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Needs Analysis and Cognitive Load Reduction: A Foundation for Developing a Smart e-Library for Botany Courses

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Abstract

The complexity of scientific (Latin) terms, a high level of element activity within the concepts, and the abstract nature of visual-spatial concepts can make botany courses quite challenging. Students often experience working memory overload as a result of the high external cognitive load caused by conventional learning platforms. In order to propose the development of a "Smart E-Library" for university-level botany courses, this study aimed to analyze student learning needs and cognitive load profiles. Undergraduate Biology Education students (n=59) participated in a descriptive-analytical survey that employed a questionnaire based on the components of Cognitive Load Theory (CLT): Germane Cognitive Load (GCL), Extraneous Cognitive Load (ECL), and Intrinsic Cognitive Load (ICL). Aiken's V was used to assess the content validity of the instrument (V = 0.833; high category). Results indicated a high intrinsic load linked to spatial visualization from 2D to 3D (59.3%) and semantic word retention (55.9%). The split-attention effect (79.7%), complicated glossary navigation (71.2%), and black and white anatomical graphics without color coding (84.7%) were among the elements that led to excessive ECL in conventional media. Meanwhile, very high levels of mental effort and engagement (>94% across all GCL indicators) were found. However, these findings cannot be directly linked to successful learning outcomes. In the next stage of development, these results will be used to determine learning requirements and create a preliminary design for the Smart E-Library. The study specifies important design requirements for the Smart E-Library, such as an interactive 3D spatial anatomy viewer, pop-up glossary, and adaptive microlearning modules, in order to address these challenges.

Keyword: Cognitive load theory, Namnam, Smart E-Library, Botany Education

INTRODUCTION

Morphology, taxonomy, physiology, and plant structure are all integrated into the core biology course of botany. It takes more than simply memorization to learn this content. Verbal explanations, anatomical illustrations, physiological processes, and their spatial relationships must all be actively connected by students. A conceptual grasp of plant structure, especially morphology, is crucial for fields like systematics and ecology (Bucksch et al., 2017). Students must make connections between abstract ideas and intricate visual shapes in order to learn botany effectively. However, students often have trouble comprehending complex and multifaceted botanical material due to working memory limits. For instance, a high level of visual-spatial cognition is necessary while studying the microscopic and abstract aspects of plant structure. Because they only offer one perspective, traditional two-dimensional (2D) representations can occasionally be inadequate. making it difficult for students to study tissue architecture and cell shapes in detail (Suprapto et al., 2024). The Cognitive Theory of Multimedia Learning states that when students can arrange, integrate, and sort textual and visual material with what they already know, the learning process is successful (Mayer, 2024). Cognitive burden that exceeds learning objectives must be avoided in instructional design.

The use of digital media such as e-libraries or smart learning platforms has the potential to support such learning conditions if designed based on the principles of cognitive load management. Effective instructional design must be able to reduce unnecessary cognitive load, manage the complexity of the material, and encourage active thinking that helps students build permanent knowledge schemas (Mayer, 2024; Sweller, 2024). This transformation of digital learning media is driven by two main reasons. First is the demands of the digital age require learning resources that function not merely as file storage but as an interactive, adaptive, and cognitively friendly Smart E-Library to enhance the efficiency of self-directed learning (Basri et al., 2025). Second, complexities of foreign or Latin terminology, microscopic tissue characteristics that are invisible to the human eye, and 3D spatial ideas that require accurate visualization, effective navigation, and supporting media (Luz & Martarello, 2022). Without adaptive media, the learning process risks becoming centered on low-level memorization, while botany education demands deep conceptual understanding to form long-term knowledge schemas.

University botany students often encounter challenges in their students' cognitive capacity. This cognitive capacity is related to their ability to process and understand complex information. When cognitive load is too high, students simply cannot process new ideas (Garnett, 2020). Students also have to connect macroscopic plant parts with microscopic details (Suprapto et al., 2024). Moreover, the field of botany is characterized by extensive taxonomic nomenclature that demands significant memory capacity for processing thus often making it difficult for students to memorize and master the terminology used in botany courses (Survani et al., 2014). They must also mentally rotate flat 2D illustration into comprehensive 3D shapes (Chaidir et al., 2024). Cognitive challenges in botany are also exaggerated by high extraneous cognitive load when learning media is poorly designed. Traditional textbooks, static PDFs, and basic slides often use terrible visuals (Garnett, 2020). Many diagrams are low-quality, black-and-white, and offer no color coding or guides to help students tell different plant tissues apart (Sweller et al., 2011)

Design limitations in existing media can also trigger the ‘split-attention effect’ due to layouts that separate images from their corresponding explanations (Garnett, 2020). According to Sweller et al. (2011), split attention is a significant contributor to high cognitive load during learning. Additionally, the process of navigating information is often complicated which they must switch back and forth to look up definitions in a separate glossary or are even forced to break their primary learning flow to independently search for supplementary visual references online.

As a result of high intrinsic and extraneous cognitive load, students' working memory resources quickly become overloaded (Sweller et al., 2011; Garnett, 2020). Students are required to expend excessive cognitive capacity simply to cope with media limitations. They spend more time piecing together fragmented information from various sources, so they lack sufficient mental resources to process botanical material. This mental effort becomes inefficient because cognitive capacity—which should be focused on deep understanding and the construction of knowledge about botany— is instead drained because of having to struggle with the poor instructional design of the learning media (Garnett, 2020).

