

**School of Education**

**University Students' Ability to Interpret Visual Representations in  
Plant Anatomy**

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**This thesis is presented for the Degree of  
Doctor of Philosophy  
of  
Curtin University**

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## DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee, Approval Number is SMEC-28-14.

A handwritten signature in black ink, consisting of a large, stylized initial 'S' followed by a cursive name, written over a horizontal dotted line.

Signature: .....

Date: 28 November 2017

## ABSTRACT

Plant anatomy is a botanical discipline that relies heavily on visual representations for communicating concepts, facts, and phenomena. Therefore, the interpretation of visual representations is at the heart of learning this discipline. However, numerous studies on external representations have revealed students' difficulties when learning from visual representations. The realistic details in a photograph, for example, may direct students' attention to irrelevant graphical components leading to incorrect interpretations of the representation. Without sufficient understanding of the content domain, moreover, students tend to focus on superficial features of a representation that results in surface-level reasoning of the concept being represented. However, few educational studies have focused on visualisations in plant anatomy. Relying on these facts, the current study was designed to investigate to what extent biology undergraduates were able to interpret visual representations in plant anatomy.

Using a case study design, the current investigation collected information related to students' ability to interpret visual representations in plant anatomy through diagnostic instruments, observations, semi-structured interviews, and document reviews. Three different diagnostic instruments referred to as Plant Anatomy Diagnostic Instrument (PADI) — the PADI-I, the PADI-II, and the PADI-III — were developed sequentially in the current study. The second and third instruments were developed based on the findings of the preceding instrument and analysis of the data collected. Three different groups of biology undergraduates who were studying plant anatomy in three consecutive semesters in one university in Indonesia with a total of 207 students were invited to participate in this investigation. Both quantitative and qualitative data were collected. Descriptive statistics were computed from the quantitative data while content analysis was applied to the qualitative information.

As a theoretical framework, the conceptual-reasoning-mode (CRM) model suggested by Schönborn and Anderson (2009) was adapted in the current investigation to understand the major factors that contributed to students' ability to interpret visual representations in plant anatomy based on interview data. According to this model, students' ability to extract meaning from visual representations is affected by seven factors, namely prior conceptual knowledge (C), reasoning ability (R), mode of the

representations (M), reasoning ability related to underlying concepts of the representations (R-C), reasoning ability related to graphical features of the representations (R-M), scientific concepts of the representations (C-M), and ability to involve all factors of this model (C-R-M).

The findings of this study revealed that the majority of biology undergraduates experienced difficulties when interpreting plant micrographs primarily because they had insufficient conceptual understanding of plant anatomy. On each of the three diagnostic instruments, less than 50% of the participants could answer the questions successfully. These findings were supported by incomplete drawings made by most undergraduates in the drawing tasks. As extracted from the results of semi-structured interviews, students' weak understanding of anatomical concepts (C) had significantly influenced their inappropriate conceptual reasoning of anatomical phenomena (R-C) and incorrect identification of components in plant micrographs (R-M). Learning problems were identified from the three factors — conceptual understanding, scientific reasoning, and identification skills — resulting in students' unsuccessful interpretations of micrographs in plant anatomy.

The results of observations and interviews with instructors indicated that the strategies used by the instructors to teach plant anatomy contributed to students' insufficient conceptual understanding of this discipline which in turn led to difficulties in interpreting visual representations in plant anatomy.

Thus, it is recommended that instructors need to strengthen students' conceptual understanding of plant anatomy so as to support their ability to interpret visual representations in this discipline. To improve students' comprehension of anatomical concepts, an understanding that a plant is a highly integrated organism and the relationship between structures and functions needs to be emphasised during the lessons of plant anatomy. Besides, students' ability to identify components in visual representations or specimens in plant anatomy needs to be considered if instructors intend to support the development of students' interpretation skills. However, further research needs to be conducted to support the findings of this case study which focused only on a particular group of students in an Indonesian university.

**Keywords:** Interpretation; Visual Representations; Plant Anatomy; the CRM Model.



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## LIST OF ABBREVIATIONS

<b>2D, 3D</b>	Two, Three dimensional
<b>C</b>	Conceptual factor
<b>C-M</b>	Conceptual-Mode factor
<b>C-R-M</b>	Conceptual-Reasoning-Mode factor
<b>CRM</b>	Conceptual-Reasoning-Mode model
<b>Dicot</b>	Dicotyledon
<b>DNA</b>	Deoxyribonucleic acid
<b>IBM</b>	International Business Machines Corporation
<b>M</b>	Mode factor
<b>Monocot</b>	Monocotyledon
<b>PADI-I</b>	Plant Anatomy Diagnostic Instrument I
<b>PADI-II</b>	Plant Anatomy Diagnostic Instrument II
<b>PADI-III</b>	Plant Anatomy Diagnostic Instrument III
<b>PBL</b>	Problem-based learning
<b>R</b>	Reasoning factor
<b>R-C</b>	Reasoning-Conceptual factor
<b>R-M</b>	Reasoning-Mode factor
<b>SEM</b>	Scanning Electron Microscope
<b>SPSS</b>	Statistical Package for the Social Sciences

# CHAPTER 1

## INTRODUCTION

### 1.1 Overview of the Chapter

This study investigates students' ability to interpret various visual representations in plant anatomy. This chapter includes the rationale, the theoretical framework, the purpose, the research design, and the significance of the study along with the structure of the thesis.

### 1.2 Rationale of the Study

Visual representations have become essential in our daily lives. Every day, we consume visual messages from online resources, newspapers, journal articles, television, books and social media. Instructions in various subject areas also heavily rely on visual representations as learning aids and communication tools (Eilam, 2012). Indeed, many textbooks are replete with visual representations (Eilam & Gilbert, 2014; McTigue & Flowers, 2011).

In this visual world, visual literacy is critical to interact successfully with visual information. The term visual literacy was firstly proposed by John Debes in 1969. He defined visual literacy as vision-related competencies that enable an individual to understand and differentiate visual information, utilise visible objects as a communication tool, and appreciate the aesthetic values of visual artworks (Fransecky & Debes, 1972). However, Debes' definition of visual literacy is potentially misleading because of the emphasis of sensory mode (i.e. eyes) instead of symbolic form, such as images (Draper, 2015). In response to the limitation, Robinson (1984) defined visual literacy as the ability to analyse and interpret visual materials. However, Eilam (2012) argued that visual literacy includes not only interpretation skills of images, but also competencies to represent, select, generate and evaluate various visual messages. Thus, having adequate visual literacy would promote an individual's capacity to recognise the relevant components of and extract meaning of visual information accurately. Furthermore, a visually literate person would be able to create and use visual representations to communicate with others.

Out of the various abilities in visual literacy, this study gave particular attention to the interpretation skills of visual representations in a specific biology field. The interpretation skills were selected because it is a prerequisite for developing the abilities to use, manipulate and construct visual information. Moreover, an individual can receive accurate visual information only by having sufficient interpretation skills of visual representations. This relationship is clearly illustrated in a study conducted by Cook, Carter, and Wiebe (2008). The authors observed that high school students with adequate conceptual understanding and skill to extract the meaning of graphical properties were able to explain correctly the main ideas of cellular transport diagrams. Similarly, Vlaardingerbroek, Taylor, and Bale (2014) reported that university students who have sufficient knowledge of scale and size could accurately identify cellular components that are visible at low magnification in diagrams and micrographs of cells.

Despite the significance of interpretation skills for learning, instructors do not pay enough attention to students' ability to interpret visual representations. Rather, students tend to develop this visual competency mainly through their own experiences (Eilam, 2012). No particular time is devoted by educators to formally teach how to interpret visual representations (Eilam, 2012; McTigue & Flowers, 2011). As observed by Coleman, McTigue, and Smolkin (2011), many teachers only point to diagrams without further explanation on the meaning of graphical features or underlying ideas in the visual representations. Indeed, most educators simply assume that interpretation skills are intuitive and students could interpret visual representations in the intended ways (Eilam & Gilbert, 2014; McTigue & Flowers, 2011; Roth & Pozzer-Ardenghi, 2013).

The aforementioned situations have contributed to exacerbating the challenges that students had experienced when learning from visual representations. Despite the beneficial effects of visual representations on students' learning (e.g., Gilbert, 2008; Host, Schönborn, & Palmerius, 2012; Mayer, 2009), many educational studies have recorded difficulties that students encounter with visual representations. For example, Patrick, Carter, and Wiebe (2005) observed that most middle-grade students struggled to recognise relevant information in pictures of DNA replication. Moreover, Schönborn and Anderson (2009) revealed difficulties that undergraduates experienced when trying to explain diagrams of immunology topics. Focusing on an

analysis of textbooks, Pozzer-Ardenghi and Roth (2005) identified high school students' many different interpretations of the same photographs of ecosystems. These difficulties stem not only from the nature of the representations but also from the students' lack of interpretation skills and the minimal support given by educators (Eilam & Gilbert, 2014; McTigue & Flowers, 2011). Therefore, it is necessary to investigate students' ability to interpret visual representations, particularly for a subject area in which visual representations are intensively used as a learning tool. The findings can be beneficial not only for informing instructors about their students' level of proficiency but also as guidance for instructional designs.

To assess students' interpretation skills of visual representations, their comprehension of concepts being represented needs to be evaluated as well because of the critical role prior knowledge plays in interpreting visual information (Cook et al., 2008; Novick, 2006; Schnotz & Bannert, 2003; Schönborn & Anderson, 2009; Winn, 1994). The evaluation of students' conceptual understanding will provide initial information to predict students' ability to interpret visual representations. As an illustration, confirming their assumption, Cook et al. (2008) found that high school students with low prior knowledge superficially interpreted diagrams of cellular transport. In line with this finding, Novick and Catley (2014) observed that university and high school students with a misconception of evolution theories had low accuracy when interpreting cladograms. Furthermore, Bond, Philo, and Shipton (2011) reported that compared to the first year undergraduates, master's students provided a more complete interpretation of a seismic image. These studies show that prior knowledge is a foundation to understand messages of visual representations (Schnotz & Bannert, 2003; Winn, 1994). Thus, information of students' conceptual knowledge is essential for investigating their interpretation skills of visual representations.

Similar to the other fields of biology, plant anatomy is a discipline that relies heavily on visual representations. However, little literature has focused on students' learning from visual representations in the context of plant anatomical structure. Burrows (2010), for instance, reported the benefits of a virtual program containing detailed photographs of flowers for university students in interpreting floral formula. However, the effect of this website on students' learning was not empirically evident. In fact, learning from visual representations in plant anatomy may be problematic for

some students. A simple line diagram that an instructor draws in the class may not necessarily help students to observe a real object under a microscope because of realistic identities, such as air bubbles and overlapping tissues. Besides, students may have difficulty to identify the same plant element in different pictures showing distinct orientations either cross or longitudinal sections (Eilam, 2013; Lord, 1990). However, these visualisation-related issues in plant anatomy are not well supported by sufficient empirical evidence. To address the lack of empirical research on visualisation in this field, this study was conducted to investigate the extent to which biology undergraduates are able to interpret visual representations, particularly photographs in plant anatomy. By doing so, students' interpretation skills can be determined and developed based on the findings of the current research. The supports to students' interpretation skills is fundamental for the development of students' visual literacy (Brumberger, 2011). Because the information of students' content knowledge was also collected, this investigation will also provide insights toward students' understanding of plant anatomy concepts. Thus, the results of this study have the potential to improve the teaching and learning of plant anatomy through visual representations.

