Students’ visual literacy: a study from plant anatomy learning

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Abstract. Plant anatomy is a branch of plant biology that focuses on the internal structures and development of a plant. This topic relies heavily on visual representations such as photographs and drawings as teaching and learning tools. Therefore, visual literacy is a core skill for biology students to study plant anatomy effectively. However, do biology students have a sufficient level of visual literacy particularly in the case of plant anatomy? This current study was conducted to provide answers to this question. To collect relevant information, this study involved 79 university sophomores studying plant anatomy in Indonesia. Using a case study design, two data collection methods included a test and semi-structured interviews to investigate to what extent biology students are visually literate in interpreting plant anatomy-based photographs. The author-designed test, Plant Anatomy Diagnostic Test (PADI), consisted of two sections. Section 1 comprised five four-tier multiple choice items linked to photographs of a plant, whereas section 2 was a drawing task. The test was distributed to all student participants, while the interview sections involved a subgroup of 15 students. All collected data were analysed separately, then the results were compared and compiled to triangulate the findings. The results of this current study supported and triangulated the fact that the biology students had difficulties to interpret, understand, and generate visualizations of the presented plants’ photographs, indicating that their visual literacy in plant anatomy was insufficient. The primary reason for students’ insufficient visual literacy was lack of conceptual understanding that resulted in their inability to apply and integrate knowledge. The implications of the research findings are also discussed.

1. Introduction
As a branch of Botany, Plant Anatomy is a study that focuses on plant internal structures including cells, tissues, and organs. Firstly introduced by Grew and Malpighi in 1670s, this old knowledge is a foundation for studying other plant sciences such as physiology, taxonomy, ecology and evolution [1]. Furthermore, the knowledge of plant anatomy is applicable to solve real-life problems, such as in the fields of pathology, horticulture, forensic and medicine [1-3].

Because of the nature of the content, plant anatomy courses intensively use visual representations as a powerful teaching and learning tool. Photographs, diagrams, and drawings are visual representations that dominate most plant anatomy textbooks and courses [2, 4-6]. These representations serve to facilitate students’ understanding of plant anatomy concepts and facts. Photographs, for example, function to bring microscopic facts of plant anatomy into a classroom by helping students to make better observations of a plant component [7, 8]. In addition, annotated diagrams and drawings of plant anatomy
can be used as useful resources to help students identify and interpret a plant component being observed under a microscope [1, 2]. Furthermore, drawing tasks in plant anatomy courses are considered as an effective technique for improving students’ observational skills [9], increasing students’ learning engagement toward the topic being studied [10], and developing students’ communication skills [8, 10]. Those benefits of visual representations, however, can only be achieved by students if they have developed visual literacy. Despite incoherent definitions proposed by scholars [11], visual literacy can simply be defined as those abilities to interpret and generate visual information [12]. Specifically, Kędra [11] identified 11 skills of visual literacy which were classified into three categories, namely, visual reading, visual writing, and other visual literacy skills such as visual thinking. However, Quillen and Thomas [8] asserted that the abilities to interpret and generate visual information represent the ends of a continuum. This means that visually literate students can be asked not only to read (at one end of the continuum) but also to create visual information (at the other end of the continuum).

The need of visual literacy becomes critical especially in this digital era. In line with rapid development of technology, visual information is predominant in our daily communications [12-14]. Therefore, visual literacy is required for effective communication processes. Due to the critical function of visual literacy, furthermore, this ability was identified as a crucial skill for 21st Century learning [12, 14, 15]. In addition, the current generation known as digital natives have a preference on images over texts [15-17]. This condition needs to be accommodated by supporting the development of their visual literacy so that this generation can use and produce visual information appropriately and wisely.