This study analyzes students' needs and cognitive loads in the Botany course as a first step toward developing a Smart Electronic Library as a solution for Botany Course. This analysis aims to identify learning difficulties, learning resource needs, and the levels of intrinsic, extrinsic, and germane cognitive load experienced by students when studying complex botanical material. As defined by Cognitive Load Theory, external load is directly related to how information is presented, while intrinsic load is caused by the complexity of the subject matter (Sweller et al., 2019; Sweller, 2023). A solid empirical foundation for creating digital content that addresses students' cognitive limitations is provided by mapping these two variables. The development of a specialized botany platform to improve traditional digital libraries is based on this methodology. Effective navigation, text and 2D/3D visual integration, an integrated glossary, and a clean layout are some of the main key features. According to Mayer (2024) and Mutlu-Bayraktar et al. (2019), successful multimedia must reduce superfluous processing so that students can readily link visual and textual signals. This design attempts to eliminate cognitive obstacles imposed by complex interfaces. In order to create an efficient and flexible Botany Smart E-Library, these data will provide a profile of student demands and cognitive-load-based design concepts.

The majority of research on biology learning obstacles has focused on recording students' challenges with taxonomy, nomenclature, and morphology (Kameswari, 2022). Students in botany classes must learn new Latin vocabulary while also comprehending intricate structural ideas (Bestari, 2024). Rather than focusing on low test scores or general complaints, research needs to empirically evaluate how intrinsic cognitive load shapes these learning barriers. This study addresses this gap by directly mapping students' learning barriers to their cognitive capacity profiles. This cognitive perspective has also not yet been applied in the design of digital libraries. Although dimensions of cognitive load have been measured in the use of digital literature in general, evaluations of conventional libraries are still limited to focusing on menu layout, storage specifications, or access speed (Nordin et al., 2026). Furthermore, digital platforms routinely overlook the cognitive load students experience when comprehending complex scientific literature (Tsegaye Kassa, 2026).

Software development in educational technology often focuses solely on the application development stage without first analyzing users' cognitive processes. This overlooked step results in digital libraries that actually cause information overload for students. To address this issue, this study uses cognitive load analysis as the foundation for platform design. By evaluating students' cognitive capacity from the outset, the Smart Digital Library can be specifically designed to minimize extrinsic cognitive load while keeping intrinsic cognitive load under control. The study, titled "Needs Analysis and Cognitive Load Reduction: A Foundation for Developing a Smart E-Library for Botany Courses," presents an empirical map of students' learning needs and cognitive limits. These findings serve as a concrete reference for developers to build an interactive and cognitively friendly Smart E-Library to overcome various barriers to learning botany in higher education.

METHOD

Descriptive quantitative approach applied in this study is combined with qualitative interpretation (a quantitative-dominant approach). Students' cognitive load profiles and learning media demands were mapped using a survey approach (Creswell & Creswell, 2018). The specifications for the creation of the Smart E-Library were then developed using the baseline data from this cognitive load assessment as the main source of information. A preliminary analysis of the features of the literature and course materials in the Botany program that can cause cognitive strain was the first step in the research process. A cognitive load scale questionnaire was then given to 59 fourth-semester undergraduate students enrolled at a state University in Banten, Indonesia on Biology Education Program. Sampling was conducted using simple random sampling from the total cohort of that semester. All participants had completed prerequisite courses in the botany cluster—including Plant Morphology, Plant Anatomy, and Plant Physiology—and thus possessed a sufficient foundation of understanding to assess the need for instructional media and the cognitive difficulty level of the material.

A structured questionnaire was used to measure the baseline cognitive load of students enrolled in traditional botany courses. The 40 statements in this test were created using the three primary dimensions of Cognitive Load Theory (Sweller): Germane Cognitive Load (GCL), Extraneous Cognitive Load (ECL), and Intrinsic Cognitive Load (ICL). To guaranty the internal consistency of the instrument, each dimension was divided into distinct indicators and sub-indicators. The instrument using Likert scale, with 1 denoting "strongly disagree" and 4 denoting "strongly agree," was used to record student responses. Neutral response options were purposefully left out in order to encourage students to give specific responses about their learning obstacles.

The ICL dimension, which includes the degree of information complexity and the sufficiency of prior knowledge, gages the inherent mental strain associated with understanding complicated botanical concepts. The ECL dimension evaluates the cognitive capacity lost as a result of flaws in media and instructional design, such as divided attention, visual ambiguity, and difficult navigation. Students' concentration and productive mental effort in creating knowledge schemas are measured by the GCL dimension. The average scores for each dimension divides to four ranges; 1.00–1.75 (Very Low), 1.76–2.50 (Low), 2.51–3.25 (High), and 3.26–4.00 (Very High). High initial ECL scores (>2.50) highlight the necessity of creating a Smart E-Library while also demonstrating the inefficiency of traditional media.