### **1.3 Theoretical Framework**

This study adapted the Conceptual-Reasoning-Mode (CRM) model proposed by Schönborn and Anderson (2009) to analyse students' ability to interpret visual representations in plant anatomy. This framework was selected because it includes many aspects of interpretations of visual representations in addition to prior knowledge and external graphical characteristics that were recognised in theories of graphic comprehension (Schnotz & Bannert, 2003; Winn, 1994). According to the CRM model, students' ability to extract meaning from visual representations are influenced by seven factors including conceptual knowledge (C), reasoning ability (R), mode of representations (M), reasoning ability related to the underlying concepts of representations (R-C), reasoning ability related to the external features of representations (R-M), scientific ideas of representations (C-M), and ability to involve all components of the model (C-R-M). Further elaboration of this framework is presented in Section 2.4.

However, not all factors in the CRM model will be visible in this study (see Section 2.4) because this framework was not utilised from the beginning of the current investigation. Initially, this study considered the functional taxonomy of multiple representations proposed by Ainsworth (1999) as a research framework to analyse students' interpretations of texts and pictures in plant anatomy. This framework was selected because of the supervisor's thorough understanding of this model and the inclusion of different modes of representations. After the collection of data, however, the researcher experienced difficulties in classifying the findings into the Ainsworth's (1999) framework. Based on the findings, the researcher and supervisor then decided to change the research orientation from texts and pictures to visual representations only. Reviewing another section of a book in which the Ainsworth's (1999) framework is presented (see Treagust & Tsui, 2013), the researcher deemed that the CRM model was appropriate for the current research orientation. Under the supervisor approval, this model is continuously adapted in this study.

#### **1.4 Purpose of the Study**

The general purpose of this study was to investigate students' ability to interpret visual representations in plant anatomy. To achieve this intended purpose, three research questions were formulated.

##### **Research Question 1: What is the extent of undergraduates' conceptual understanding of plant anatomy concepts?**

This research question was formulated to examine the student participants' comprehension of the underlying concepts of plant anatomy. Students' performances on the instruments that were designed by the researcher and on the instructor-designed tests were analysed at the beginning of this study for initial prediction of students' interpretation skills (Cook et al., 2008) and for understanding misconceptions that students held when interpreting visual representations (Novick & Catley, 2014).

##### **Research Question 2: How do undergraduates interpret visual representations in plant anatomy?**

The ability of undergraduates to interpret visual representations in plant anatomy was investigated by analysing students' responses to the interview questions using the relevant factors in the CRM model. This analysis enabled the researcher to determine

to what extent students are able to interpret visual representations in plant anatomy accurately and to identify which factors of interpretation play more prominent roles in students' interpretation skills.

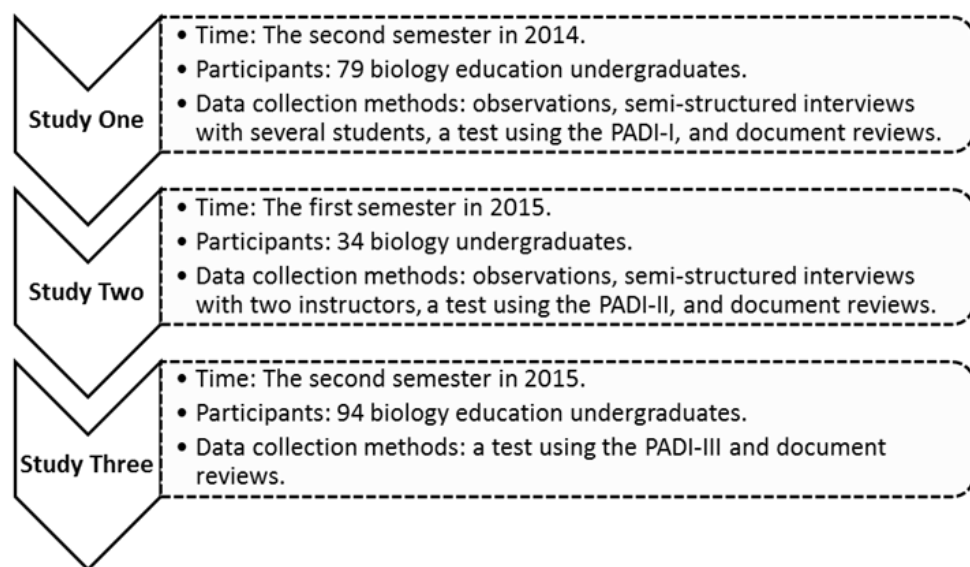
**Research Question 3: How do the instructors perceive the teaching of plant anatomy to support undergraduates' ability to interpret visual representations in plant anatomy?**

To gain insights on the impact of instructional designs and strategies on students' interpretation skills of visual representation, this study collected information on the instruction, mainly from instructors' reflections and researcher's observations. Thus, in contrast to the first and second questions which focused on students' performances, this research question centred on instructional aspects of plant anatomy.

## **1.5 Research Design**

This investigation adopted a case study design (Merriam, 2009; Yin, 2014). A total of 207 biology undergraduates studying plant anatomy in one state university in Indonesia within the period of 2014-2015 was selected as a unit of analysis or the case of this study. Both quantitative and qualitative data were gathered to provide a more complete information of the phenomenon being investigated. While the quantitative data provide a general picture of students' domain knowledge and a prediction of their interpretation skills, the qualitative data function to confirm the findings which were derived from the quantitative information. However, the qualitative data may contradict information which was invisible in the quantitative results. The contradictory or additional information are useful for illuminating the readers about the focus of the investigation (Patton, 2002). In the current research, the qualitative data were collected using observations, semi-structured interviews and documents reviews. The quantitative data were collected by reviewing the instructors' reports and through three different diagnostic instruments referred to as the PADI-I, the PADI-II, and the PADI-III, which were developed in this study to examine students' conceptual knowledge and interpretation skills of visual representations in plant anatomy.

Three subsequent studies were conducted in this current research within three consecutive semesters because of the changes that had been made to the research instruments (see Section 3.3.2 Step 4). Those three studies involved different participants and the diagnostic instrument used in the following study had been improved based on the results of the preceding study. The data collection strategies implemented in each study also varied from one to the other because of conditions as explained in Section 3.3.4. A brief description of each study is presented as a flowchart in Figure 1.1. Detailed explanations of the three studies can be found in Chapter 3.



**Figure 1.1** A flowchart of the three studies in this investigation.

## 1.6 Significance of the Study

This investigation obtained information that is potentially beneficial for teaching and learning of plant anatomy. Specifically, this investigation is significant for three reasons, as outlined in the following paragraphs.

First of all, these research findings can support the development of students' ability to interpret visual representations in plant anatomy. The primary focus of this study was students' competency in making meaning of visual representations in plant anatomy. Thus, students' strengths and difficulties when interpreting plant anatomy illustrations were captured in this investigation. The information can provide instructors with insights toward their students' interpretation skills and encourage them to give serious attention to this particular competency. Furthermore, using the



CRM model, this study identified the more prominent factors that affect students' ability to interpret visual representations. Focusing on the significant factors, instructors can design special treatments for preventing similar difficulties that future students may experience.

Secondly, the results of this study have potential implications for instruction in plant anatomy. Students' conceptual understanding and misconceptions were recorded and reported in the current investigation. In addition, the way students make sense of pictures of plant anatomy was analysed deeply. Based on the information of students' knowledge and interpretations, instructors of plant anatomy can design more appropriate teaching strategies to optimise the use of visual representations, to remediate students' conceptual errors, or to prevent students from experiencing similar interpretation difficulties as recorded in this study. Furthermore, the instructors' reflections of teaching plant anatomy that were presented in this study provide valuable information for selecting or creating supportive instructional designs.

Thirdly, this study provides a diagnostic tool for evaluating students' interpretations of plant anatomy representations. Apart from the few educational studies on plant anatomy, to the researcher's knowledge, no instrument has been created to investigate students' knowledge of this discipline. To capture the intended information, therefore, the researcher developed three different instruments using a procedure as outlined by Treagust (2012) and Wang (2004). The last developed tool, referred to as the PADI-III, was considered as the most appropriate analytical tool because it was refined based on the results of the use of the first and second instruments. The PADI-III can assess not only students' understanding of plant anatomy images but also their conceptual knowledge of anatomical structures. Adopting the two-tier multiple choice format proposed by Treagust (1988), the PADI-III enables the collection of information from a large group of students at one time. Besides, a quick and objective assessment of students' responses to this instrument is possible. Thus, the PADI-III is suitable for assisting instructors who seek an effective and efficient way to examine students' understanding of plant anatomy.

## **1.7 Structure of this Thesis**

Using a standard structure, this thesis is divided into seven chapters. Each chapter is outlined briefly in the following paragraphs.

Chapter 1 is an introduction to this thesis including the rationale, purposes, research questions, and potential significance of this study. The theoretical framework and the research design are also introduced briefly in this chapter.

A review of literature in Chapter 2 provides comprehensive descriptions about plant anatomy and interpretation of visual representations. Moreover, in this chapter, the CRM model as a theoretical framework that guides the analysis of collected data is described in detail.

Chapter 3 details the methods that were used in each stage of this investigation as schematized in Section 1.5. The descriptions of the research methods in this chapter include the research context, research strategy, research procedures, selection of participants, and methods for data collection and analysis. In the last parts of Chapter 3, the trustworthiness of this study and ethical issues related to this investigation are also described.

The findings of this investigation are presented in three sequential chapters, namely Chapters 4, 5 and 6. Each of the three chapters addresses one of the three research questions shown in Section 1.4. Thus, while Chapter 4 reveals facts related to students' conceptual understanding of plant anatomy, the ability of students in interpreting visual representations in plant anatomy are detailed in Chapter 5. Then, the contribution of instructional aspects on students' ability to interpret visual representations are discussed in Chapter 6.

Finally, the discussions, conclusions, and recommendations of the research findings are presented in Chapter 7. In the section of Discussions and Conclusions, answers to each research question are discussed in detail, linked to the relevant literature, and concluded. Some limitations of the current investigation is then outlined. In the later part of Chapter 7, the recommendations based on the findings of this study are discussed.

# **CHAPTER 2**

## **LITERATURE REVIEW**

### **2.1 Overview of the Chapter**

This chapter reviews the literature on the role of visual representations in teaching and learning of plant anatomy. The CRM model as the theoretical framework of this study is later elaborated in this chapter.

### **2.2 Plant Anatomy**

#### **2.2.1 The Content and Application of Plant Anatomy**

Plant Anatomy is a branch of botany that studies internal contents and arrangements of a plant body including cells, tissues, and organs (Cutler, Botha, & Stevenson, 2007; Fahn, 1990). This discipline deals with the relationship between the anatomical structures and functions of plant components. For example, while terrestrial plants have small cavities, aquatic species tend to develop tissues with large intercellular spaces to facilitate gas exchange (Evert, 2006). The ontogenetic and evolutionary development of plant parts are also reviewed in plant anatomy (see Beck, 2010; Evert, 2006) to provides insights on the varying degrees of anatomical complexity of various plant components.

Plant anatomy was introduced to the public in the 1670s by Marcello Malpighi and Nehemiah Grew. Understanding of plant anatomy can provide insights toward internal processes that are occurring within a plant. As an illustration, while most of the plant cells stay alive during a plant growth, tracheary elements undergo programmed cell death to build a continuous column system (Beck, 2010). This structure facilitates a rapid and efficient movement of water from roots toward the top of the plant. In addition to plant physiology, this discipline is essential for other plant sciences such as ecology, taxonomy, evolution, genetics, biochemistry, and reproduction (Cutler et al., 2007; Fahn, 1990). Indeed, a thorough understanding of this discipline can be utilised to solve problems in other applied fields including pathology, horticulture, forensic, and medicine (Cutler et al., 2007; Dickison, 2000). Dickison (2000), for example, describes several court cases to demonstrate how the

knowledge of plant anatomical structures can be applied to provide convincing evidence in legal situations.

