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# ANALYSIS ON THINKING SKILL: COGNITIVE LOAD MANAGEMENT IN CONNECTED INTEGRATED LEARNING

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**ABSTRACT**

Connecting related concepts can enable learners to obtain holistic knowledge but designing integrated learning must consider high element interactivity between concepts, so that learning would not result in excessive cognitive load, which will instead hinder learning. The promising benefit of learning plant anatomy and physiology in connected integrated learning was analyzed by assessing preservice biology teachers' identification and information analysis skills. The influence of learning approach on their cognitive load was also analyzed. Results suggested the advantage of learning in an integrated way, in which cognitive load can be managed by considering the correlation between cognitive load elements.

**ABSTRAK**

Menghubungkan konsep-konsep yang berkaitan dapat memfasilitasi peserta didik dalam memperoleh pengetahuan secara holistic, tetapi merancang pembelajaran terpadu harus mempertimbangkan interaktivitas tinggi antar konsep sehingga pembelajaran tidak menimbulkan beban kognitif yang berlebihan, yang justru akan menghambat pembelajaran. Manfaat yang menjanjikan dari mempelajari anatomi dan fisiologi tumbuhan dalam pembelajaran terpadu dianalisis dengan menilai keterampilan identifikasi dan analisis informasi calon guru biologi. Pengaruh pendekatan pembelajaran terhadap beban kognitif mereka juga dianalisis. Hasil menunjukkan keunggulan pembelajaran secara terpadu dimana beban kognitif dapat dikelola dengan mempertimbangkan korelasi antara elemen beban kognitif.

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## INTRODUCTION

Thinking is a complex phenomenon with varying definitions and classification, but experts agree that thinking skills are essential tools for effective teaching in which two major kinds of thinking skills have been identified for classroom instruction: skills essential for learning in general and those most helpful in learning specific subjects (Beyer, 2008). Thinking skills for science or scientific skills focus on the thinking and reasoning skills that support forming and modifying concepts and theories about the natural world (Zimmerman, 2007). Learning about natural world phenomena, such as vital processes of the living organism, have its own complexity because it involves connected biology concepts.

Van Merriënboer and Sweller (2005) pointed out that the most important characteristic of complex learning is when students must learn to deal with materials incorporating an enormous number of interacting elements. Such learning happens, for example, when learning about plant structure and functions involved in photosynthesis. To understand photosynthesis, students must understand both plant anatomy and physiology to comprehend the mechanism of carbon dioxide and water intake from air and soil or the mechanism of electron transfer and energy transformation within plant cells. Alas, studies have shown how understanding plant structure and functions is still challenging (Zangori and Forbes, 2016; Yenilmez and Tekkaya, 2006), even for undergraduate biology students (Wynn, Pan, Rueschhoff, Herman, and Archer, 2017; Parker et al., 2012) or preservice science teachers (Ermayanti, Rustaman, and Rahmat, 2016; Thompson, Lotter, Fann, and Taylor, 2016).

Thinking involves a complex set of cognitive and metacognitive skills in which developing and consolidating such skills require considerable exercise and practice (Zimmerman, 2007). Therefore, teachers and learners must actively involve in developing their thinking skills. One way to encourage learners to be active in the thinking process is by relating novel information with information kept in their memory and connecting, reorganizing, and developing the information to achieve a goal or discover a solution to a specific complex issue (Kirschner, Sweller, Kirschner, and Zambrano, 2018; Pachman, Sweller, and Kalyuga, 2013; Sweller, 2010). The highly interactive concept within the relevant study domain would result in a cognitive scheme that enables students to obtain holistic knowledge (Matlin, 2009). Thus, the implementation of learning by integrating related and connected concepts is promising for studying highly related concepts such as plant anatomy and physiology, but as Meissner and Bogner (2013) emphasize, learning strategy must also consider the effect of learning on students' cognitive load.

Based on cognitive load theory, the cognitive load consists of intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL) (Sweller, 1994, 1998; Ayres and Paas, 2008) in which the allocation of working memory resources to deal with intrinsic cognitive load refers to the intrinsic complexity of information; extraneous cognitive load concerned with the way instruction is designed; and germane cognitive load concerned with the acquisition of knowledge (Sweller, 2010). Therefore, this study will analyze cognitive load management when preservice biology teachers learn plant structure and function in an integrated learning course.