To verify the content validity of the instrument or product based on expert consensus, the instrument was first evaluated using Aiken’s V. Aiken's V is a statistical coefficient used to measure the degree of expert agreement regarding the content validity of a measurement instrument; it ranges from 0 to 1, with higher values indicating stronger content validity (Tajuddin et al., 2025). The categorization criteria for Aiken’s V coefficients are based on the following ranges: $V < 0.40$ is classified as Low; $0.40 \leq V < 0.80$ is classified as Moderate; and $V \geq 0.80$ is classified as High (Aiken, 1985). The summary of the content validity results for the 40 instrument items is presented in Table 1 below.

Table 1. Summary of Results of the Aiken's V Content Validity Test

Assessment Indicator	Result / Score
Number of Instrument Items	40 items
Number of Validators (n)	3 validators
Mean Aiken’s V Index ($\bar{V}$)	0.833 (High Category)
Range of Aiken’s V Index	0.556–1.000
Items in the High Category ($V \geq 0.80$)	24 items (60.0%)
Items in the Moderate Category ($0.40 \leq V < 0.80$)	16 items (40.0%)
Items in the Low Category ($V < 0.40$)	0 items (0.0%)

The content validity score is in the "Very Good/High" range with an average value of 0.833. With V values ranging from 0.556 to 0.778, 16 items (40.0%) fall into the Moderate group, while 24 items (60.0%) have a validity index in the High category ($V \geq 0.80$). There are no products in the Low category ($V < 0.40$). These findings show that every test item may accurately reflect the competency indicators being examined in terms of content, construction, and language and has been authorized by experts for use in the data collection phase.

Descriptive quantitative approaches were used to process all of the collected quantitative data. Following the stages of data reduction, data display, and conclusion drawing (Miles, Huberman, & Saldana, 2014), a mixed qualitative and quantitative approach was used to analyze the gathered empirical data. The findings were utilized to create recommendations and requirement specifications for the creation of the Smart E-Library.

RESULTS AND DISCUSSION

An assessment using an instrument designed to evaluate cognitive needs and cognitive load in a Botany course was conducted on 59 students from the Biology Education program. The instrument was developed based on the three main constructs of Cognitive Load Theory (CLT): Intrinsic Cognitive Load (ICL; the inherent load of the material), Extrinsic Cognitive Load (ECL; the external load resulting from media design), and Relevant Cognitive Load (GCL; the constructive cognitive effort exerted).

Intrinsic Cognitive Load (ICL) Profile

The botany curriculum is characterized by a very high level of interactivity among its elements. An analysis of the difficulty levels perceived by students regarding 17 conceptual indicators in the botany curriculum revealed a varied distribution of difficulty levels, ranging from verbal aspects, terminology, and microscopic anatomy to visual-spatial reasoning (Figure 1).

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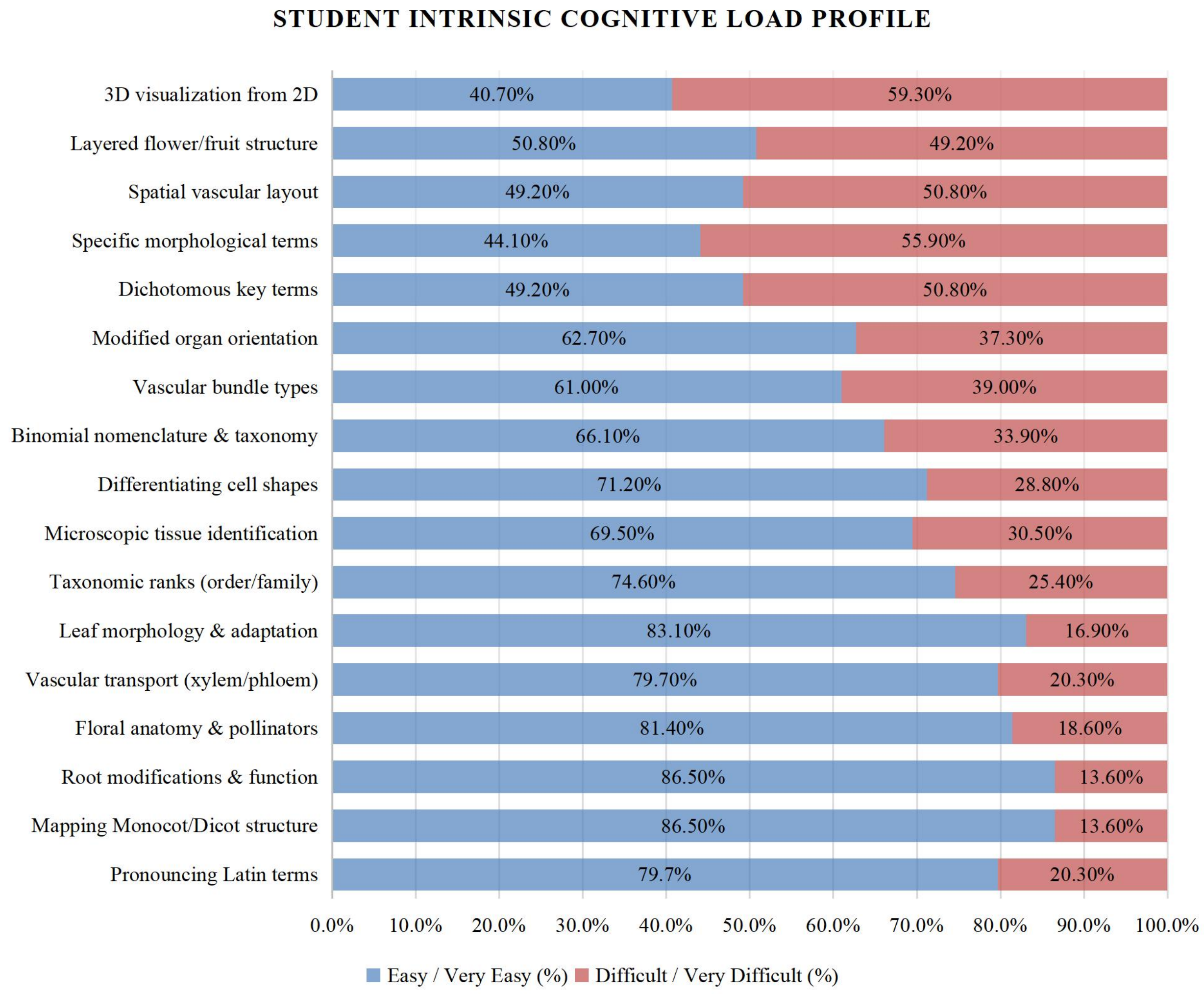