### **2.2.2 The Teaching and Learning of Plant Anatomy**

For many years, most plant anatomy courses have adopted an instructional strategy that only involves cataloguing and demonstrating plant structures (Susiyawati, Ibrahim, Atweh, & Rahayu, 2015; Timmerman, Strickland, & Carstensen, 2008). Using a separated-subject approach (Timmerman et al., 2008), plant anatomy courses place emphasis on the factual content knowledge without mentioning the connection to other areas and the real-life applications. Furthermore, laboratory activities tend to focus on the verification of existing theories instead of building inquiry skills. This traditional teaching method is implemented to not only plant anatomy classes but also other botany courses (Hershey, 1996; Uno, 2009), such as plant taxonomy (Brosi & Huish, 2014).

The application of conventional teaching strategies to botanical disciplines has had adverse impacts on students' interest toward learning botany (e.g., Brosi & Huish, 2014; Hershey, 1996; Uno, 2009). For example, Hershey (1996) revealed that because of the overuse of preserved specimens, the limited hands-on activities, and the lack of knowledge applications, students attribute botany as a dry and uninteresting discipline. They are unable to see the fascinating and valuable aspects of botany. Thus, many students consider learning botanical subjects only as a prerequisite to complete their study at the university (Herrington, Reeves, & Oliver, 2010).

Due to the decline in students' enthusiasm in learning botany, Kramer, Zorn-Arnold, and Havens (2010) reported that many universities have progressively reduced the number of botany courses resulting in the shortage of qualified botanists. This condition affects botanical sectors, such as botanic gardens and plant conservation, and also teaching and learning of botany. For instance, due to the diminished emphasis on botany in university coursework, science instructors tend to refer to plants less frequently in science class (Frisch, Unwin, & Saunders, 2010; Hershey, 1996; Uno, 2009). The infrequent exposure to plants, unsurprisingly, has led to students' limited understanding of the plant domain (Bebbington, 2005; O'Brien, 2010). This fact has paved the way to a condition referred to as "plant blindness".

Initially coined by Wandersee and Schussler (1999), this metaphorical phrase describes a person's inability to perceive, value and appreciate the existence of plants in the environment. Public plant blindness, unfortunately, has adversely affected plant conservation projects (Balding & Williams, 2016).

To curb public plant blindness and increase students' motivation to learn botany, it is deemed necessary to change the teaching strategies. Most botanists recommend the use of inquiry-based instruction as a strategy to teach botanical subjects (Grover & Stovall, 2015; Hemingway, Dahl, Hafler, & Stuessy, 2011; Uno, 2009). Grounded in the constructivist theory, inquiry-based instruction refers to a teaching method that guides students to engage in the content of learning and to take ownership of the learning through science process skills (Minner, Levy, & Century, 2010). This instructional strategy encompasses different types of teaching models including open inquiry, discovery-oriented inquiry, case-based learning, project-based learning, and problem-based learning (Aulls, Magon, & Shore, 2015). Using inquiry-based teaching approaches, students' conceptual understanding and motivation to learn may improve because the students are consciously involved in each step of knowledge construction and skill development (Hemingway et al., 2011; Justice, Rice, Warry, & Laurie, 2007; Minner et al., 2010). Thus, by implementing inquiry-based instruction in botany courses, students' botanical literacy and appreciation to plants are expected to improve.

The study of plant anatomy relies on the careful observation and interpretation of plant anatomical structures, in line with the essence of an inquiry-based approach. However, the process of observing and interpreting plant structures can be challenging, especially for novices. The anatomy of fresh specimens under a microscope can be complex and complicated for identification (Eilam & Gilbert, 2014). Indeed, different 2D dissection orientations of a 3D plant body, such as longitudinal or cross sections, produce different appearances to make students frustrated when observing the plant's anatomical structures (Eilam, 2013; Lord, 1990). Furthermore, the variation of plant structures within the same species because of growth processes or environmental conditions (Dickison, 2000) have resulted in students' difficulties in understanding basic concepts of plant anatomy.

Most instructors of plant anatomy rely on visual representations to facilitate the learning of students who have problems with the observation, interpretation, or understanding of plant structures. The visual representations are utilised as a tool for bringing microscopic phenomena of plant anatomy into the classroom for a better observation of plant components (Eilam & Gilbert, 2014; Novick, 2006; Quillin & Thomas, 2015). Besides, annotated pictures are useful resources for assisting students who are struggling in identifying and interpreting plant parts under a microscope (Bowes & Mauseth, 2008; Cutler et al., 2007). The use of visual representations also aids students to understand explanations of anatomical concepts in textbooks (Eitel, Scheiter, Schüler, Nyström, & Holmqvist, 2013; Mayer, 2005; Schnotz, 2005). Furthermore, students' difficulties in understanding the connection points of plant components in a real 3D structure of a plant can be treated using the simultaneous use of diagrams and photographs of 2D and 3D structures (Eilam, 2013). It is possible because the combination of different modes of representations can serve one or more of the three basic functions of multiple representations — to complement, constraint and construct (Ainsworth, 1999, 2006). Two different representations have the complementary function when they contain different information that supports each other. In contrast, the constraining role is played by multiple representations when properties of a representation enable to constrain misinterpretation of another form of representation. Furthermore, the combination of representations is considered having the constructing function when learners are able to make abstraction, to extend knowledge, and to relate different representations.

Interaction with visual representations affects not only students' knowledge of the content but also their psychomotor and affective domains. For example, as a common task in most laboratories of plant anatomy, drawing a diagram of a specimen under a microscope is found to be a useful technique to improve students' observational skills of microscopic objects (Baldwin & Crawford, 2010; Dempsey & Betz, 2001). This drawing activity is also deemed as an alternative strategy to increase students' engagement of the topic being taught (Ainsworth, Prain, & Tytler, 2011; Van Meter & Garner, 2005). By generating their own pictures, moreover, students will learn how to communicate their ideas while understanding the specific convention of representations (Ainsworth et al., 2011; Prain & Tytler, 2012; Quillin & Thomas, 2015), such as the use of shading to represent the thickness of cell walls.

The aforementioned examples show that visual representations are essential for teaching and learning of plant anatomy. What are the types of visual representations that are utilised in learning plant anatomy? How do these representations assist students' interpretations of plant structures? These two questions are discussed in the following section.

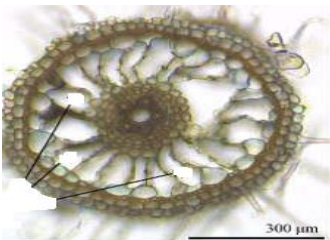
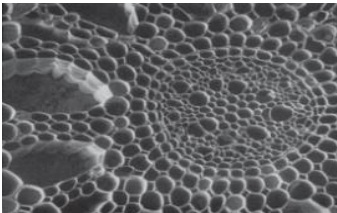
### 2.2.3 Visual Representations in Plant Anatomy

Visual representations are important tools to facilitate students' learning of plant anatomy. Two types of visual representations that are commonly utilised in plant anatomy courses and textbooks include photographs and diagrams (see Beck, 2010; Bowes & Mauseth, 2008; Burrows, 2010; Rudall, 2007; Santoso, Budiono, & Puspitawati, 2007). As a learning aid, each of these visual representations has its own strengths and limitations as discussed in the following paragraphs.

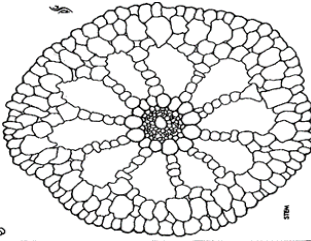
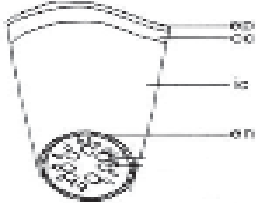
#### 2.2.3.1 Photographs (Micrographs)

Photographs are one of the visual representations that have been extensively utilised in plant anatomy textbooks (e.g., Bowes & Mauseth, 2008; Rudall, 2007; Schweingruber, Börner, & Schulze, 2013). Because the photographs of anatomical structures are commonly taken through optical microscopes or Scanning Electron Microscopes (SEM), the term of micrographs is applied (see Dickison, 2000). Table 2.1 shows examples of plant micrographs made using an optical microscope and an SEM.

**Table 2.1** *Examples of Plant Anatomy Visual Representations*

Visual Representation	Example	Caption
Micrograph (taking through an optical microscope)		A cross-section of a root of <i>Oryza sativa</i> subsp. <i>japonica</i> (Jung, Lee, & Choi, 2008)
Micrograph (taking through an SEM)		A cross-section of a root of <i>Stratiotes</i> , magnification $\times 75$ (Cutler et al., 2007)

**Table 2.1 Continued**

Visual Representation	Example	Caption
Detailed Diagram		Anatomical structure of a stem of an aquatic plant <i>Najas flexilis</i> (Dickison, 2000)
Simple Line Diagram		Anatomical sectors of a root in a cross section (Cutler et al., 2007)

Because a photograph retains the details of a real object, it is classified as a realistic visual representation (Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009; Van Gendt & Verhagen, 2001) or a concrete representation (Goldstone & Son, 2005; Moreno, Ozogul, & Reisslein, 2011). The values of concrete representations have traditionally been recognised by numerous educational research studies. When investigating the effect of realism on students' performance on a visual test about anatomy of rat, for example, Van Gendt and Verhagen (2001) found that realistic pictures facilitate the recognition of real objects. The resemblance between concrete visualisations and real world can also serve as an external resource, thus, viewers do not have to use the specific convention to understand the representations, thereby reducing cognitive load (Butcher, 2006; Goldstone & Son, 2005). Besides, the realistic details of concrete visual representations supports the construction of mental models of the object being depicted leading to an accurate analogical reasoning (Schwartz, 1995). These three findings indicate that realistic visual representations may be especially helpful for learning topics that are related to concrete objects, such as plant anatomy. However, concrete representations can also be a useful tool in making abstract concepts become more concrete and visible to support the understanding of the abstract ideas (Gilbert, 2005; Goldstone & Son, 2005; Patrick et al., 2005). Furthermore, concrete representations can attract attention and promote students' intrinsic motivation to learn because the inclusion of the realistic details makes these



representations more entertaining (Goldstone & Son, 2005; Liu, Won, & Treagust, 2014; Pozzer-Ardenghi & Roth, 2005; Rourke & O'Connor, 2012).

Despite the cognitive and motivational advantages, overexposing students to realistic visual representations may hinder their learning. Realistic details of the illustrations often direct learners' attention to the uninformative superficial features rather than the underlying principles (Liu et al., 2014; Patrick et al., 2005; Scheiter et al., 2009). Besides, the use of lifelike representations restricted students' ability to apply the basic idea of a realistic visual representation to solve other problems that superficially are dissimilar but are constructed under the same concept (Goldstone & Sakamoto, 2003; McNeil & Uttal, 2009; Moreno et al., 2011). Furthermore, without a careful design, a photograph may lead to various interpretations of the object being depicted (Eilam, 2013; Liu et al., 2014; Pozzer-Ardenghi & Roth, 2005).