## METHOD

Subjects were twenty-one (21) preservice biology teachers from the 2019/2020 academic year who had taken the Plant Anatomy course in the first semester and Plant Physiology in the second semester at a private university in Kuningan-West Java. The thinking skill of preservice biology teachers were evaluated with two processes: 1) an integrated learning in which the students perform tasks regarding plant anatomy (root, stem, and leaf) and plant physiology (transpiration and photosynthesis) and 2) two five-items evaluation tests concerning plant structure-function and a students' questionnaire concerning their perception of the instructional procedure. Students' test and questionnaire results were analyzed to deconstruct how students manage cognitive load in a connected integrated learning.

The integrated learning process was implemented based on four (4) principles: 1) Utilizing prior knowledge in long-term memory to construct a concept of plant structure that is related to the concept being taught, 2) Utilizing multirepresentation in relating plant structure and function as an attempt to provide meaningful information delivery, 3) Providing contextual problem in learning structure-function relation, and 4) Providing objective performance guidance consisted of active verbs to guide students' performance in relating structure and function. Integrated learning consists of three stages, coherent concept connection, concept construction, and concept development (see Figure 1).

Thinking skills in identifying plant organ structure were evaluated using four scale rubrics with indicators: 1) identifying plant tissue and organ, 2) identifying the differences in structure and function based on plant habitat, 3) determining the basic concept of differences in organ structure changes based on plant habitat, and 4) determining principle of differences in organ structure changes based on plant habitat. Students' skills were then categorized as very good (score 3.2-4.0), good (score 2.7-3.1), fair (score 2.3-2.6), poor (1.7-2.2), and very poor (score 0.0-1.6) based on Arikunto (2010). Further, students' skill in analyzing information was measured with an essay test with four indicators: 1) identifying components of the structure that are relevant to the function, 2) relating structure to function, 3) assimilating concepts, and 4) integrating concepts of structure to function. The scoring system for information analysis skills refers to Bao et al. (2009) in which 75-100 score is considered as very good, good (score 61-74), fair (score 51-60), poor (35-50) and very poor (score 25-34).

Students' cognitive load consisted of three components: intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL). ICL is determined by element interactivity and prior knowledge in which intrinsic load is high when learners must connect highly related elements (Klepsch, Schmitz, and Seufert, 2017). Customarily, when students' score in processing information is high then their intrinsic cognitive load (ICL) for processing the information is low. GCL refers to the working memory resources that the learner devotes to deal with the intrinsic cognitive load associated with information (Sweller, 2010). Therefore, when students' score on a content-related test is high, students' germane cognitive load is considered good. ECL is connected to instructional procedure and therefore was measured using students' subjective self-re-

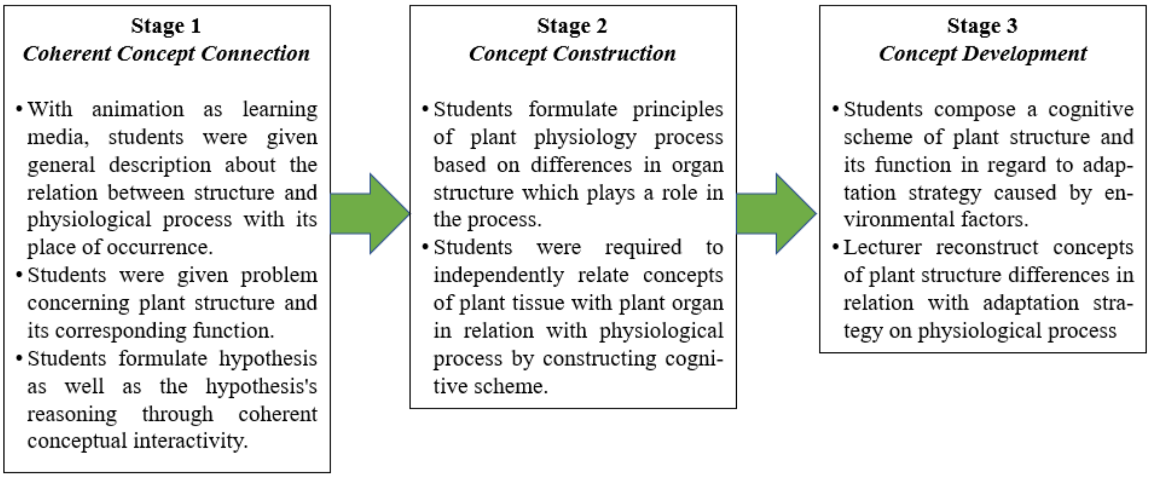


**Figure 1.** Plant Anatomy and Physiology Connected Integrated Learning Stages

ported rating scale questionnaire of perceived mental effort in relating plant structure and function (Brünken, Seufert, and Paas, 2010). The rating scale used a Likert scale stating very easy, easy, not easy, neither easy nor difficult, and very difficult. The result of cognitive load measurement was then analyzed quantitatively using multivariate correlation and regression tests to obtain the relation and contribution between the three cognitive load components. The statistics calculation was conducted using Statistical Package for Social Science (SPSS) 20 for Windows.