Figure 1. Horizontal Stacked Bar Chart: Difficulty Levels Regarding Spatial Visualization and 3D Plant Organs

Findings shows that 91.6% of respondents (83.1% Agree, 8.5% Strongly Agree) stated that the Botany course material is too many conceptual components that must be memorized simultaneously to support these quantitative ICL statistics. Along with that, 91.5% of respondents (74.6% Agree, 16.9% Strongly Agree) stated that the material is extremely complex, requiring students to memorize Latin terminology while analyzing anatomical imagery. Additionally, 91.5% of respondents concurred that botany topics are strongly related, which suggests a lack of knowledge about one tissue structure will immediately limit comprehension of following content.

Extraneous Cognitive Load (ECL) Profile

ECL refers to excessive cognitive load that does not support the learning process; rather, it is caused by design flaws, format limitations, and inefficiencies in the presentation of current conventional learning media. Student responses regarding ECL indicators are presented in Table 2.

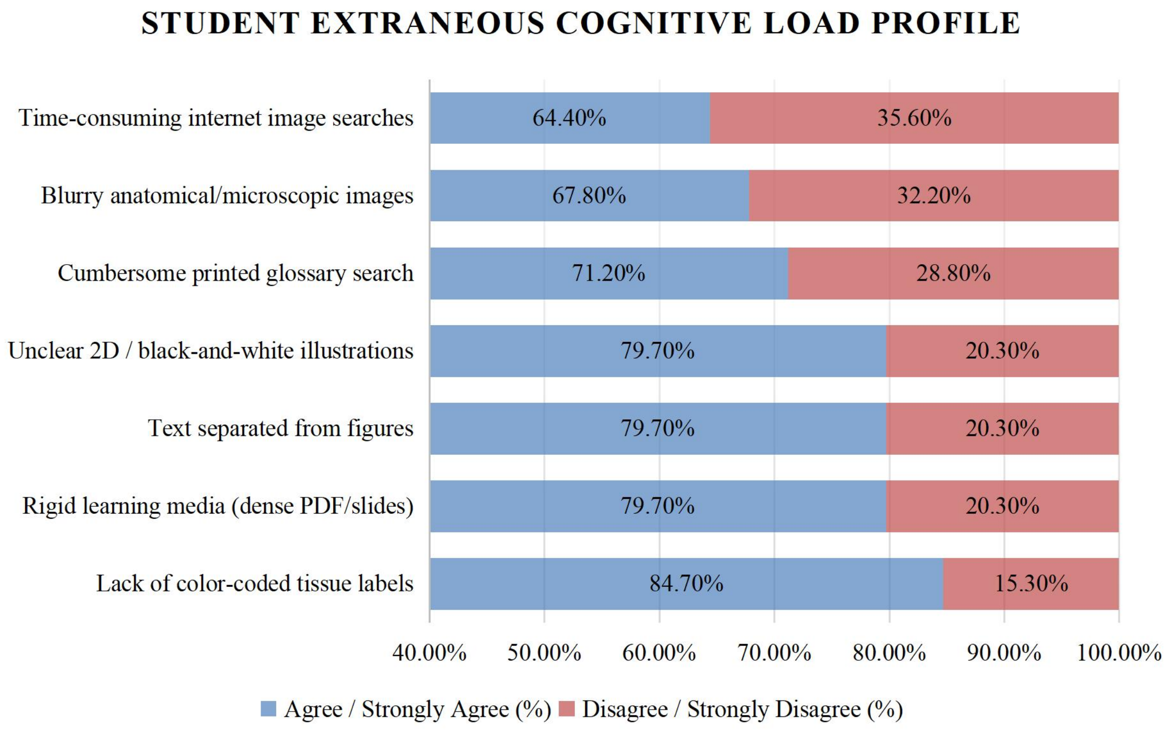

Figure 2. Horizontal Stacked Bar Chart of Constraints Associated with Conventional Learning Media (Extraneous Load)

According to data on the limitations of traditional media, most students face substantial cognitive challenges since tissue diagrams lack visual differentiators or color-coding, which results in modality deficits and high mental load. Additionally, a split-attention effect and cognitive fatigue are brought by strict material format, text positioned apart from graphics, and dependence on two-dimensional pictures. These visualization constraints make it difficult for students to mentally picture the items in three dimensions; in the meantime, difficult manual navigation and hazy graphics frequently cause distractions, forcing students to spend time looking for outside reference sources.