#### 2.2.3.2 *Diagrams*

Plant anatomy textbooks are also replete with various diagrams of plant anatomical structures (see Beck, 2010; Bowes & Mauseth, 2008; Cutler et al., 2007; Evert, 2006). Adopting a definition proposed by Hall (1996), in this study, a diagram is referred to as a visual representation that simplifies a reality to convey particular information. Thus, different from micrographs which are rich in realism, diagrams contain less of the realistic details, such as colours, textures, and backgrounds, but retain the relevant and salient characteristics of an object being depicted. Depending on the amount of the information being conveyed, diagrams of plant anatomy can be found either in detailed or simple line presentations as illustrated in Table 2.1.

Despite containing less resemblance to the real objects, diagrams have been extensively used in biological fields (Perini, 2013). The simplicity of a diagram (compared to photographs) was found to be beneficial to facilitate students in extracting the underlying idea of the reality being represented (Butcher, 2006; Goldstone & Son, 2005; Scheiter et al., 2009; Schwartz, 1995). It is possible because the realistic details which may distract students' attention could be eliminated in a diagram (Mayer, 2005; Perini, 2013) or essential properties of the object which might be blurred in reality can be clearly seen and understood in a diagram (Scheiter et al., 2009). In other words, when observing a diagram, students are less burdened to distinguish between relevant and irrelevant information, thus, minimising cognitive

load. Besides, a diagram enables the visualisation of abstract processes or phenomena that are invisible in realistic visual representations, thus, providing in-depth explanation of the object being represented (Gilbert, 2005; Liu et al., 2014; Novick, 2006). Furthermore, because diagrams do not directly refer to a particular object, students' acquired knowledge from these simplified representations is potentially transferable to novel situations (see Goldstone & Sakamoto, 2003; Moreno et al., 2011; Van Gendt & Verhagen, 2001).

Although the power of simplified representations on students' learning is evident, relying only on diagrams as a learning aid prevents students to gain holistic knowledge of the information being conveyed. As illustrated by Ferguson and Hegarty (1995), students who had an experience with a real world situation solved application problems better than their counterparts who were only exposed to diagrammatic representations. A similar phenomenon was also observed by Schwartz (1995) when comparing university students' explanations of realistic and abstract pictures. According to Schwartz (1995), the lack of accuracy and realistic details in a diagram hindered students to construct a mental model of the represented object. As a result, the students struggled to build imagery-based analogy leading to the incorrect reasoning of the object being depicted. Furthermore, without adequate understanding of symbol conventions in representations, reduction of realistic details in a diagram may result in the incorrect interpretation of reality (Butcher, 2006; Constable, Campbell, & Brown, 1988; Goldstone & Son, 2005; Novick, 2006).

As described in this section, the type of visual representations influences the way the viewer interpret the information being represented. How can the graphical design affect the process of interpreting visual representations? What other aspects influence the interpretation of visual representations? The answers to the two questions are available in the next section.

## **2.3 The Interpretation of Visual Representations**

### **2.3.1 Theoretical Perspectives**

Interpretation of visual representations is a result of the interaction between graphical features and readers' ability (Boling, Eccarius, Smith, & Frick, 2004; Eilam, 2012; Malamed, 2009; Schönborn & Anderson, 2009). The impact of images' quality on an

individual's interpretation has been traditionally recognised particularly by proponents of the theories about signs and symbols or semiotics (Ainsworth, 2006; Anglin, Vaez, & Cunningham, 2004; Roth, Pozzer-Ardenghi, & Han, 2005). These semioticians emphasised formats, designs, and contents of representations as essential aspects for enhancing readers' understanding of visual representations. For example, Roth et al. (2005) proposed some rules to assist students in learning from photographs, such as the use of appropriate captions, background, and arrows. These semiotic theories have provided useful guidance for representation-based teaching (Boling et al., 2004; Rourke & O'Connor, 2012; Scheiter et al., 2009). However, focusing on visual messages independently of the recipients is incomplete because understanding of visual representations is also affected by personal characteristics (Boling et al., 2004; Eilam, 2013; Malamed, 2009; Won, Yoon, & Treagust, 2014). Thus, it cannot be simply assumed that all readers can read the visual information in the designer's intended way. A number of theories proposed several personal aspects that could influence an individual in understanding visual representations including cognitive ability (Schnotz & Bannert, 2003), knowledge of graphical conventions (Gilbert, 2005), culture (Cooper, 2002), motivation (Bradley, 2000) and gender (Eilam, 2012). This suggests that both graphical characteristics and readers' abilities need to be considered when using visual representations as a communication tool.

In supporting the idea of the reciprocal interaction between visual representations and the readers, Winn (1994) and Schnotz and Bannert (2003) proposed two broad processes in understanding pictures from a psychological perspective, perceptual and semantic processing. In the perceptual stage, an individual detects, discriminates, and configures symbol system in pictures that results in the visual perceptions of the picture's surface structure. This surface-level interpretation is based on sensory perceptions of picture's compositions, such as colour, spatial arrangement, and topography and requires little cognitive resources. To gain the meaning of the pictures, the perceptual information is then processed semantically by involving the individual's existing knowledge. This process leads to the construction of a mental model of the depicted information. When compared to the visual perception, the mental model is more abstract because it excludes irrelevant graphical characteristics but includes additional information from prior knowledge. When the viewer's

understanding concurs with the interpretation results, comprehension of pictures is achieved.

From an educational perspective, Schönborn and Anderson (2009) also offered a model that discussed affecting factors on students' ability to interpret visual representations. Concurring the aforementioned theories, in this model, Schönborn and Anderson (2009) clearly mentioned that students' interpretation skills of visual representations are profoundly affected by the design of representations and their cognitive ability. In contrast to Winn's (1994) account, Schönborn and Anderson (2009) divided the cognitive factor into prior knowledge and reasoning ability based on the results of their preliminary investigations (Schönborn, Anderson, & Grayson, 2002). Thus, the author identified three primary factors that influence students' successful interpretations of visual representations including the design of representations, prior knowledge of underlying concepts brought by the representations and reasoning ability. In this model, Schönborn and Anderson (2009) also proposed other affecting factors (see Section 2.4) that were fundamentally constructed based on the interaction between each of the triad — the design of representations, prior knowledge and reasoning ability.

As discussed above, the existing theories indicate the importance of graphical characteristics and personal cognitive abilities for interpreting visual representations. What do investigations on representations suggest related to the interpretations of visual representations? Are the research findings consistent with or against the aforementioned theoretical perspectives? Numerous research studies on visual representations are discussed in the next section in response to the questions.

### **2.3.2 Empirical Perspectives**

Students' learning from visual representations has received attention from numerous researchers in education (Schönborn & Anderson, 2009; Tang, Delgado, & Moje, 2014; Tippett, 2016). From 2000-2014, for example, Tippett (2016) recognised 38 studies that focused on students' interpretations of diagrams. A great number of research on this area placed emphasis on the saliency of physical forms of visual representations on students' learning. According to this group of studies, graphical compositions, such as colours and arrows (e.g., Plass, Heidig, Hayward, Homer, & Um, 2014; Pozzer-Ardenghi & Roth, 2005), complexity of images (e.g., Chapman,

Stapleton, Rodgers, Micallef, & Blake, 2014; Host et al., 2012) and mode of representations (e.g., Goldstone & Son, 2005; Moreno et al., 2011) profoundly influence students' interpretations of visual information. Patrick et al. (2005), for example, observed that colours and shapes in depictions of DNA replication attracted attention of middle-grade students. However, most of the students failed to capture the underlying ideas of the representations because they focused only on these visual cues. van Buuren, Heck, and Ellermeijer (2016) also reported students' misconceptions in physics because of the use of the same icon (arrows) to represent different functions (flows and connectors). When investigating the different presentations of diagrams about the circulatory system, similarly, Butcher (2006) inferred the superiority of a simplified diagram over a detailed diagram on university students' ability to integrate relevant information in generating inferences. She further explained that the simplified representation provided greater support for developing a correct mental model of the domain than did the more complex diagram. Taken together, these studies recommended the careful designs of visual representations to promote students' understanding of visual information.

Instead of focusing on the physical forms, other studies on representations highlighted the significant role of the readers as meaning makers of visual messages (e.g., Jee et al., 2014; Novick & Catley, 2014; Vlaardingerbroek et al., 2014). The authors of these studies asserted that the process of interpreting visual representations depends on individual characteristics. Thus, the same image may be interpreted differently by different readers depending on their expertise (Bond et al., 2011), prior knowledge (Cook et al., 2008), conceptual understanding (Chittleborough & Treagust, 2008), reasoning ability (Dasgupta, Anderson, & Pelaez, 2016), and knowledge of graphic conventions (Kragten, Admiraal, & Rijlaarsdam, 2015). As an example, Cook et al. (2008) found that color, shape, size, and arrow direction were salient graphical components for both low and high prior knowledge high school students to interpret cellular transport diagrams. However, unlike their counterparts who could extract the conveyed message from these visual cues, the students with inadequate domain knowledge focused only on the external features of the diagrams leading to a surface-level interpretation. To provide a possible explanation of this phenomenon, Corradi, Elen, Schraepen, and Clarebout (2014) conducted an investigation by involving university students with low prior knowledge of abstract

representations in chemistry. The authors found that multiple representations may hinder learning of students with low prior knowledge because of their inability to distinguish irrelevant from relevant information in the representations.

Understanding the saliency of graphical format and personal aspects, some educational studies attempted to investigate the relationship of these two factors when students are interacting with visual representations (e.g., Brucker, Scheiter, & Gerjets, 2014; Cheng & Gilbert, 2015; Rundgren & Tibell, 2010). In contrast to the preceding findings, for instance, Scheiter et al. (2009) found no significant effect of prior knowledge on university students' learning from highly complex visual representations of cell replication. However, an investigation conducted by Canham and Hegarty (2010) showed that undergraduates' performances in interpreting weather maps improved after the instruction about meteorology and the elimination of irrelevant information from the visual representations. These contradictory results are also demonstrated clearly in a study by Won et al. (2014) that investigated high school students' explanations of different modes of visual representations in human respiratory system. The authors observed that while all participants can explain the underlying concept represented by a bell jar model, distinct strategies were applied by different students when interpreting a breathing mechanism diagram. Students with a thorough conceptual understanding tended to integrate both representations for expressing their knowledge whereas the application strategy from the model to the diagram was adopted by participants who have incomplete understanding of the concept. These phenomena indicate the dynamic interaction between graphical and personal aspects during interpretation of visual representations (Malamed, 2009; Treagust & Tsui, 2013; Won et al., 2014). This complex process of interpreting visual representations seems to be the potential reason behind the discrepancy of the research findings on students' learning from visual representations (McTigue & Flowers, 2011; Tippett, 2016).

The discussion above shows that the findings of current studies on interpretations of visual representations are in line with the existing theories about graphic comprehension (see Section 2.3.1). While many studies focused on graphical formats that provided a great contribution to the semiotic theories, other investigations recommended designs for representation-based teaching to enable the accommodation of students' personal differences. However, the two-way interaction

between these two aspects also recognised by several studies supporting the theoretical perspectives (Schnotz & Bannert, 2003; Schönborn & Anderson, 2009; Winn, 1994). Therefore, an assessment of students' ability to interpret visual representations is necessary for understanding which aspect of interpretation that needs more consideration. In the next section, the methods for diagnosing students' interpretation skills of visual representations are discussed.

### **2.3.3 Diagnosing Students' Ability to Interpret Visual Representations**

Interpretation of visual representations is a central practice in various fields, particularly in science learning. A variety of visual representations, such as photographs (Pozzer-Ardenghi & Roth, 2005), animations (Kelly & Jones, 2007), videos (Brucker et al., 2014), models (Won et al., 2014), diagrams (Liu et al., 2014) and graphs (Bowen & Roth, 2005) has been intensively used in science classrooms to promote students' understanding of concepts or phenomena being taught. Indeed, Slough, McTigue, Kim, and Jennings (2010) reported 12 different types of visual representations in sixth-grade science textbooks. To successfully learn from these visual representations, therefore, students need to develop sufficient interpretation skills.