## RESULTS AND DISCUSSION

### Preservice Teachers' Thinking Skills in Identifying Plant Organ Structure and Analyzing Information

Students' thinking skills in identifying plant organ structure differ between indicators in which skill in analyzing information concerning stem based on habitat was lower than for root or leaf (Table 1). Torkar, Veldin, Glazar, and Podlesek (2018) conducted a study for three age groups: primary school students, secondary school students, and preservice teachers in Slovenia in which they found that although preservice teachers comparatively have a better understanding of how internal structure such as vacuole affected by the environment, 10% of them do not correctly understand it in submicroscopic level. The need for a higher level of understanding was also similarly reflected in students' information analysis skill results, in which results for the transpiration concept are lower than photosynthesis (Table 2). In learning the transpiration concept, students face a more complex information due to the necessity to simultaneously relate the structures of three plant organs (root, stem, and leaf) and the physiological process to the transpiration concept. Whereas, when learning the photosynthesis concept students only need to relate to their understanding of leaf structure and function. Thompson et al. (2016) study in preservice elementary teachers found that some of the preservice teachers still hold alternate conceptions of the transpiration process such as plants absorb but do not release water or that plants take water via roots before it travels to stems and leaves to remains there and becomes part of the plant. The preservice teachers in their study rarely discussed how plants also have a mechanism to return water to the environment via cellular respiration and transpiration. This reflected how the complexity of the transpiration process becomes one of the plant mechanisms that the students find harder to analyze and comprehend. Although the difference in complexity resulted in different scores per indicator, the average results suggested that students' thinking skill in identifying plant structure was 3.2 or can be categorized as excellent (very good). Similarly, skills in analyzing information with 79 average scores also considered very good.

### Cognitive Load Management in Learning Plant Anatomy and Function Integrally

Intrinsic cognitive load (ICL), extraneous cognitive load (ECL) and germane cognitive load (GCL) were measured from tests and questionnaire results in which high scores in students' skills in identifying plant organ structure (Table 1)

**Tabel 1.** Students' Plant Structure Identification Skill

| No. | Indicators | Root | Stem | Leaf | Average |
|---|---|---|---|---|---|
| 1 | Identifying components of plant organ structure | 3.4 | 3.3 | 3.2 | **3.3** |
| 2 | Identifying differences in organ structure based on plant habitat | 3.1 | 3.0 | 3.4 | **3.2** |
| 3 | Determining basic differences in organ structure change based on habitat | 3.3 | 3.1 | 3.1 | **3.2** |
| 4 | Determining principles in organ structure change based on habitat | 3.6 | 3.2 | 3.2 | **3.3** |
| | **Average** | **3.3** | **3.1** | **3.2** | **3.25** |

**Tabel 2.** Students' Information Analysis Skill

| No | Indicator | Transpiration | Photosynthesis | Average |
|---|---|---|---|---|
| 1 | Analyzing relevant structure components to fuction | 70 | 78 | **74** |
| 2 | Analyzing structure and function relation | 75 | 80 | **78** |
| 3 | Asimilating concepts | 78 | 83 | **82** |
| 4 | Integrating structure concepts to function | 85 | 78 | **82** |
| | **Average** | **77** | **80** | **79** |

**Tabel 3.** Correlation Between Cognitive Load Elements

| No | Relationship between components | Coefficient of correlation ($r^2$) and determination (r) | | Notes |
|---|---|---|---|---|
| 1 | Mental effort on identification skill | -0.677 | 0.823 | p= 0.00*< 0.01 |
| 2 | Indentification skill on information analysis skill | 0.773 | 0.856 | p= 0.00*< 0.01 |
| 3 | Mental effort in information analysis skill | -0.589 | 0.768 | p= 0.00*< 0.01 |

and in analyzing information (Table 2) proved that they can easily relate plant structure to its corresponding function which made their intrinsic cognitive load (ICL) for processing the information was low. Further, students' information analysis skill average reached 79 score which indicated that students successfully acquire and construct knowledge in longterm memory. Students' questionnaire results further corroborate this notion in which their self-reported perceived mental effort in relating plant structure and function was 2.35 (maximum score was 5 for *very difficult*). It can be surmised that students feel that their mental effort for learning in plant anatomy and function in connected integrated learning is moderate (neither easy nor difficult).