Due to the limits of the traditional learning materials used, the majority of students experience cognitive challenges. The lack of color differentiation for tissues (84.7%) is a major problem that can lead to mental overload and modality impairments. Students must therefore independently identify pertinent portions of the image to integrate with conceptual explanations, which puts a greater cognitive strain on them in the absence of obvious color-coding to separate plant tissues (Mayer, 2014).

Cognitive Profile and Self-Reported Germane Cognitive Load (GCL)

GCL in this study refers to students' reported mental effort and engagement in strategies intended to support comprehension and knowledge construction. The evaluation results for the GCL indicators are presented in Figure 3. Because the instrument is self-report based, these scores should be interpreted as perceived cognitive engagement rather than direct evidence of successful schema construction or learning achievement.

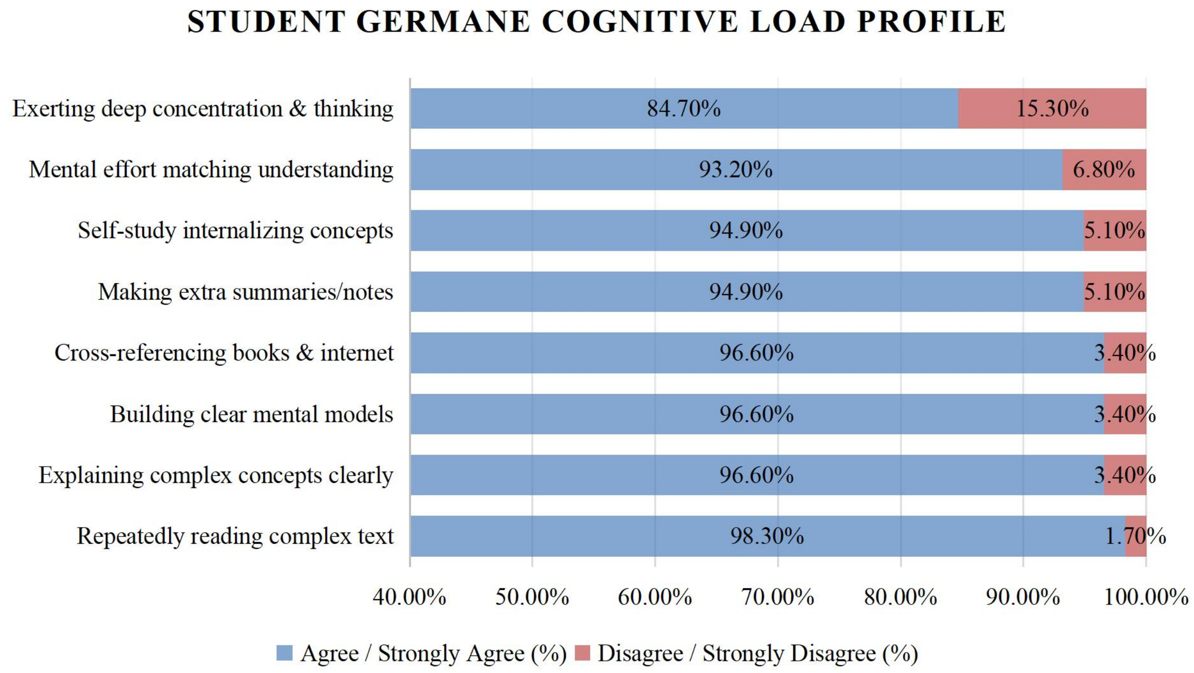

Figure 3. Horizontal Stacked Bar Chart of Independent Mental Effort Indicators (Germane Load)

Nearly all students showed remarkably high levels of commitment and cognitive engagement in understanding the subject, according to data on independent cognitive effort and learning-related techniques. Most regularly reread difficult books, incorporated different learning resources on their own, and put in extra effort to produce generative summaries. These answers show that students regularly used self-directed and generative learning techniques, such as reading aloud repeatedly, cross-referencing educational materials, and creating notes or summaries. These indicators, however, represent students' perceived involvement and mental effort rather than objectively verified learning accomplishment or retention because they were tested by self-report. In the end, the learners' high level of focus and in-depth thinking caused them to believe that the amount of mental work required was appropriate for the level of comprehension attained.

Key cognitive concepts from Cognitive Load Theory (Sweller et al., 2011; Paas & van Merriňboer, 2020) and visual-spatial information processing theory (Mayer, 2014) are integrated with quantitative empirical data in the presentation of these research results. As the justification for creating the Smart E-Library ecosystem, the analysis focuses on identifying the causal relationships between the intricacy of Botany content (ICL), the constraints of traditional media (ECL), and the requirement that students engage in independent mental effort (GCL).

Phonetic vs. Semantic Cognitive Dissonance and Spatial Visualization Barriers (Intrinsic Load)

The study's empirical results highlight the basic problem of cognitive processing dissonance in botany students. According to data, 79.7% of students find it easy to pronounce Latin morphological terms, but the results vary when it comes to understanding and articulating concepts: 50.8% of students have trouble understanding the meanings of unfamiliar terms found in identification keys, and 55.9% of students have significant difficulty recalling the meanings of specific morphological terms (like phyllotaxis, perianth, and peduncle).