An evaluation of students' meaning-making processes of visual representations is important for the development of their interpretation ability. This type of assessment will provide insights toward students' existing knowledge (Novick & Catley, 2014), conceptual understanding (Tsui & Treagust, 2007), representational competence (Cheng & Gilbert, 2015), difficulties when interacting with visual representations (Won et al., 2014), and the strength and weakness of particular representations (Rundgren & Tibell, 2010). Using the information, instructors can design supportive teaching strategies that accommodate students' current level of proficiency as well as optimising the use of visual representations as a learning tool (Cook et al., 2008; McTigue & Flowers, 2011; Treagust & Tsui, 2013).

However, the teachers' assessments commonly focus only on the content knowledge but overlook students' interpretation ability of visual representations (Eilam, 2012; McTigue & Flowers, 2011). Consequently, most instructors do not realise difficulties that students experienced when learning from visual representations (Roth & Pozzer-Ardenghi, 2013). These difficulties may hinder students' learning (Gilbert, 2005) but

are hard to be resolved because the cause is invisible to the instructors' understanding. Therefore, diagnosing students' ability to interpret visual representations is an initial critical step for supporting students to successfully interact with visual information.

There are three common strategies for diagnosing students' ability to interpret visual representations, namely, interviews, written tests, and drawings. Each of these strategies is described in the following paragraphs.

#### *2.3.3.1 Interviews*

As a means of assessment, interviews are invaluable for probing students' actual understanding, knowledge and ability (Fuller, 2012; Johnson & Johnson, 2002; Southerland, Smith, & Cummins, 2005). While other assessment methods provide only an approximate prediction of students' achievement, interviews with interactive conversations give instructors accurate understanding of an individual's competencies and ways of thinking (Fuller, 2012). Therefore, instructors can explicitly address problems that students experienced during the learning process, such as their misconceptions (see Gomez-Zwiep, 2008; Mintzes, Wandersee, & Novak, 2001). Furthermore, Dick (2005) identified other benefits of using interviews as an assessment tool including minimising plagiarism, providing immediate feedback and correction to students' understanding, supporting the development of students' communication skills, and improving the relationship between teacher and students.

Many studies on representation have also relied on interviews for examining students' understanding of visual representations as well as collecting research data (e.g., Chittleborough & Treagust, 2008; Cook et al., 2008; Piht, Raus, Kukk, Martin, & Riidak, 2014; Pozzer-Ardenghi & Roth, 2005; Schönborn & Anderson, 2009). For example, Pozzer-Ardenghi and Roth (2005) revealed a variety of students' interpretations of the same ecology-related photographs after interviewing some high school students with different prior knowledge and experiences. However, the authors identified the changes of students' meaning-making processes when captions and texts were presented implying the importance of these semiotic resources for students' learning from visual representations. Despite the superiority of interviews to capture detailed information of students' thinking, discomfort or stress that



students may feel during the conversations can impede the benefit of this strategy (Southerland et al., 2005). To triangulate the findings, thus, some studies combined the interview results with information from other strategies, such as a two-tier test (Won et al., 2014), a questionnaire (Rundgren & Tibell, 2010), drawing (Cheng & Gilbert, 2015), and eye tracking (Patrick et al., 2005).

Practically, however, interviews are considered ineffective to be used by instructors to diagnose all students' interpretation skills of visual representations. This method requires a significant amount of time and effort for preparation, interviewing, and analysing that can be a challenge for teachers whose have tight schedules (Lin, 2004; Southerland et al., 2005; Treagust, 2012). Besides, substantial training and practices to design appropriate probes of interviews are necessary to collecting targeted information (Johnson & Johnson, 2002; Southerland et al., 2005). Furthermore, the information that are obtained from a small number of students cannot be generalised to understand a portrait of the whole students in the classroom (Pesman & Eryilmaz, 2010). Because of these limitations, the interview strategy is not recommended for classroom teachers as a diagnostic method (Lin, 2004; Sesli & Kara, 2012; Treagust, 2012).

#### 2.3.3.2 *Written Tests*

In addition to oral explanations, a written test can be utilised to diagnose students' knowledge and ability (Johnson & Johnson, 2002; Lai & Chen, 2010; Treagust, 2012). This diagnostic tool enables a quick assessment of students' conceptions from a large population (Cetin-Dindar & Geban, 2011; Tsui & Treagust, 2010; Wang, 2004). Thus, a teacher can obtain a general picture of students' preconceptions before instruction or their understanding level after commencing a particular topic. Using results of the test, for example, instructors can design an appropriate teaching strategy to either improve understanding or treat misconceptions that most students hold. Despite the less-time consuming advantage of written tests, students' writing ability and test-taking skills need to be taken into account when using this strategy as a means of diagnostic assessments. Students who have difficulties to express their thoughts in written form may be disadvantaged when long answers or explanations are required in the tests (Johnson & Johnson, 2002). Students' responses to written tests may also reflect their test-taking ability, such as guessing and word matching instead of their actual understanding leading to invalid assessment of students'

knowledge (Caleon & Subramaniam, 2010; Griffard & Wandersee, 2001; Lai & Chen, 2010).

Written tests are also used in research on visual representations to investigate students' interpretations of visual information. Two formats of tests that are commonly utilised for collecting students' written responses about visual representations include essay tests (e.g., Bowen & Roth, 2005; Karazsia, 2013; Rundgren & Tibell, 2010) and multiple-choice questions (see Karazsia, 2013; Vlaardingerbroek et al., 2014). Each of these formats has its own strength and weakness. Unlike the assessment of essay tests which is highly subjective and time consuming, the scoring of students' responses to multiple-choice questions is quick and free of bias (Johnson & Johnson, 2002). However, Johnson and Johnson (2002) asserted that whereas essay items can assess students' actual knowledge and higher order reasoning, multiple-choice questions commonly ask students lower-order thinking in which guessing is potentially high.

However, the alternative format of multiple-choice items, such as a two-tier diagnostic test, has been extensively adopted in various research studies (Lin, 2004; Sesli & Kara, 2012; Wang, 2004; Won et al., 2014). In contrast to the conventional version where each item focuses only on factual knowledge, this test consists of two questions in each item that ask about conceptual understanding and reasoning, respectively (Treagust, 1988, 2012). Using this format, thus, students' guessing on the two-tier multiple-choice tests can be minimized. Furthermore, Treagust (1988) argued that this current version of multiple-choice questions enables detection of students' misconceptions or alternative conceptions. This is made possible because the distractors of the reasoning part of this diagnostic test are constructed based on students' responses to open-ended questions.

#### 2.3.3.3 *Drawings*

Students' generated drawings have been intensively used in numerous educational studies as a magnifying glass of students' conceptual understanding (e.g., Ilkorucu-Gocmencelebi & Tapan, 2010), knowledge (e.g., Hay, Williams, Stahl, & Wingate, 2013), misconceptions (e.g., Dikmenli, 2010; Köse, 2008) and experiences (e.g., Topsakal & Oversby, 2012). As a diagnostic strategy, drawing is beneficial for four reasons. Firstly, when compared to other techniques, drawing is a simpler strategy

that can be prepared quickly (Köse, 2008). No complicated preparation is required before the collection of students' drawings. The instructors or researchers simply administer a blank paper as a drawing space to the participants. Secondly, drawing provides an opportunity for students to express their thoughts freely without having to match their ideas with the knowledge of test designers (Nyachwaya et al., 2011; Ormançı & Ören, 2011). In contrast to the forced-choice items that require students to select the correct answers, in a drawing test students can choose their own image to be drawn as a representation of their ideas. Thirdly, the drawing strategy enables the capture of holistic knowledge and ideas that students possess. For example, Jee et al. (2014) reported that students' understanding of highly spatial domains, such as geoscience, can be precisely revealed using drawing instead of written tests. Besides, students' mental models of scientific concepts are more apparent in their drawing compared to verbal language (Dikmenli, 2010; Moseley, Desjean-Perrotta, & Utley, 2010). Furthermore, students' conceptual difficulties that are invisible in their responses to multiple-choice tests can be clearly inspected in their generated drawings (Nyachwaya et al., 2011). Lastly, the drawing method facilitates students who have difficulty in expressing their thoughts verbally (Rennie & Jarvis, 1995).

Because of the potential value of drawings, this method has also been employed for diagnosing students' ability to interpret visual representations. For example, when asking undergraduates, master's students, and geoscientists to draw and highlight a seismic image, Bond et al. (2011) recognised the degradation in details in the drawings created by novices compared to experts reflecting their level of interpretation ability. A similar finding was also observed by Jee et al. (2014) when comparing psychology and geoscience students' sketches of the same geoscience-related visual representations. The authors found that the sketches generated by geoscience students emphasised domain-related information which was missing in the novices' drawings indicating the role of domain knowledge for perceptual skills of visual representations. Furthermore, Cheng and Gilbert (2015) suggested that students' interpretations of visual representations which contain spatial relationships, such as diagrams of the human circulatory system, can be captured comprehensively when both their verbal explanations and generated drawings are provided.

However, the use of drawing as a diagnostic strategy has several limitations that need to be taken into account. As observed by Jee et al. (2014), assessing drawings of a

large number of students requires a much longer time compared to the evaluation of students' responses to forced-choice items. Without clear marking criteria, moreover, the variations in students' drawings make the assessment challenging and highly subjective (White & Gunstone, 1992). Hay et al. (2013) also cautioned that relying only on drawings as the primary information may lead to incomplete interpretations of ideas being communicated because as a representation of an individual's mental model, drawings are affected by an individual's knowledge, experience, confidence and context. Furthermore, this strategy may cause anxiety of students with low drawing skills (Matern & Feliciano, 2000; Reiss & Tunnicliffe, 2001; Stagg & Verde, 2018). Consequently, instructors need to, at least, assure that the aim of drawing is to diagnose knowledge and understanding instead of artistic ability.

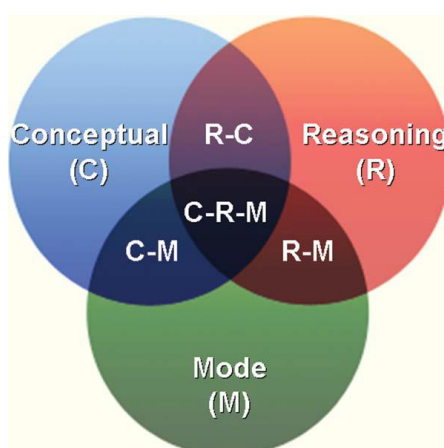
In spite of the limitations of each strategy, the information collected using each diagnostic method is critical, particularly for teachers to support students' learning. As suggested by Cook et al. (2008), for example, using the information about students' interpretation ability, instructors can select and apply the most appropriate visual representations as learning aids that meet students' diverse conditions. Besides, students' difficulties in interpreting visual representations that are captured using the diagnostic strategies can be a foundation for instructors to design teaching strategies that enable the remediation or prevention of the problems being revealed (Bowen & Roth, 2005; Patrick et al., 2005; Schönborn & Anderson, 2009). Furthermore, students' perspectives and feedback on visual representations in textbooks provide invaluable information for publishers in creating supportive learning resources (Eilam, 2013; Piht et al., 2014).