Management of cognitive load in a connected integrated learning facilitated students' learning by providing relevant information about plant structure while learning about plant function. Likewise, when learning about plant structure, students were guided to determine principles of changes in plant organ structure related to its habitat. Thus, the students are accustomed to automatically connect plant organs with the related physiological process. Studies have previously uncovered that when students receive information with low relevancy, they will obtain poor learning results (Korbach, Brünken, and Park, 2016; Sweller and Sweller, 2006; Van Merriënboer Kirschner, and Kester 2003). The same poor results will also happen when students pick irrelevant information, making it challenging to organize and relate the information in coherent mental processing. Therefore, integrated learning assists the students in managing cognitive load by emphasizing the thinking process, knowledge domain accommodation, cognitive system process, and self-system (Rahmat and Hindriana, 2014).

Moreover, Gordon, Tindall-Ford, Agostinho, and Paas (2016) as well as Pouw, Rop, De Koning, and Paas (2019) state that learning sources must be appropriately organized because excessive learning sources negatively influences learning results. Novel information organization and assimilation are facilitated by prior knowledge, which provides a working framework for accessing information from long-term memory (Gurlitt and Renkl, 2010). De Jong (2010) and Sweller (2010) claim that, compared to GCL, ICL would significantly affect working memory due to cognitive schemes guided by element interactivity related to ICL. Thus, the learning that increases the use of working memory by emphasizing ICL affects the increase of GCL.

Statistical analysis of the relationship between each cognitive load indicated a significant difference ($p \leq 0.01$), indicating that learning process has facilitated students in developing cognitive schemes that they can apply to solve problems related to changes in plant structure and function. Furthermore, the correlation test between plant organ structure identification skill and information analysis skill shows a positive coefficient correlation value ($r^2$) of 0.773. This result shows that the better students' ability to identify plant organ structures, the higher their information analysis skill scores. It means that the students can utilize their knowledge about plant structure to execute information related to plant function.

Likewise, the correlation test between mental effort and information analysis skills shows a negative correlation (-0.589). This result shows that the lower students' mental effort is in relating knowledge of plant structure when learning about plant function, the higher students' information analysis skills. Thus, the well-managed ECL is a response to connected integrated learning that influences the decrease of GCL. In addition, the correlation test proves that the three stages of learning (coherent concept connection, concept construction, and concept development) in connected learning encourage students to organize information and determine strategy in relating novel information and managing the information as a part of their long-term memory. Therefore, using a learning strategy in stages can optimize students' cognitive process during the learning process. If ICL is maintained within working memory capacity it will resulted in lower ECL and GCL. Scharffenberger and Bogner (2010) supported our findings that learning activity that encourages students to construct cognitive schemes can lower ICL, leading to cognitive achievement and positive change in learning efficiency.

## CONCLUSION

Students' thinking skill in identifying plant structure and analyzing information can be considered as excellent because they can easily relate plant structure to its corresponding function and can successfully acquire and construct knowledge in longterm memory. Mental effort for learning plant anatomy and function in connected integrated learning was moderate in which the strategy of dividing learning in stages can optimize students' cognitive process during the learning process. If ICL is maintained within working memory capacity it will resulted in lower ECL and GCL leading to cognitive achievement.

## REFERENCES


Arikunto, S. (2010). Prosedur Penelitian: Suatu Pendekatan Praktek. Jakarta: Rineka Cipta.

Ayres, P., & Paas, F. (2008). Interdisciplinary Perspectives Inspiring a New Generation of Cognitive Load Research. *Educational Psychology Review*, **21**(1), 1-9.

Bao, L., Cai, T., Koenig, K., Fang, K., Han, J., Wang, J., Liu, Q., Ding, L., Cui, L., & Luo, Y. (2009). Learning and scientific reasoning. *Science*, **323**(5914), 586–587.

Beyer, B. K. (2008). What Research Tells Us about Teaching Thinking Skills. *The Social Studies*, **99**(5), 223–232.

Brünken, R., Seufert, T., & Paas, F. (2010). Measuring Cognitive Load. In J. Plass, R. Moreno, & R. Brünken (Eds.), *Cognitive Load*

*Theory* (pp. 181-202). Cambridge: Cambridge University Press.

De Jong, T. (2010). Cognitive load theory, educational research, and instructional design: some food for thought. *Instructional Science*, **38**(2), 105–134.

Ermayanti, Rustaman, N.Y., & Rahmat, A. (2016). Improving Preservice Biology Teachers' Spatial Thinking in Plant Anatomy Course through Framing. *Jurnal Pengajaran MIPA*, **21**(2), 185-190.

Gordon, C., Tindall-Ford, S., Agostinho, S., & Paas, F. (2016). Learning from instructor managed and self-managed split attention materials. *Applied Cognitive Psychology*, **30**(1), 1-9.