This phenomenon implies that students have only attained the level of surface-level phonetic processing in the context of cognitive psychology. Without any motor-articulatory difficulties, they can read and pronounce Latin terminological symbols. However, when that knowledge needs to be connected to semantic conceptual structures in long-term memory (semantic-level comprehension), cognitive schemas are not formed (Minicucci & Blumstein, 2013). According to 91.6% of respondents, this situation is made worse by the high element interactivity inherent in botany material, which requires processing taxon names, morphological terminology, cell structures, and life cycles all at once within the constrained working memory capacity (Baddeley, 2012).

Visual-spatial thinking and mental rotation were found to present the biggest ICL (Intrinsic Cognitive Load) issues. When e-library resources only offered static 2D images or cross-sectional/longitudinal slices, 59.3% of students found it difficult to visualize the entire 3D structure of plant parts. Additionally, 50.8% of students struggled to visualize vascular bundles as continuous spatial entities that stretched from the veins in leaves to the roots and stems. Theoretically, the ability to rotate, rebuild, and project 2D items into spatially oriented 3D mental pictures is necessary for comprehending plant anatomy (Hegarty, 2010). The task of autonomous 3D visual reconstruction overwhelms students' working memory when learning resources only display static 2D visuals, leaving them with insufficient cognitive capacity to understand complex plant physiological systems.

Inefficiency of Conventional Learning Media as a Trigger for Extraneous Cognitive Load

Research results clearly reveal that students' Extraneous Cognitive Load (ECL) is greatly increased by the usual learning resources used today, such as large PDF textbooks,

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text-heavy slides, and modules with static pictures. As stated by Sweller (2010) and Sweller et al. (2019), ECL is caused by traits or methods of presenting information that are not necessary for accomplishing learning objectives and instead take working memory resources away from the schema development process. ECL was found to be triggered by four main phenomena:

1. Deficit in Modality and Visual Discrimination: The lack of visual cues on tissue pictures, such as color-coding or distinct labels, is associated with the greatest ECL indication (84.7%). The appearance of parenchyma, collenchyma, and sclerenchyma cells is quite similar in conventional, monochromatic microscope section images. Students must independently find relevant image sections to integrate with conceptual explanations in the absence of enough visual cues, which increases the demands of visual search and indirectly drains working memory resources (Mayer, 2014).
2. Split-Attention Effect: According to 79.7% of respondents, the placement of explanatory text far away from the supporting images—for example, on a different page—causes divided attention. Separating text and images violates the spatial contiguity principle, based to the Cognitive Theory of Multimedia Learning (Mayer, 2014). In order to find the matching explanatory text, students must constantly change their focus (saccadic eye movements) and retain visual information pieces in working memory.
3. Spatial Visualization Breakdown & Cognitive Fatigue: 78.0% of students feel mentally exhausted from attempting to figure out the true structure of static visuals, and 79.7% of students are overwhelmed by dense PDF files or static slides. Without providing suited visual input, this dense, non-interactive structure makes the brain and eyes work harder (Hegarty, 2010; Suprapto et al., 2024).
4. Navigation Friction and External Search Redundancy: 64.4% of students were compelled to waste time and mental energy looking for comparative images online, while 71.2% of students complained about the difficult procedure of consulting printed glossaries. Such search activities can be seen as a source of unnecessary processing or load that may exhaust the cognitive resources available for the primary learning process if they do not directly support learning objectives and result from constraints in the design of learning resources (Sweller, 2010; Mayer, 2014).

Self-Reported Germane Cognitive Effort in the Context of Extraneous Load

Despite the significant limitations associated with traditional learning media, students reported extremely high levels of independent mental effort, which makes the GCL findings noteworthy. According to the research, 98.3% of people read challenging literature on a regular basis, 96.6% compared several books and online resources, 94.9% put in extra effort to create summary notes, and 96.6% said that their thinking enabled them to develop clear mental models. Strong self-reported engagement and the application of generative learning techniques are demonstrated by these results. However, the questionnaire does not explicitly assess the caliber, effectiveness, or longevity of the learning outcomes that result from students' assessed mental effort and learning-related events. Nevertheless, this high level of student effort does not always translate into effective learning; working memory resources used to overcome information presentation challenges can exhaust the resources available for processing the intrinsic complexity of the material (Sweller, 2010; Sweller et al., 2019).

The high GCL percentages could initially seem to point to a successful learning process. However, as no objective measure of learning achievement, conceptual understanding, or retention was used in conjunction with the questionnaire, the current data does not permit the establishment of that conclusion. According to the Cognitive Load Theory, high reported effort may also represent the extra work students put in when learning materials are challenging to navigate or understand. However, high germane effort can also be associated with constructive cognitive processing. Therefore, the most secure interpretation of this study is that students report both significant extraneous demands and significant mental effort to comprehend Botany materials. The information does not prove that this effort was unsuccessful, ineffective, or compensating on its own.