However, the aforementioned benefits are difficult to achieve without further analysis of the information being collected using the diagnostic strategies. For analytical purposes, a theoretical framework is necessary as a lens for a better interpretation of students' interpretation skills. In this research study, the CRM model proposed by Schönborn and Anderson (2009) was selected to guide the researcher in evaluating students' ability to interpret visual representations. Further descriptions about this model are presented in the next section.

## 2.4 The CRM Model as Analytical Framework of Interpretive Abilities of Visual Representations

Investigating students' learning problems in biochemistry, Schönborn and Anderson (2009) constructed a model to determine factors affecting students' ability to interpret visual representations. This framework is referred to as a conceptual-reasoning-mode (CRM) model. The CRM stands for three primary factors that the authors identified in their initial research (Schönborn et al., 2002). The triad consists of students' prior *conceptual* knowledge of visual representations (C factor), students' *reasoning* skills related to the graphical formats and the underlying concepts of visual representations (R factor), and the *mode* of visual representations being presented (M factor). These three factors were found to be the primary sources of students' difficulties in learning from diagrams in biochemistry (Schönborn et al., 2002).

In a follow-up study on students' interpretations of visual representations in immunology, Schönborn and Anderson (2009) found that the interaction between each of the three primary factors (C, R, and M elements) significantly influenced the way students interpret visual representations. Therefore, Schönborn and Anderson (2009) proposed seven components of the CRM model that affect students' ability to interpret visual representations. When represented in a Venn diagram (see Figure 2.1), the CRM model is seen to be composed of the triad of C, R, and M factors, and four other components including reasoning-conceptual (R-C), reasoning-mode (R-M), conceptual-mode (C-M), and conceptual-reasoning-mode (C-R-M) factors.



**Figure 2.1** A Venn diagram representing the seven factors of the CRM model. This diagram is adopted from Schönborn and Anderson (2010).

As shown in Figure 2.1, the seven components of the CRM model are interdependent one to another leading to difficulty in determining which component has a prominent contribution (Schönborn et al., 2002). However, in this model, Schönborn and Anderson (2009) considered each of the seven factors independently to understand the main sources of students' difficulties when interpreting visual representations. Thus, instructors, for example, can explicitly address students' problems with visual representations. In the following paragraphs, each component of the CRM model is described in relation to the current investigation.

### **Conceptual (C) factor**

In this model, the C factor is defined as prior conceptual knowledge or preconceptions of particular scientific concepts that a student holds before being exposed to any representations of the concepts. Disregarding the dynamic interaction between graphical and individual characteristics, in this factor, the authors aim to diagnose students' knowledge including alternative conceptions, misconceptions and mental models that students might bring when interacting with relevant visual representations. In contrast to Schönborn & Anderson's (2009) study, students' preconceptions of plant anatomy were not assessed in the current investigation. Instead, their conceptual understanding — the manifestation of students' knowledge and ability to apply their knowledge into new contexts (Konicek-Moran & Keeley, 2015) — was reflected in their responses to the diagnostic tests (see Chapter 4). In this investigation, the students' conceptual understanding was used as initial information to predict students' interpretation skills of visual representations.

### **Reasoning (R) factor**

According to Schönborn and Anderson (2009), the R factor represents perceptual and semantic processing (see Schnotz & Bannert, 2003) that students employ when interacting with visual representations. Thus, this factor provides information about both students' skills to perceive and understand the meaning of visual clues and graphical features and ability to use existing knowledge for explaining the underlying concepts being represented. In other words, the evaluation of the R factor depends on the results of students' reasoning related to representations (R-M factor) and students' reasoning related to concepts (R-C factor). Each of these two factors is discussed in the next parts.

### **Mode (M) factor**

Despite using the word “mode”, in the CRM model, the M factor refers to not only the format of visual representations, such as diagrams, photographs or graphs, but also graphical features including colours, spatial arrangements, symbols, topography, labels, captions and other visual cues inside the same modes of representations. However, the current investigation described the M factor as graphical characteristics, such as colours, shapes and size of a particular or the same types of visual representations that may influence students’ interpretations of the representations. To illustrate, a micrograph of a dicotyledonous root may have blue and red colours with a transparent background. A student may incorrectly interpret these colours as natural features of the organ if he or she has no understanding about staining process in making permanent microscopic slides. The M factor, specifically for static representations, remains constant over time (Schönborn & Anderson, 2009). However, different individuals may perceive it differently because of the differences in cognitive resources or experiences (see Cook et al., 2008; Jee et al., 2014). In the CRM model, the evaluation of the M factor was validated by an immunologist, researchers and students. However, the potential effects of the M factor on students’ interpretation skills in the current investigation was extracted and analysed from their explanations of graphical compositions in the visual representations.

### **Reasoning-Conceptual (R-C) factor**

The R-C factor is an interactive element between the reasoning and conceptual aspects of the CRM model. This factor describes students’ ability to use and apply their conceptual framework to understand the underlying concepts of a visual representation. Thus, in contrast to the C factor which focuses on the nature of students’ preconceptions of the underlying concepts that relevant to a particular picture before looking at the actual representation, the R-C factor examines to what extent students are able to utilise their preconceptions to interpret the idea of a representation. To perform this cognitive process, a student may rely on knowledge transfer, knowledge integration, analogical reasoning and deductive or inductive reasoning (Schönborn & Anderson, 2009). As an illustration, a student may use deductive reasoning to recognise an unknown plant organ that is represented in a micrograph. Starting with the concept of stem anatomy, for example, the student

identifies whether the picture is showing anatomical characteristics of a stem, such as collateral vascular bundles, narrow cortex and endarch xylem. If the picture meets the criteria, the student concludes that the organ in the micrograph is a stem, otherwise he or she will reiterate the process using another concept. In the current investigation, the R-C factor was identified from students' concept-based explanations during interview sessions.

### **Reasoning-Mode (R-M) factor**

As an interaction between reasoning and mode factors, the term R-M portrays students' ability to explain the meaning of graphical compositions inside visual representations. To perform this skill successfully, a student needs to have knowledge about graphic conventions, such as understanding two-dimensional appearances of a three-dimensional object and decoding different shapes and shading in an illustration (Eilam, 2013; Gilbert, 2005; Kragten et al., 2015). Without this knowledge, the student may incorrectly interpret visual representations. For example, tubes of xylem in 3D format appears as circles in 2D cross sections but becomes elongated shapes in 2D longitudinal sections. These different 2D shapes of a single object may be confusing for students who are unable to imagine 3D formats in various rotations. In contrast to the R-C factor which focuses on students' explanation of the underlying concept of a visual representation, the R-M concentrates on their responses related to visual cues, such as colours, shapes, sizes and spatial arrangements in the representation.

### **Conceptual-Mode (C-M) factor**

The interaction between the conceptual and the mode (C-M) factor reflects the nature of a scientific concept being represented by graphical features, format, or symbols in a visual representation. For instance, botanists (e.g., Beck, 2010; Cutler et al., 2007) explained the concept of xylem in their textbooks by drawing thickened circular-shaped structures in a simple diagram of a cross section. Thus, the information of the C-M factor is obtained in isolation from students' interpretations, rather this information is from experts' judgments which are available in textbooks, captions or journals where the representation is presented. In the current investigation, the C-M factor is determined by examining prescribed textbooks (Esau, 1965; Fahn, 1990), the students' handbook (Santoso et al., 2007) and the instructors' power-point presentations. The evaluation of this factor is necessary to ensure that students have



studied the required knowledge to interpret the representations and that the complexity of the scientific concepts are appropriate for the students' educational level (Anderson, Schönborn, Plessis, Guptar, & Hull, 2013).

### **Conceptual-Reasoning-Mode (C-R-M) factor**

Schönborn and Anderson (2009) argued that students need to involve all components of the CRM model for a successful interpretation of visual representations. This ability is assessed in the C-R-M factor. During the interpretation of visual representations, however, only R-C and R-M factors are apparent in students' explanations while C, M and C-M remain implicit. Therefore, the authors suggested that the evaluation of the C-R-M factor is obtained by coding students' engagement with R and C factors (R-C) and their involvement with R and M factors (R-M). In the current investigation, thus, the C-R-M factor was determined only when a student are able to provide both sound reasoning related to the graphical features (R-M) and correct explanation related to the underlying concepts of the representations (R-C) compared to the scientific accepted knowledge (C-M).

The separation of the interdependent components in the CRM model developed by Schönborn and Anderson (2009) may be confusing for people who understand the two-way interaction between graphical and individual characteristics during the process of interpretation of visual representations. However, by looking at individual factors in this model, researchers or instructors can diagnose students' level of competencies as well as the specific sources of students' difficulties when learning from visual representations. For teaching purposes, furthermore, Anderson et al. (2013) developed guidelines and provided an example how instructors can create tasks that enable the assessment of each factor in the CRM model. The results of this evaluation is invaluable information for instructors for designing appropriate tutorial to either remediate students' difficulties, support the development of students' skills or prevent the similar problems for future courses. In other words, the CRM model is not only useful as an analytical tool for research (e.g., Dasgupta et al., 2016) but also has a potential benefit for teaching practices.

## **2.5 Summary of the Chapter**

In this chapter, a review of literature about plant anatomy, interpretations of visual representations, and the theoretical framework of this study has been described in

detail. Based on the review, it is apparent that plant anatomy is a botanical subject that relies heavily on visual representations as a learning aid. Micrographs and diagrams are essential tools for representing and communicating concepts and ideas in plant anatomy. Although these visual representations were beneficial for improving students' learning, various research studies have observed students' difficulties in interpreting these depictions. This is understandable because, as supported theoretically and empirically, the process of interpreting visual representations is strongly affected by not only the nature of the representations but also by personal characteristics. Thus, diagnosing students' ability to interpret visual representations, particularly in plant anatomy, may prevent the erroneous understanding of the information being depicted that would potentially hinder students' learning and achievement. For this purpose, three common diagnostic strategies were utilised, namely interviews, written tests and drawings. In order to derive useful information from students' interpretations being collected, the CRM model was used as an analytical tool. The components in this model provide guidance to determine to what extent students are capable of interpreting visual representations that are valuable for instructors to design the most appropriate teaching strategies.

When considering this literature review, it is argued that this investigation on students' ability to interpret visual representations in plant anatomy is relevant to educational practice. The findings of this study may provide instructors with insights about both students' level of proficiency in interpreting visual representations and conceptual understanding of plant anatomy. The students' difficulties that are potentially captured in this research may also provide ideas for educators to create a supportive learning environment. The aforementioned information can be collected using particular research methods; the methods that are utilised to carry out the current investigation are described in Chapter 3.

# **CHAPTER 3**

## **RESEARCH METHODS**

### **3.1 Overview of the Chapter**

This chapter focuses on the research methods of this investigation including the research context, research design and trustworthiness of this study. The ethical considerations are also discussed in the later part of the chapter.

### **3.2 Research Context**

This investigation was conducted at the Biology Department of an Indonesian university. As one of five departments in the Mathematics and Natural Science Faculty, the Biology Department runs two study programs for undergraduates, namely biology and biology education. In the beginning of four semesters, undergraduates of these two study programs enrol in the same basic biology courses, but biology education students are also required to take extra units related to teaching and education. Consequently, at the end of fourth semester biology education students earn more credits than their counterparts.

Plant Anatomy is one of the compulsory courses for each biology student who has passed the Plant Morphology unit. Plant Anatomy classes are available in each semester. In the first half of a study period, this course is provided only for biology education students, whereas the biology undergraduates enrol in this subject in Semester Two. This 16-week course is run once a week comprising a two-hour lecture and a three-hour laboratory session.

