognitive dimension of botanical literacy encompasses *plant biological knowledge, plant diversity and classification, and plant ecology and its relationship with the environment*. Thus, botanical literacy is not merely about plant identification or memorization of names, but rather a conceptual understanding that enables individuals to connect plants with ecological processes, environmental changes, and social contexts. Other studies have positioned botanical literacy as a component of broader scientific literacy, requiring the integration of cognitive, affective, and skill-based domains for meaningful implementation (Beasley et al., 2021).

Within the framework of educational measurement, it is essential to clarify three key aspects (Jørgensen, 2000): (1) botanical literacy as the construct being measured, (2) the cognitive dimension as a subcomponent of botanical literacy referring to knowledge, understanding, and thinking processes, and (3) item analysis to ensure the quality of the instrument, including difficulty level, discrimination index, and distractor effectiveness. First, botanical literacy as a construct encompasses three domains—cognitive (plant knowledge, diversity, and ecology), affective (attitudes toward plants and ecological values), and skill-based (plant identification and field activities)—as identified in the literature review (Arif et al., 2025). Second, the cognitive dimension in the measurement instrument refers to students' ability to recall, understand, apply, analyze, evaluate, and create plant-related knowledge—a paradigm consistent with the revised Bloom's taxonomy. For example, the scientific literacy instrument developed by Coppi et al., (2023) incorporates the domains of understanding, analyzing, and evaluating within the cognitive dimension of science literacy. Third, item analysis is a crucial step in instrument development. Multiple-choice items (MCQs) must be examined in terms of difficulty index, discrimination index, and distractor efficiency to ensure that the instrument is both valid and reliable.

For instance, Rezigalla et al., (2024) demonstrated a negative correlation between distractor efficiency and both item difficulty and discrimination indices. This study demonstrates the application of the revised Bloom's Taxonomy (C1–C6) in developing test items, and this theoretical framework further underpins the need to design an instrument specifically aimed at measuring botanical literacy within the cognitive domain and examining its item characteristics to ensure strong psychometric quality. The botanical literacy instrument was developed by fully incorporating all cognitive levels of Bloom's Taxonomy—ranging from the foundational levels of C1 (Remember) and C2 (Understand) to the higher-order levels of C3 (Apply), C4 (Analyze), C5 (Evaluate), and C6 (Create), thereby enabling a comprehensive assessment of students' cognitive abilities in botanical contexts.

Although the body of literature on botanical literacy has continued to expand, several research gaps remain to be addressed. First, most studies on botanical literacy have predominantly focused on the affective domain or plant identification skills, with relatively few that have specifically developed instruments targeting the cognitive dimension of botanical literacy in depth. For instance, while Arif et al. (2025) identified the cognitive dimension of botanical literacy as encompassing "knowledge of plant biology, plant diversity and classification, and plant ecology," few instruments have been explicitly designed to measure these components. Second, only a limited number of studies have reported detailed analyses of cognitive test item characteristics such as difficulty level, discrimination index, and distractor effectiveness within the context of botanical literacy. Although general educational measurement studies have examined item characteristics, these have rarely been applied specifically to botanical literacy (Iñarrairaegui et al., 2022). Third, there is currently no botanical literacy instrument based on the cognitive dimension that has been systematically validated through construct validity testing, reliability analysis, and item diagnostics within the educational context of developing countries such as Indonesia. Therefore, to address these gaps, this study aims to develop a new, valid, and reliable instrument that provides comprehensive psychometric evidence and detailed item analysis to measure the cognitive dimension of botanical literacy.

Based on the preceding background, This study therefore aimed to develop and validate a multiple-choice instrument to measure the cognitive dimension of botanical literacy among university students, reporting on its content validity, reliability, and item characteristics (difficulty, discrimination, and distractor effectiveness).

B. Methods

This study employed a Design and Development Research (DDR) approach as proposed by (Richey & Klein, 2014), consisting of two main phases: the *design phase* and the *development phase*. The design phase involved conceptual analysis and item construction, while the development phase included content validation, empirical

testing, and construct analysis to ensure the validity and reliability of the developed instrument. A total of 378 respondents were selected using a stratified random sampling technique and participated in both the pilot and validation stages. The participants were university students from various higher education institutions across Indonesia, representing diverse demographic characteristics in terms of gender and academic semester. Gender was included as a variable because previous studies have suggested potential differences in ecological awareness, attitudes toward plants, and levels of engagement in biology learning between male and female students (Uno et al., 2022; Schussler & Olzak, 2008). Meanwhile, academic semester was considered to capture variations in students' academic experience, particularly regarding their exposure to botanical content and laboratory activities. Generally, early-semester students possess limited conceptual understanding, whereas advanced students have broader experience in field practice and scientific investigation (Suwono et al., 2022).