High GCL and ECL scores together draw attention to an important aspect of the design. Students showed considerable mental effort, including taking notes, independently comparing sources, and reviewing the content, even though they complained about the lack of visual representation, divided attention, and complexity of the navigation. These findings indicate that students actively overcome various obstacles in current learning media. However, the data from this questionnaire cannot yet be used to conclude the occurrence of cognitive fatigue, burnout, a decline in learning efficiency, or a decline in higher-order thinking skills. Drawing such conclusions requires additional supporting evidence, such as data on time-on-task, objective indicators of learning outcomes, or direct measurements of cognitive fatigue. In order to improve the Smart E-Library's instructional design criteria, the GCL data in this study are mainly utilized to measure students' level of learning effort.

Strategic Implications and Development Architecture of a Smart E-Library for Botany Courses

Based on a thorough diagnosis of Germane Cognitive Load (GCL), Extraneous Cognitive Load (ECL), and Intrinsic Cognitive Load (ICL), the creation of a Smart E-Library is now an urgent necessity rather than just an inventive solution. The Smart E-Library is an intelligent digital ecosystem based on the ideas of Cognitive Load Reducing Architecture, rather than just a repository or storage area for passive PDF materials.

An empirical foundation for developing initial design specifications for a future Smart E-Library is provided by the needs study. The qualities listed below were not created, put into practice, or tested empirically in this study. Therefore, rather than being verified interventions or proven solutions, they should be viewed as suggested specifications drawn from the stated learning challenges and cognitive-load patterns. To determine whether these features truly reduce unnecessary cognitive workload, promote learning, or enhance learning outcomes, more development and assessment will be necessary. Based on the identified patterns of cognitive load and learning barriers, several key feature specifications are proposed to address the platform's development needs:

1. 3D Interactive Spatial Anatomy Viewer Feature (Addressing Reducing Spatial ICL): To overcome the primary obstacle students face in visualizing the 3D form and orientation of vascular bundles (a difficulty reported by 59.3% of students). The proposed Smart E-Library could incorporate interactive 3D anatomical objects. Students can rotate, section (cross-section or longitudinal), and zoom in or out on plant organs in real-time. The integration of interactive 3D anatomical objects has the potential to assist students in performing external visuospatial transformations, thereby reducing their reliance on the mental manipulation of 2D representations (Hegarty, 2010; Suprapto et al., 2024).
2. Color-Coded Anatomy & Hyper-Labeled Visuals (Addressing Reducing ECL Modality & Split-Attention): Solving the main problem of traditional media, where 84.7% of consumers felt burdened by the absence of distinguishing colors. A consistent color-coding scheme for microscopic pictures (for example xylem in red, phloem in green, and parenchyma in yellow) is one suggested design standard. Additionally, upon cursor hover or touch, explanatory labels are constantly matched directly with visual objects (hyper-labeling), which may eliminate the split-attention effect (79.7%) (Mayer, 2014).
3. Smart Pop-Up Glossary & Contextual Lexicon (Addressing Reducing ECL Navigation Friction): To help around the time-consuming task of searching for Latin phrases (71.2%). An automatic contextual glossary that might offer succinct explanations is another suggested specification. Students do not need to exit the main reading page in order to see a brief explanation, etymology, and thumbnail illustration when they touch or hover their mouse over technical terminology (such phyllotaxis, perianth, or amphicribral).
4. Adaptive Microlearning Modules & Chunking Strategy (Managing Content Complexity): Small, hierarchically structured learning units (microlearning modules) are used to break

down dense and extensive botany topics. Particularly in the early phases of learning, before students integrate all components into a more sophisticated schema, breaking botany topics into smaller parts is a way to manage complexity and element engagement (Sweller, 2010). With this method, pupils can progressively develop knowledge schemas (scaffolding) without experiencing mental exhaustion. This method is suggested as a means of breaking up difficult botany material into smaller learning chunks. Future research on development should assess its impact on learning outcomes and cognitive overload.

CONCLUSION

Botany students face significant Intrinsic Cognitive Load (ICL) challenges when it comes to the semantic interpretation of morphological terms (55.9% found it difficult) and the visuospatial processing and mental rotation required for 3D plant organ structures (59.3%). Conventional learning resources were shown to actively produce excessive Extraneous Cognitive Load (ECL) due to the absence of color-coding (84.7%), the split-attention effect (79.7%), strict content layout (79.7%), and difficulties navigating the glossary (71.2%). These results should be interpreted as evidence of significant self-reported mental effort and engagement rather than as direct evidence of learning efficiency or achievement, even though over 94% of students supported the active learning strategies included in the Germane Cognitive Load (GCL) indicators and reported very high levels of GCL engagement. The coexistence of high reported GCL and ECL suggests that students actively interacted with botany resources while also encountering challenges related to traditional educational media. These results offer an empirical foundation for developing initial design specifications for a future Smart E-Library, such as enhanced visual representation, integrated terminology assistance, more effective information navigation, and organized presentation of complicated content. Future research must develop and empirically assess the suggested traits.