When this investigation was conducted, each plant anatomy course was taught by a team consisting of three instructors, namely Mr. Daun, Mrs. Bunga, and Mr. Akar (each name provided is a pseudonym). However, only two instructors guided plant anatomy courses in the last part of this investigation because Mr. Daun had retired. Each instructor had a responsibility to teach one or two particular topics of plant anatomy in every semester. During the lectures, each instructor introduced or sometimes explained a topic that students need to further explore in the laboratory session. An inexperienced instructor frequently sat at the back of the classroom,

observed the students, and provided assistance if needed while a senior instructor guided the lesson. The instructor who taught the topic then supervised students' work during a three-hour laboratory session. One or two co-assistants who are commonly senior students were involved in the laboratory activity to provide assistance for students who experienced difficulties, for example, in using a microscope, making a wet mount slide, or deciding what specimen to examine. Throughout each semester, those three instructors handled each available class in a sequence order. At the end of a study period, thus, all students from the different classes should have studied the content of plant anatomy (see Appendix A) in the same order.

### **3.3 Research Design**

As mentioned in Chapter 1, this investigation involved three sequential studies. Aiming to address the same research questions, these three studies were conducted to gain accurate information of the phenomenon under investigation. For example, the research instrument used in the first study (Study 1) provided findings that were used to improve the subsequent studies (Studies 2 and 3). The components of the research design of each study including research strategy, research procedures, selection of participants, and data collection and analysis methods are discussed in the following sections.

#### **3.3.1 Research Strategy**

This investigation was conducted using the case study as a research strategy. This strategy was employed because this research aimed to gain a clear picture of students' ability to interpret visual representations in plant anatomy in a particular context without any intentions to generalise the results to a larger population (Cohen, Manion, & Morrison, 2011; Creswell, 2013). Because the construction of meanings of visual representations is not passive and is dependent on graphical and individual characteristics (Treagust & Tsui, 2013; Won et al., 2014), this dynamic and complex phenomenon can be effectively elicited using case study research (Stake, 1995). Moreover, this single instrumental case study (Stake, 2005; Yin, 2014) — an inquiry of a case (i.e., students who studying plant anatomy in a particular university) to understand a particular issue (students' interpretation ability of visual representations) — occurred in a natural environment without any interventions. Thus, each case study can capture participants' behaviours in a real situation,

including their natural conceptions of the subject matter and interpretations of visual representations. These aforementioned conditions fit within the definition of a case study proposed by Yin (2014).

A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. (p. 16)

Although it is a qualitative inquiry (Creswell, 2013; Merriam, 2009; Stake, 2005), Yin (2014) argued that a case study can go beyond thick description of the case by mixing quantitative and qualitative evidence. The quantitative data in a case study can serve to complement qualitative information for providing a more complete understanding of the case (Johnson & Christensen, 2012) or to clarify the qualitative findings (Gillham, 2000). Concurring this assertion, various information was collected in this investigation using both quantitative and qualitative methods (see Section 3.3.4).

### **3.3.2 Research Procedures**

Prior to data collection activities, the researcher designed a paper-and-pencil diagnostic test for each study. This instrument functioned as the main tool for collecting information about students' conceptual understanding of plant anatomy and interpretation ability of visual representations in this discipline. The diagnostic instrument was developed using steps outlined by Treagust (2012) and Wang (2004). Each phase of the instrument development is described below.

#### *Step 1: Identifying Propositional Knowledge Statements*

In this initial step, the scope of plant anatomy concepts was determined by reviewing propositional knowledge statements in three college-level plant anatomy textbooks (Beck, 2010; Dickison, 2000; Rudall, 2007), one students' handbook of plant anatomy (Santoso et al., 2007) and instructors' PowerPoint presentation slides. This step provided access to the actual curriculum and teaching content. For this investigation, however, the content domain was restricted only to anatomical structures of vegetative plant organs. Based on the three sources, a total of 71 statements comprising 4, 17, 16, 19, and 15 propositions, respectively, for the topics: plant cells, tissues, stems, roots, and leaves were identified as a requirement to understand the anatomy of vegetative plant organs. The first draft of the plant

anatomy propositional knowledge statements is documented in Appendix A of this thesis.

### *Step 2: Developing a Concept Map*

A concept map of plant anatomy was created by including most of the propositional knowledge statements that had been identified in Step 1. By constructing a concept map, key concepts of plant anatomy and the connection between the concepts can be seen clearly (Novak, 1991), thus avoiding unnecessary information and preventing missing essential ideas. This concept map also enabled the verification of the internal consistency of the plant anatomy content coverage that was tested by comparing the mapped ideas with the list of propositional knowledge statements (Treagust, 2012).

### *Step 3: Validating the Content*

The first drafts of both the propositional knowledge statements and the concept map were then reviewed and content validated by two university instructors who had a thorough understanding of plant anatomy, namely Mr. Daun and Mrs. Bunga. These instructors had more than 20 years' experience of teaching plant anatomy in the university under investigation. At this step, only two instructors were involved because Mr. Akar had limited experiences in teaching plant anatomy courses (see Section 6.1.2). By validating the content domain by presentation of the two drafts to the two in-service instructors, the alignment between the curriculum and the teaching processes could be validated. The validation is also essential for ensuring the accuracy of the content domain being investigated in this research (Cohen et al., 2011; Fraenkel, Wallen, & Hyun, 2012; Treagust, 2012). Based on the instructors' comments and feedback, any inappropriateness and irregularities of the content domain that were documented in the list of propositional knowledge statements and the concept map were deleted, revised or modified.

In fact, both Mr. Daun and Mrs. Bunga agreed that the proposed propositional knowledge statements were accurate and relevant to the plant anatomy content domain, teaching materials, and targeted participants. Therefore, the first draft of the propositions was directly utilised as the final version of the plant anatomy propositional knowledge statements for this research. While Mrs. Bunga also approved the content and design of the constructed concept map, Mr. Daun suggested a different layout for improving comprehensibility and readability of the

concept map. Furthermore, he remarked that differences between primary and secondary roots were necessary to be clearly shown on the concept map. Accordingly, by taking into account Mr. Daun's views, the concept map was revised, redrawn, and related again to the propositions to increase the accuracy of the content boundary. Final versions of both propositional knowledge statements (see Appendix A) and concept map (see Appendix B) were then utilised as a framework for designing plant anatomy diagnostic instruments.

Steps 1, 2 and 3 that have been discussed above were conducted only in the first study. These steps were deleted from the second and third studies because a valid content domain of plant anatomy had now been determined. This means that in Studies 2 and 3, the diagnostic instruments were directly developed by reviewing the existing knowledge statements and concept map. The format and content of the researcher-designed diagnostic instrument used in each study are described in the following step.

#### *Step 4: Developing Diagnostic Instruments*

In order to collect the desired information, the researcher developed a research instrument referred to as a Plant Anatomy Diagnostic Instrument (PADI) for each study. Each of the PADIs was constructed by combining two components including the validated plant anatomy content domain and three examples of plant anatomy tests that were collected from the Internet (i.e., Khan, n.d.; Priyadars, n.d.; Roman, n.d.). In the current research, the tests were used as a reference to construct questions for the PADIs. However, the format of the diagnostic instrument that was utilised in each study was different as discussed in the following three sections.

**The First Instrument** The diagnostic instrument that was administered in the first study is referred to as a Plant Anatomy Diagnostic Instrument I (PADI-I). This instrument consisted of two different parts. The first part was designed by modifying the format of the two-tier diagnostic instrument proposed by Treagust (1988). Instead of two questions in each item, the first part of the PADI-I was expanded into four-tier questions to be able to assess students' proficiency of basic skills in learning plant anatomy including observation and interpretation (Brosi & Huish, 2014). To achieve the goal, each item of Part 1 of the PADI-I was equipped plant anatomy photographs which were collected from the Internet. Except the photograph in Item 5, all

micrographs that were displayed in the PADI-I were selected based on the similarity to the images that were presented in the previous version of students' handbook of Plant Anatomy and lecturers' PowerPoint slides. The presentation of the majority of images in the two learning sources was also considered when selecting the images for the test. For example, while other pictures in the test were presented in colours, Item 4 contained two black and white micrographs of roots because the images under the topic of root anatomy in the students' handbook are commonly displayed without colours. It is because primary structures of a root has limited mechanical tissues due to the condition of its environment (Cutler et al., 2007).

Therefore, Part 1 of the PADI-I consisted of five items where each of them contained four tiers of linked multiple-choice questions and one, two, or three plant anatomy photographs. The first tiers asked about basic plant anatomy concepts related to the micrographs being presented. To investigate students' conceptual understanding of plant anatomy, the first tiers were mostly created in the form of problem-solving questions using novel situations rather than classic textbook tests. The second and third tiers, respectively, assessed participants' skills in identifying and labelling micrographs that were displayed in the first tiers. To examine students' reasoning ability, the last tiers provided options of possible reasons for the selected answers given in the first tiers. Each tier contained a set of three, four, or six choices. Item 3 in Part 1 of the PADI-I is presented in Figure 3.1 as an example.



A young woman is found killed in a location. During the investigation, police found a piece of leaf attached to her clothes. Under the microscope, the leaf shows an anatomical structure as shown in the picture. Based on the anatomical structure of the leaf, where do you predict the location of the crime?

- ★ a) Area with high sunlight intensity.
- b) Area with high salinity.
- c) Submerged area.
- d) Shaded area.

Which parts of the picture support your answer?

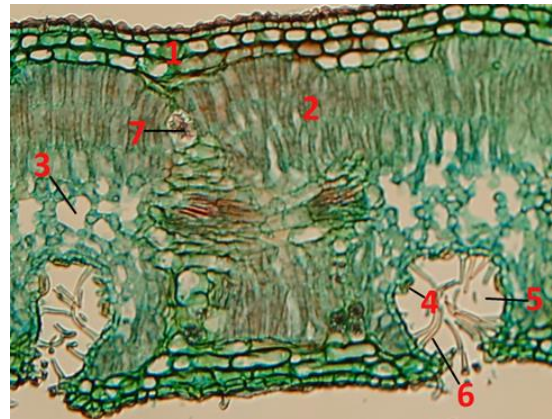
- a) 3 and 4.
- ★ b) 1 and 5.
- c) 1 and 2.
- d) 6 and 7.

What is the name of the parts?

- a) Intercellular space and stomata.
- b) Multiple epidermis and palisade parenchyma.
- c) Trichomes and salt gland.
- ★ d) Multiple epidermis and substomatal chamber.

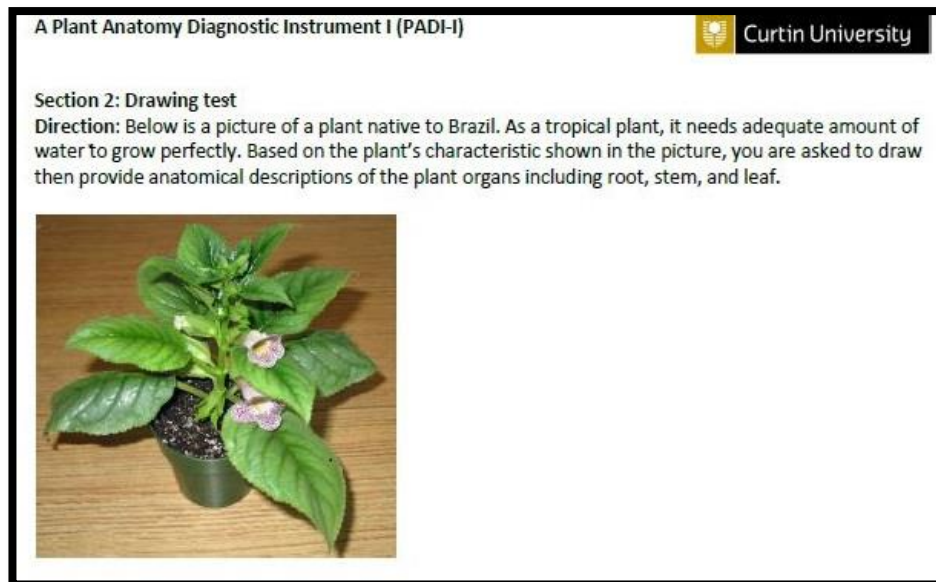
The reason is...