Gurlitt, J., & Renkl, A. (2010). Prior knowledge activation: How different concept mapping tasks lead to substantial differences in cognitive processes, learning outcomes, and perceived self-efficacy. *Instructional Science*, **38**(4), 417-433.

Kirschner, P. A., Sweller, J., Kirschner, F., & Zambrano, J. (2018). From cognitive load theory to collaborative cognitive load theory. *International Journal of Computer Supported Collaborative Learning*, **13**(2), 213-233.

Klepsch, M, Schmitz, F., & Seufert, T. (2017). Development and Validation of Two Instruments Measuring Intrinsic, Extraneous, and Germane Cognitive Load. *Frontiers Psychology*, **8**,1997 doi:10.3389/fpsyg.2017.01997

Korbach, A., Brünken, R., & Park, B. (2016). Learner characteristics and information processing in multimedia learning: A moderated mediation of the seductive details effect. *Learning and Individual Differences*, **51**, 59–68.

Matlin, M. E. (2009). *Cognitive Psychology*. New Jersey: John Wiley and Sons. Inc.

Meissner, B., & Bogner, F. X. (2013). Towards cognitive load theory as guideline for instructional design in science education. *World Journal of Education*, **3**(2), 24-37.

Pachman, M., Sweller, J., & Kalyuga, S. (2013). Levels of knowledge and deliberate practice. *Journal of Experimental Psychology: Applied*, **19**(2), 108-119.

Parker, J. M., Anderson, C. W., Heidemann, M., Merrill, J., Merritt, B., Richmond, G., & Urban-Lurain, M. (2012). Exploring Undergraduates' Understanding of Photosynthesis Using Diagnostic Question Clusters. *CBE—Life Sciences Education*, **11**(1), 47–57.

Pouw, W., Rop, G., De Koning, B., & Paas, F. (2019). The cognitive basis for the split-attention effect. *Journal of Experimental Psychology: General*, **148**(11), 2058-2075.

Rahmat, A., & Hindriana, A. F. (2014). Beban kognitif mahasiswa dalam pembelajaran fungsi terintegrasi struktur tumbuhan berbasis dimensi belajar. *Jurnal Ilmu Pendidikan*, **20**(1), 66-74.

Scharfenberg, F., & Bogner, F. X. (2010). Instructional efficiency of changing cognitive load in an out of school laboratory. *International Journal of Science Education*, **32**(6), 829-844.

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, **22**(2), 123-138.

Sweller, J., & Sweller, S. (2006). Natural information processing systems. *Evolutionary Psychology*, **4**(1), 147470490600400130.

Sweller, J. (1994). Cognitive Load Theory: Learning Difficulty and Instructional Design. *Journal of Learning and Instruction*, **4**, 295-312.

Sweller, J. (1998). Cognitive Load During Problem Solving: Effects on Learning. *Journal of Cognitive Science*, **12**, 257-285.

Thompson, S. L., Lotter, C., Fann, X., & Taylor, L. (2016). Enhancing Elementary Preservice Teachers' Plant Processes Conceptions. *Journal of Science Teacher Education*, **27**(4), 439-463.

Torkar, G., Veldin, M., Glazar, S.A., & Podlesek, A. (2018). Why do plants wilt? investigating students' understanding of water balance in plants with External Representations at the Macroscopic and Submicroscopic Levels. *Eurasia Journal of Mathematics, Science and Technology Education*, **14**(6), 2265-2276.

Van Merriënboer, J. J. G., Kirschner, P. A., & Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist*, **38**(1), 5-13.

Van Merriënboer, J. J. G., & Sweller, J. (2005). Cognitive Load Theory and Complex Learning: Recent Developments and Future Directions. *Educational Psychology Review*, **17**(2), 147-178.

Wynn, A.N., Pan, I.L., Rueschhoff, E.E., Herman, M.A.B., & Archer, K. (2017). Student Misconceptions about Plants-A First Step in Building a Teaching Resource. *Journal of Microbiology & Biology Education*, **18**(1), doi.org/10.1128/jmbe.v18i1.1253.

Yenilmez, A., & Tekkaya, C. (2006). Enhancing Students' Understanding of Photosynthesis and Respiration in Plant through Conceptual Change Approach. *Journal of Science Education and Technology*, **15**(1), 81-87.

Zangori, L., & Forbes, C.T. (2016). Development of an Empirically Based Learning Performances Framework for Third-Grade Students Model-Based Explanations about Plant Processes. *Science Education*, **100**(6), 961–982.

Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental Review*, **27**(2), 172–223.