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REFERENCES

Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, *45*(1), 131–142. https://doi.org/10.1177/0013164485451012

Basri, I., Giatman, M., Mukhaiyar, R., Taali, T., Samala, A. D., & Dewi, I. P. (2025). Digital Education Transformation: Overcoming Existing E-Learning Platform Limitations with Smart Learning Solutions. *TEM Journal*. https://doi.org/10.18421/tem142-63

Bestari, I. A. P. (2024). Pengembangan Aplikasi Android Kamus Morfologi Tumbuhan Berilustrasi untuk Meningkatkan Penguasaan Istilah Ilmiah. *Wahana Matematika dan Sains: Jurnal Matematika, Sains, dan Pembelajarannya*, *18*(1), 40-54. https://doi.org/10.23887/wms.v18i1.77044

Bucksch, A., Atta-Boateng, A., Azihou, A. F., Battogtokh, D., Baumgartner, A., Binder, B. M., Braybrook, S. A., Chang, C., Coneva, V., DeWitt, T. J., Fletcher, A. G., Gehan, M. A., Diaz-Martinez, D. H., Hong, L., Iyer-Pascuzzi, A. S., Klein, L. L., Leiboff, S., Li, M., Lynch, J. P., ... Topp, C. N. (2017). Morphological plant modeling: Unleashing geometric and topological potential within the plant sciences. *Frontiers in Plant Science, 8*, 900. https://doi.org/10.3389/fpls.2017.00900

Chaidir, D. M., Suprapto, P. K., Ardiansyah, R., & Diella, D. (2024). Prospective biology teacher in learning using three-dimensional software: Interest, 3D representation and learning outcomes. In *AIP Conference Proceedings* (Vol. 2622, No. 1, p. 030010). AIP Publishing LLC.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Garnett, S. (2020). *Cognitive load theory: A handbook for teachers*. Crown House Publishing.

Kameswari, D. (2022). Pengetahuan mahasiswa biologi terhadap penggunaan terminologi bahasa Latin. *Research and Development Journal of Education*, *8*(1), 256-262. http://dx.doi.org/10.30998/rdje.v8i1.11187

Luz, C. F. P., & Martarello, N. S. (2022). THE PALYNOTHECA COLLECTION AND THREE DIMENSIONAL MODELS OF POLLEN GRAINS AND SPORES AS TEACHING RESOURCES FOR A MEANINGFUL LEARNING OF BOTANY. *International Journal of Biological and Natural Sciences*. https://doi.org/10.22533/at.ed.813272220101

Mayer, R. E. (2024). The past, present, and future of the cognitive theory of multimedia learning. *Educational Psychology Review, 36*, Article 8. https://doi.org/10.1007/s10648-023-09842-1

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative data analysis: a methods sourcebook* (3rd ed.). SAGE Publications.

Minicucci, D., Guediche, S., & Blumstein, S. E. (2013). An fMRI examination of the effects of acoustic-phonetic and lexical competition on access to the lexical-semantic network. *Neuropsychologia*, *51*(10), 1980–1988. https://doi.org/10.1016/j.neuropsychologia.2013.06.016

Nehm, R. (2019). Biology education research: building integrative frameworks for teaching and learning about living systems. *Disciplinary and Interdisciplinary Science Education Research, 1*. https://doi.org/10.1186/s43031-019-0017-6

Nordin, N. A., Abd Halim, N. D., & Dahri, N. A. (2026). An empirically validated pedagogical framework to reduce cognitive load in online learning environments. *Iran Journal of Computer Science*, 9(1), 24. https://doi.org/10.1007/s42044-025-00382-1

Sana, F., & Fenesi, B. (2025). Working Memory and Instructional Fit: Reintroducing Aptitude–Treatment Interaction in Education Research. *Behavioral Sciences, 15*. https://doi.org/10.3390/bs15060765

Suprapto, P. K., Ardiansyah, R., Diella, D., Chaidir, D. M., Hendrawan, A. M., Diana, S. W., & Amarulloh, A. (2024). Plant anatomy: Definition, classification of plant organs and tissue, and design of a visuospatial transformation learning model for teaching biology. *Indonesian Journal of Science & Technology*, *9*(2), 557–584. https://doi.org/10.17509/ijost.v9i2.72105

Survani, R., Ardiansyah, R., Nurqalbi, N. R., Nuraeni, E., Wulan, A. R., & Rahmat, A. (2014). Kemampuan analisis informasi versus usaha mental mahasiswa dalam perkuliahan anatomi tumbuhan untuk menunjang literasi kuantitatif. In *MATHEMATICS AND SCIENCES FORUM 2014*.

Sweller, J. (2024). Cognitive load theory and individual differences. *Learning and Individual Differences, 110*, 102423.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer.

Tajuddin, N. I. I., Abas, U., Aziz, K. A., Nor, R., Izni, N., Sudin, M. N., Anim, N. A. H. B. M., & Noor, N. M. (2025). Content Validity Assessment Using Aiken's V: Knowledge Integration Model for Blockchain in Higher Learning Institutions. *International Journal of Advanced Computer Science and Applications*. https://doi.org/10.14569/ijacsa.2025.0160659

Tsegaye Kassa, S. (2026). Cognitive benefits and risks of digital technology engagement. *Discover Psychology*, 6(1), Article 10. https://doi.org/10.1007/s44202-025-00527-0

Zoe Diaz-Martin, Dongfang Wang, Elethia Tillman, Mentewab Ayalew, Leveraging Plants for a Broad, Competency-Based Undergraduate Biology Curriculum, *Integrative and Comparative Biology*, Volume 65, Issue 6, December 2025, Pages 1937–1945, https://doi.org/10.1093/icb/icaf030