The instrument development procedure in this study followed a systematic sequence consisting of indicator and item development, content validation, and empirical testing with construct analysis. The item development process was based on an extensive literature review and analysis of the botanical literacy framework, focusing specifically on the cognitive dimension. The cognitive dimension emphasized students' understanding of plant biology, plant diversity and classification, and plant ecology in relation to the environment. Content validation was conducted by three experts in biology education and botany using a form based on the Content Validity Index (CVI). Items with an Item-Level CVI (I-CVI) value below 0.78 were revised or removed, while the overall Scale-Level CVI/Average (S-CVI/Ave) reached 0.92, indicating a high level of content validity (Polit & Beck, 2006). Subsequently, empirical testing and construct analysis were carried out. The cognitive dimension underwent item analysis to identify the psychometric characteristics of each item based on the difficulty index, discrimination index, and distractor effectiveness. Items with moderate difficulty levels (0.30–0.70) and discrimination indices above 0.30 were retained as high-quality items. This process ensured that each cognitive item effectively distinguished respondents with different levels of botanical understanding, thereby strengthening the overall construct validity of the instrument.

C. Result And Discussion

Design Phase

The design phase focused on formulating the conceptual foundation and developing the indicators of the botanical literacy instrument based on both theoretical and empirical reviews. Referring to the framework of Design and Development Research (DDR) proposed by Richey & Klein, (2014), this phase comprised three main activities: (1) analyzing needs and construct theories, (2) developing the domains and aspects of botanical literacy, and (3) designing indicators and constructing the initial set of

instrument items. A literature analysis was conducted to review previous models of botanical literacy, relevant measurement instruments, and the requirements of Education for Sustainable Development (ESD) within the context of biology education. The analysis revealed the need for a multidimensional approach that assesses cognitive abilities supporting the development of ecological attitudes and actions. Accordingly, the botanical literacy framework proposed by Arif et al., 2025), emphasizes Cognitive Outcomes, consisting of specific aspects as summarized in Table 1.

Table 1. Domain cognitive botanical literacy

Domain	Aspect	Description
Cognitive Outcomes	Plant biological knowledge	Includes understanding the structure, function, and fundamental processes in plants (photosynthesis, respiration, reproduction, and growth)
	Diversity and classification of plants	Able to identify and understand various plant species and the basic principles of taxonomy.
	Plant ecology and its relations with the environment	Understand the critical role of plants in ecosystems, including symbiotic relationships, food chains, and soil stabilization.

Refrences: (Arif et al., 2025)

Based on this framework, each domain was elaborated into operational indicators that were then translated into instrument items. The cognitive dimension was developed in the form of 35 multiple-choice questions, representing three key aspects: *plant biological knowledge, plant diversity and classification, and plant ecology and its relationship with the environment.* During the content validation stage, all items from the three dimensions were evaluated by five experts in biology education and botany using the Content Validity Index (CVI). Based on the experts' assessments, the final number of items used for empirical testing consisted of 35 items for the cognitive dimension. The overall Scale-Level CVI/Average (S-CVI/Ave) value of 0.92 indicated a very high level of content relevance and alignment (Polit & Beck, 2006). The results of this design phase served as the foundation for the development phase, which involved empirical testing and construct analysis through item-level evaluation to ensure the instrument's psychometric robustness.

Development phase

The development phase focused on empirical testing to ensure the construct validity and reliability of the botanical literacy instrument that had been designed in the previous phase. Following content validation by three experts, the instrument was administered to 378 respondents, who were university students from various higher education institutions across Indonesia. This analysis aimed to evaluate the suitability of the instrument's multidimensional structure, which included the cognitive domain. The item analysis for the cognitive dimension consisted of 35 multiple-choice

questions administered to the 378 students, assessing the psychometric properties and internal consistency of the instrument.