In spite of the importance of visual literacy, this ability has not been included in most universities’ curricula [11, 14, 18]. Most educators thought that seeing is a natural skill which does not require additional training [7, 18, 19]. Furthermore, Oblinger and Oblinger [20] argued that the current generation has inherently developed visual literacy through intensive interaction with visual media and images. In fact, exposing students to various visual information does not necessarily develop their visual literacy [12, 13]. As observed by Roth and Pozzer-Ardenghi [18], senior high school students proposed various interpretations of the same photograph in their biology textbook. Using a survey method, similarly, Brumberger [15] concluded that the undergraduates who known as digital natives had insufficient visual literacy. It is unsurprising because as mentioned by Kędra [11] visual representations are commonly used by teachers to illustrate rather than to convey information. Consequently, students received limited knowledge of the use of visual representations. Furthermore, Eilam [21] reported that most students tend to rely on their own experiences to develop visual literacy because of teachers’ lack of attention to this ability.

Research about visual literacy on teaching and learning is pervasive across disciplines, levels of education, and contexts [22]. Focusing on science learning, many studies reported students’ difficulties when interacting with visual information [15, 23-27]. For example, Won et al. [25] found that students’ incomplete conceptual understanding was the reason of their incorrect interpretation of visual representations of the human breathing system. In addition to conceptual understanding, Schönborn and Anderson [23] proposed six other factors affecting students’ interpretation of visual representations. The seven factors were formulated from three basic components including conceptual (C), reasoning (R), and mode of representations (M). The importance of prior knowledge was also observed by Tytler et al. [26] when investigating students’ difficulty in generating drawings. Furthermore, Brumberger [15] reported contradictory findings to the argument that suggested a sophisticated level of visual literacy of the current generation.

Despite the extensive literature discussing students’ interaction with visual information, there has been minimal empirical research that focuses on students’ visual literacy in plant anatomy in which visual representations, such as photographs, are predominant. Therefore, this study investigated students’ interpretation, understanding, and visualization of plant anatomy photographs. By focusing on these objectives, this research findings are expected to be able to contribute in improving teaching and learning of plant anatomy.
2. Method

This research was conducted in the Biology Department of a university in Surabaya, Indonesia. Overall, a total of 79 biology undergraduates studying plant anatomy participated in this study. These students were enrolled in three separate classes comprising 22 - 31 students. All participating students were undergraduates with ages ranging from 19 to 23 years. When this study was conducted, all students were in the third semester.

This study applied a case study design to investigate biology students’ visual literacy in plant anatomy. To collect relevant information, two data collection methods including a test and semi-structured interviews were applied. The test was taken by all participants using the author-designed instrument known as Plant Anatomy Diagnostic Test (PADI). The PADI consisted of two sections that included five four-tier multiple choice items linked to plant photographs at Section 1 and a drawing task at Section 2. Each item of Section 1 of the PADI comprised four linked multiple-choice questions asking about a concept, a photograph identification, a photograph annotation, and a reasoning, respectively. An example of Section 1 of the PADI is presented in Figure 1. In this section, correct and incorrect items were given scores 1 and 0, respectively. An item was considered as correct when each of the four-tier questions can be responded correctly. An incorrect response to at least one of the four-tier questions makes the item gets score 0. For Section 2, a rubric was used to assess students’ drawings and labelling as shown in Figure 2. The semi-structured interviews, differently, involved a subgroup of 15 participating students and were conducted one week after the test administration using an interview protocol.

This investigation collected both quantitative and qualitative information. The former were generated from students’ scores on the PADI that were determined using a scoring guideline and a rubric, and the latter were based on their responses to the interview questions. Both types of data were analysed separately, then, the results were compared and compiled to triangulate research findings [28, 29]. The quantitative data were analysed using descriptive statistics including means and percentages, whereas content analysis was used as a strategy to analyse the qualitative data.

![Figure 1. Item 3 of Section 1 on the PADI.](image-url)
3. Results and Discussion
The analysis of the results for both the quantitative and qualitative data of this study are presented in this section. The quantitative data are presented first followed by the qualitative data. The results and discussion are presented in separate subsections for easy reading.

3.1. Results
To understand the ways in which students interpreted plant anatomy photographs, the results of the test were firstly analysed. The percentages of the students’ answer combinations on the first section of the PADI are presented in Table 1.

Table 1. Percentage of students who correctly answered Section 1 of the PADI (n=79)

| Test Item | Percentage of students who provided correct responses (%) |
|-----------|----------------------------------------------------------|
|           | Tier 1 Tier 2 Tier 3 Tier 4 All Tiers                    |
| 1         | 72.2 31.6 24.1 20.3 13.9                                  |
| 2         | 50.6 44.3 44.3 43.0 27.8                                  |
| 3         | 73.4 35.4 35.4 58.2 25.3                                  |
| 4         | 25.3 74.7 64.6 29.1 11.4                                  |
| 5         | 50.6 49.4 21.5 26.6 11.4                                  |
| Average   | 54.4 47.1 38.0 35.4 18.0                                  |

The data reveal that most participants struggled to correctly answer the test on Section 1. As shown in Table 1, the percentage of students who provided correct answers to all tiers of Section 1 of the PADI ranged from 11% to 27%. Compared to other tiers, furthermore, Tier 4 which assessed students’ reasoning has the lowest average value indicating that students had difficulty in interpreting and understanding the features of the plant photographs. It is surprising because all the photographs which were presented in Section 1 of the PADI had been exposed to the students during lecture or laboratory sessions. This fact alone indicates that the students had not develop visual literacy to the expected level. In line with the results of Section 1, students’ responses to Section 2 of the PADI demonstrated their difficulty in communicating their understanding about plant anatomy in the form of a drawing.

Figure 2. The results of Section 2 on the PADI.

The results in Figure 2 show that most of students created incomplete drawings with partial labelling for all plant organs including stem, root, and leaf. Indeed, the percentages of students who drew comprehensive drawings with comprehensive labelling is less than 5%. These results indicate that students’ conceptual understanding of plant anatomy is inadequate and they are not able to communicate their interpretation and understanding of the plant photograph presented in Section 2. In addition, as
shown in Figure 2, more than 10% of students provided incorrect drawings or no responses to Section 2 of the PADI. This phenomenon has illustrated the importance of conceptual understanding on students' visual literacy, especially when generating visual information.

The data collected from the PADI indicate that most of students who participated in this study have insufficient visual literacy, especially in interpreting, understanding, and generating visualizations of presented in plant photographs. These results are supported by students’ responses to the interview questions. The following recorded responses confirm students’ difficulties when answering the questions in the PADI.

Student 1: …In my opinion, this item [Item 3] was difficult. I did not know how to make an analogy to integrate [my knowledge], to answer this [Item 3].
Student 2: …This picture [the photograph in Item 2] seems like a root, but I thought the structure looked like a stem. It [the structure] is similar to a plant that I have observed during laboratory session…Oh, I don’t know, I am confused.
Student 3: …I am confused, how could we predict plant anatomical structures from the morphological characteristics like this [pointing to the photograph in Section 2]? different plants may have different anatomical structures but not all…Therefore, I drew only the general structures of the plant organs that I already knew.

The sample of students’ interview responses above are indicative of the problems that students faced when completing the PADI. Student 1, for example, had difficulty to answer Item 3 because she was unable to combine knowledge about plant structure and function. As shown in Figure 1, Item 3 is a case study question that focuses on the application of plant anatomy knowledge. Differently, Student 2 had difficulty identifying the photograph in Item 2 because she could not differentiate the anatomy of a root from a stem. The problem of knowledge integration was also experienced by Student 3. She could not determine or predict the anatomy of plant photograph by looking at the plant morphological characteristics shown in the photograph. This difficulty also was apparent in the student’ drawing. These interview data triangulated with the results from section 1 of the test demonstrated evidence of students’ insufficient visual literacy.