Table 2. Item Analysis of the Cognitive Domain

Item	Difficulty Index	Difficulty Level	Discrimination Index	Validity Estimate	Distractor Effectiveness
C1	0,714	Easy	0,363	0,397	Effective
C2	0,382	Moderate	0,533	0,521	Effective
C3	0,49	Moderate	0,515	0,493	Effective
C4	0,267	Difficult	0,393	0,386	Effective
C5	0,562	Moderate	0,542	0,546	Effective
C6	0,847	Easy	0,512	0,52	Effective
C7	0,781	Easy	0,558	0,572	Effective
C8	0,67	Moderate	0,394	0,428	Effective
C9	0,816	Easy	0,364	0,348	Effective
C10	0,401	Moderate	0,38	0,356	Effective
C11	0,72	Easy	0,534	0,54	Effective
C12	0,432	Moderate	0,542	0,541	Effective
C13	0,301	Moderate	0,344	0,343	Effective
C14	0,521	Moderate	0,475	0,448	Effective
C15	0,626	Moderate	0,571	0,584	Effective
C16	0,715	Easy	0,506	0,519	Effective
C17	0,807	Easy	0,335	0,33	Effective
C18	0,539	Moderate	0,476	0,531	Effective
C19	0,326	Moderate	0,573	0,55	Effective
C20	0,271	Difficult	0,561	0,581	Effective
C21	0,803	Easy	0,479	0,468	Effective
C22	0,592	Moderate	0,552	0,534	Effective
C23	0,372	Moderate	0,373	0,349	Effective
C24	0,298	Difficult	0,562	0,583	Effective
C25	0,321	Moderate	0,399	0,387	Effective
C26	0,471	Moderate	0,562	0,553	Effective
C27	0,593	Moderate	0,433	0,425	Effective
C28	0,83	Easy	0,404	0,413	Effective
C29	0,469	Moderate	0,487	0,511	Effective
C30	0,33	Moderate	0,486	0,493	Effective
C31	0,788	Easy	0,492	0,518	Effective
C32	0,841	Easy	0,475	0,503	Effective
C33	0,668	Moderate	0,442	0,434	Effective
C34	0,831	Easy	0,559	0,566	Effective
C35	0,521	Moderate	0,499	0,518	Effective

Table 2 presents the item analysis results for the cognitive dimension, which consisted of 35 multiple-choice questions administered to 378 students. The findings indicate that the instrument demonstrates excellent psychometric properties. The reliability coefficient calculated using the Kuder–Richardson 20 (KR-20) formula was 0.86, indicating a high level of internal consistency and confirming that all items measured a homogeneous construct students' cognitive understanding of plant biology. A KR-20 value above 0.70 is widely recognized as an indicator of a stable and dependable instrument, consistent with the recommendations of Rezigalla et al., (2024) dan Kumar et al., (2021), who emphasized that KR-20 values ≥ 0.70 reflect good reliability for multiple-choice instruments. Therefore, the reliability coefficient of 0.86 obtained in this study clearly exceeds the minimum standard, demonstrating that this instrument is highly dependable for measuring cognitive botanical literacy.

The difficulty index (p) values ranged from 0.267 to 0.847, indicating a well-distributed level of item difficulty. Specifically, 11 items were classified as difficult (p = 0.25–0.44), 12 as moderate (p = 0.45–0.69), and 12 as easy (p = 0.70–0.85). This distribution ensured that the instrument could measure students' abilities across various levels and avoided bias caused by items that were excessively easy or difficult. The mean difficulty index of 0.56 indicated a moderate level of difficulty, which is appropriate for the context of university-level biology education. A balanced distribution pattern of this kind was also observed in the study by Chauhan et al., (2023), who emphasized that an even proportion of easy, moderate, and difficult items contributes to optimal measurement performance.

The discrimination index (D) values ranged from 0.33 to 0.57, indicating that all items had good discriminative power. According to Classical Test Theory (CTT), items with D values greater than 0.30 are considered acceptable because they can effectively distinguish between high- and low-ability respondents (Puthiaparampil & Rahman, 2021). The mean discrimination index of 0.46 suggests that the instrument consistently and validly identified variations in students' cognitive abilities. This indicates that these items are highly effective for identifying high-achieving students, as the concepts assessed are inherently challenging, such as the cognitive complexity of advanced botanical processes, the abstract nature of certain plant structures, or the requirement to integrate multiple concepts simultaneously.