3.2. Discussion
The research results in the preceding subsection indicate that most of undergraduates who participated in this study struggled to interpret, understand, and generate explanations of the plant photographs presented in the PADI. This fact is triangulated by the results of interview sessions. In other words, the undergraduates in this study had not developed visual literacy of plant anatomy to the expected level of proficiency. Similar findings were observed by Matusiak et al. [13] when examining students’ academic papers and presentations. As reported by the authors, students were unable to select, evaluate, and use visual resources appropriately. The problems are also apparent in other science topics, such as biochemistry [23], cells [27], and human anatomy [30].

As identified in this study, the main reason for students’ unsophisticated visual literacy was their insufficient conceptual understanding of plant anatomy. This finding is confirmed by the results of many research investigations on students’ visual literacy [23, 25, 26, 30]. Ruiz-Gallardo et al. [30], for instance, reported that students’ misconceptions contributed to their incorrect interpretations and generated drawings of human anatomy diagrams. According to Schnitz [31], domain knowledge contributes substantially to the construction of students’ visual mental models of the visual images being observed. Without sufficient domain knowledge, students may have incorrect or only a surface level interpretation and comprehension of the presented visual information [23, 32]. The critical function of a mental model was also identified by Quillin and Thomas [8] in their framework of drawing construction. Thus, students’ inadequate cognitive structure which forms their basic mental model construction may affect their drawing production which is representative of their mental model.

As captured in the interview sessions, students’ insufficient conceptual understanding influenced their ability to apply knowledge. This finding is also apparent in other studies [23, 25, 33]. For example,
Schönborn and Anderson [23] observed that student’s lack of comprehension about antibody concepts led to a misconception that was reflected in their incorrect interpretation of electron micrographs of antibodies. Based on this observation, the authors suggested that reasoning ability related to conceptual knowledge (R-C) is one of the factors affecting students’ interpretation of visual representations. The phenomena of student’s inert knowledge can also be explained using the structure deficit explanation proposed by Berthold and Renkl [34]. According to this explanation, an individual’s deficit conceptual understanding causes unavailable information to be applied to solve relevant problems in different contexts.

In addition to inert knowledge, students’ difficulties in integrating knowledge because of their inadequate conceptual understanding were observed in this study. This phenomenon may have occurred because the students learned plant morphology and anatomy in different semesters rather than as one holistic course. Consequently, the students struggled to find the relationship between plant morphology and anatomy which are naturally interrelated [35]. Furthermore, Cutler et al. [1] contended that the separation of plant components during teaching potentially decreases students’ learning motivation toward botany. Students may think that knowledge of botany is meaningless [36] leading to the difficulty of knowledge integration in long-term memory [37].

4. Conclusion

A photograph is a powerful tool for teaching and learning plant anatomy. However, the results of this study which were collected using a test and semi-structured interviews revealed that most of participating students had insufficient visual literacy, especially on the ability to interpret, understand, and generate explanations of a presented plant photograph. The main reason for students’ insufficient visual literacy was related to their inadequate conceptual understanding of plant anatomy which had negative impacts on their ability to apply and integrate knowledge.

Based on the research findings, we suggest three recommendations to improve plant anatomy teaching and learning. Firstly, as students’ visual literacy was found insufficient, their involvement in observation, interpretation, and generated-drawing activities need to be facilitated. This means that the use of visual representations of plant anatomy such as photographs is not only as illustrations of concepts but as source of information [11]. In this way, students can learn from the educators’ explanations how to interpret or produce drawings from the plant components being observed. Secondly, the integration of plant morphology and anatomy is required to support the development of students’ conceptual understanding. By combining these two aspects of botany students have increased opportunity to construct a better understanding about plant structures [35]. Lastly, we recommend instructors expose students to various real-life applications of plant anatomy in order to overcome their difficulties in transferring knowledge as captured in this study.

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