The item validity coefficients (r-biserial) ranged from 0.33 to 0.58, indicating that each item was positively correlated with the total test score. This finding reinforces the evidence that all items measured the same underlying construct. These results are consistent with the findings of Testa et al., (2018), who demonstrated that positive correlations between individual items and total scores serve as strong indicators of construct validity.

All items also demonstrated good distractor effectiveness, as each distractor option was selected by at least 5% of respondents. This finding indicates that the distractors functioned as intended and effectively minimized the likelihood of correct answers resulting from random guessing. Studies by Rezigalla et al., (2024) and Testa et al., (2018) have emphasized that well-functioning distractors contribute directly to improving both the discrimination power and overall validity of a test.

Overall, the analysis results indicated that the cognitive domain instrument demonstrated excellent validity and reliability, with a balanced distribution of item difficulty, strong discrimination indices, and optimally functioning distractors. Therefore, this instrument is considered suitable for assessing students' cognitive abilities in understanding plant biology concepts, classification, and ecology—the core components of botanical literacy—and for supporting the implementation of Education for Sustainable Development (ESD) as emphasized by UNESCO (2020).

The results of the development indicate that the cognitive dimension instrument was effective in systematically and structurally measuring students' cognitive abilities in botanical literacy. This finding is particularly significant as a response to the need for a botanical literacy assessment tool that not only evaluates knowledge (cognitive) but also contributes to shaping ecological character and environmental skill competence, as emphasized in SDG 4.7 and the Education for Sustainable Development (ESD) framework (UNESCO, 2022). Recent studies in plant literacy highlight that instruments focusing solely on the cognitive domain such as plant identification quizzes tend to capture only a limited portion of actual literacy, while affective aspects and concrete actions are often overlooked (Pany et al., 2024).

This instrument complements the limitations of the early model proposed by Fančovičová & Prokop, (2011), which primarily assessed cognitive domains and basic attitudes toward plants through outdoor educational programs but did not explicitly measure practical skills. Moreover, other instruments such as the Plant Awareness Questionnaire and similar plant literacy tools (Pany et al., 2024) tend to focus on perception, recognition, and enthusiasm toward plants without incorporating factor validation related to practical or psychomotor skills. Theoretically, this study extends the framework of botanical literacy by positioning the cognitive dimension as an integral part of a multidimensional construct. Thus, botanical literacy is conceptualized as encompassing *what is known, what is felt, and what is done* (Hubbard, 2024). Recent studies on plant literacy further emphasize the necessity of including concrete behavioral elements in defining botanical literacy, as reflected in the concept of (Re)growing Plant Awareness (Dünser et al., 2025).

Educators can use Botani-Co to monitor progress toward SDG 4.7 by employing it as a diagnostic tool to determine how well students understand botanical concepts related to biodiversity and sustainability. The results help identify areas where

students struggle, allowing instructors to adjust their teaching strategies more effectively. The findings also inform curriculum design to address "plant blindness" by highlighting which concepts are most difficult for students, enabling educators to develop learning materials, field activities, or inquiry-based approaches that foster greater awareness and appreciation of plants.

Limitation

The study has several limitations. First, the sample was drawn from a single country (Indonesia), which restricts cross-cultural generalizability. Second, the instrument measures only the cognitive dimension; therefore, future research should integrate affective and psychomotor measures to provide a more holistic assessment of botanical literacy. Third, although this study has established the instrument's validity and reliability, further research is needed to examine its predictive validity.

D. Conclusion

This study produced a valid and reliable botanical literacy instrument focusing on the cognitive dimension. Each aspect demonstrated strong empirical evidence that met rigorous psychometric criteria, including construct validity, internal consistency, and item effectiveness. The high reliability coefficient and stable factor structure obtained from the analyses indicate that the instrument provides an accurate representation of students' botanical literacy competence. Beyond producing a high-quality instrument, this study also contributes a new conceptual and empirical framework for measuring botanical literacy within the cognitive domain. From an applied perspective, the findings offer significant implications for the development of holistic and sustainability-oriented biology education. The instrument can serve as both a diagnostic and evaluative tool to assess students' botanical knowledge. Consequently, this research supports the realization of Sustainable Development Goal (SDG) 4.7, which emphasizes the creation of educational systems that foster scientific literacy, ecological awareness, and a sense of responsibility toward sustainability.

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