- a) the structure facilitates the leaves to capture light as much as possible.
- ★ b) the structure prevents the plant from excessive transpiration.
- c) the structure helps the plant excluding salt deposit.
- d) the structure facilitates a faster gas exchange.
- e) I do not know.
- f) other (Explanation: \_\_\_\_\_)



**Figure 3.1** Item 3 in Part 1 of the PADI-I. The star symbols (★) indicate the correct answers.

Part 2 of the PADI-I was designed using drawings as a diagnostic strategy to measure students' conceptual understanding (see Ilkorucu-Gocmencelebi & Tapan, 2010; Köse, 2008; Topsakal & Oversby, 2012). This part contained only one item with one photograph showing morphological characteristics of a particular plant. This item required students to predict, draw, and annotate anatomical diagrams of the vegetative organs of the depicted plant based on the photograph and a description provided. This drawing test is illustrated in Figure 3.2. Through these activities, students' ability to integrate and apply knowledge of both plant morphology and anatomy can be examined. By combining both the multiple choice questions and the drawing test formats, the PADI-I was expected to be able to capture holistic information and provide reliable checks of students' conceptual understanding of plant anatomy. A complete version of the PADI-I can be found in Appendix C1.



**Figure 3.2** Drawing test in the PADI-I.

**The Second Instrument** When students' responses to the PADI-I were examined, this instrument had evidently failed to capture students' conceptual understanding of plant anatomy. Most of the participants found it difficult to successfully complete the instrument (see Section 4.2.1). Consequently, a second instrument, named a Plant Anatomy Diagnostic Instrument II (PADI-II), was developed by revising and redesigning the PADI-I. As was the case with the PADI-I instrument, the PADI-II, which was administered in Study 2, also consisted of two distinct parts. The first part was designed using both short-answer and extended-answer questions (Johnson & Johnson, 2002). Through these formats, the instrument was expected to be able to explore a broad range of student-generated ideas about plant anatomy concepts being tested (Johnson & Johnson, 2002). In this part, nine items were presented. Each of the nine items contained three or four simple textbook questions which required one or two short responses and one or two extended answers. Sufficient space was provided after each question to enable students to clearly convey their understanding. In contrast to the PADI-I where most of the photographs were presented in colours, only one black and white picture were presented in each item of Part 1 of the PADI-II. The decision to use colourless images in the PADI-II was the fact that colours in visual representations distracted students' attention when interpreting the representations (see Section 4.2.3). Furthermore, the displayed images in the PADI-II were quite different from those presented in the PADI-I. While the photographs in the PADI-I were more specific to particular phenomena, the images that were

selected for the PADI-II were more common and general to accommodate the simple textbook questions in this test. As an illustration, Item 4 in the first part of the PADI-II is presented in Figure 3.3.

The picture on the right is showing a cross section of a leaf blade. Please determine in which side is the adaxial surface located! (Side A/Side B)

\_\_\_\_\_

Please give reasons for your answer!

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Based on the anatomical structure, in which plant can we find this leaf? (Monocotyledon/Dicotyledon plant). Please give reasons for your answer!

\_\_\_\_\_

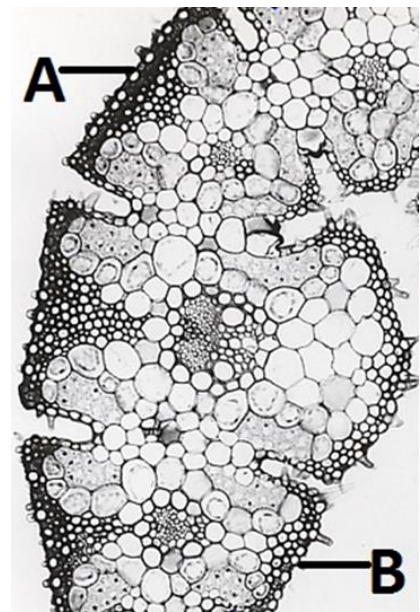
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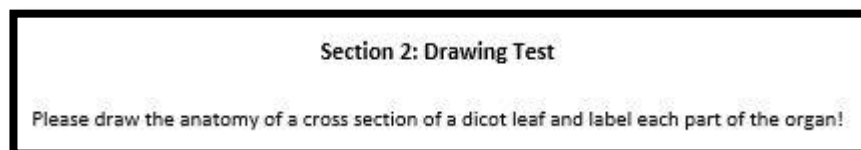
\_\_\_\_\_

\_\_\_\_\_



**Figure 3.3** Item 4 in Part 1 of the PADI-II.

In the second part, the drawing test format adopted in the PADI-I was retained. However, the test was replaced with a simpler question without a picture. To complete this part, the participants were only required to draw and annotate a diagram of any dicotyledonous leaf (see Figure 3.4). Based on the content, thus, the PADI-II functioned to catalogue students' actual conceptual understanding of plant anatomy including their alternative conceptions of concepts being taught. A complete version of the PADI-II is presented in Appendix D1.



**Figure 3.4** Drawing test in the PADI-II.

**The Third Instrument** Although the PADI-II was able to capture the nature of students' conceptual understanding of plant anatomy, the format of Part 1 of the PADI-II proved to be inefficient for practical usage. The free-response format needed extra assessment time (Johnson & Johnson, 2002) because it recorded a variety of students' answers including correct explanations, alternative conceptions, or even irrelevant statements. Besides, an issue about the scoring reliability of this format (Johnson & Johnson, 2002) forced the researcher to involve more than one assessor resulting in a complicated and potentially unreliable assessment of students' responses to the PADI-II. Therefore, the PADI-II was redesigned and modified into the third diagnostic instrument referred to as a Plant Anatomy Diagnostic Instrument III (the PADI-III) that was administered in Study 3.

The PADI-III was designed containing two different parts. The first part was composed of nine items of multiple-choice questions, each of which included the same picture as presented in the first part of the PADI-II, except for Item 3 (see Item 9 in the PADI-III). The change to the image was based on the finding that students did not expose to the relevant specimens either during the lecture or laboratory sessions (see 4.3.3). Therefore, the more common image of the topic under assessment was selected for the PADI-III. Instead of using short-answer questions, furthermore, Part 1 of the PADI-III adopted the format of the two-tier diagnostic instrument introduced by Treagust (1988). The first tier asked about a general concept of plant anatomy that was related to the picture being displayed, whereas the second tier required students to select the most appropriate reason for the answer given in the first tier. Distractors provided in these multiple-choice questions were derived from higher frequencies of students' answers to the first part of the PADI-I and the PADI-II and their responses to interview questions in Study 1. Figure 3.5 shows an item of the first part of the PADI-III as an illustration.

The literature mentions that an adaxial epidermis contains a huge amount of tannin. To test this, a scientist makes a cross section of a leaf then observes it under a microscope. The leaf's anatomy is similar to the picture on the right. To find the adaxial epidermis, which side of the picture should be the focus of his observation?

- (A) Side A
- ★ (B) Side B

The reason is:

- (1) On this side, the cells are thick and compact.
- (2) On this side, there are a small number of stomata.
- (3) On this side, there are a small number of trichomes.
- (4) The phloem is oriented toward this side.
- ★ (5) The xylem is oriented toward this side.
- (6) The chlorenchyme is oriented toward this side.
- (7) I have my own answer.




**Figure 3.5** Item 3 in Section 1 of the PADI-III. The star symbols (★) indicates the correct answers.

Similar to the other instruments, the second part of the PADI-III was a one-item drawing test. In this part, students were required to predict, draw and label an anatomical diagram of a leaf based on a photograph and a description provided (see Figure 3.6). Appendix E1 displays a complete version of the PADI-III.

**Section 2: Drawing Test**

The picture on the right shows leaves of a terrestrial monocotyledonous plant. This C<sub>4</sub>-plant lives in area with high sunlight intensity. To support the C<sub>4</sub> photosynthetic pathway, the leaves develop Kranz anatomy. Besides, during the hot of the day, the leaves are rolled to minimise transpiration. Because of vertical orientation, the stomata can be found in both sides of the leaves. Based on the provided information and the morphological structure of the plant, please draw the anatomy of a cross section of the leaf and label each part of the organ that you think it should be! Please use a pencil so that you can more easily make corrections to your drawing.



**Figure 3.6** Drawing test in the PADI-III.

### Step 5: Validating Diagnostic Instruments

In contrast to the validation of the content domain (see Step 3) where only two instructors were involved, the first draft of each developed diagnostic instrument—the PADI-I, the PADI-II or the PADI-III—was content and face

validated by an expert panel consisting of the three in-service instructors of plant anatomy in the university under investigation and one biology expert from Curtin University. The validation process of the three instruments was conducted separately and in sequence. In this case, a valid instrument was determined by four criteria. The first aspect was the accuracy of each item in an instrument to assess the content domain. The appropriateness of the content of an instrument including test format and difficulty level for the targeted participants was the second aspect of the validation. The third aspect of the validation process was the scientific correctness of the answer keys for an instrument. Lastly, the clarity of instructions, questions, and pictures provided was also taken into account during the validation process. If an item in an instrument did not meet the aforementioned criteria, it was revised, modified, or replaced. The instruments that had been revised were then translated into Indonesian and pilot tested with a small number of students. Details of these activities are described in Step 6.

#### **Step 6: Translation and Pilot Study**

Prior to a pilot study, each English version instrument that had been revised in the previous step was translated into Indonesian because targeted participants were Indonesian students. This translation process was conducted to avoid students' misunderstanding and misinterpretation of the tests' contents because of the difference in language. For this translation purpose, the blind back-translation technique described by Brislin (1970) was adopted. In the first step, the bilingual researcher translated the original English version of each diagnostic instrument into Indonesian. Subsequently, the Indonesian version of each instrument was blindly translated back into English by a trustworthy bilingual translator. Lastly, the researcher's supervisor and co-supervisor, as a native English speaker and a fluent English speaker respectively, compared the English version of the instrument produced by the researcher and the translator. The supervisor and co-supervisor did not recognise any significant differences in meaning between the original and the back-translated of the three instruments. Accordingly, the Indonesian version of each diagnostic instrument was ready to be administered for a pilot study.

The Indonesian version of the diagnostic instruments was pilot tested with undergraduates at the university under investigation. The pilot test of the PADI-I was conducted by involving one class consisting of 20 biology students. These



participants had studied plant anatomy concepts in the previous semester. It means the participating students did not enrol in a plant anatomy course when the pilot study was conducted. Those students were selected because they had been expected to have adequate conceptual understanding of the content domain being tested. The PADI-I was pilot tested at the beginning of a semester during a regular class period. In addition to reducing disruption to regular teaching and learning activities, this time was selected to minimise students' memory of plant anatomy concepts being interfered with new information from other disciplines.

The PADI-II was pilot tested with eight biology students studying plant anatomy. This group of students was a part of the main participants involved in the second study. However, these students were excluded during the administration of the final version of the PADI-II by giving them the final version of the PADI-I to be completed. The reason for selecting these participants was to get accurate information about targeted participants' conceptual understanding of plant anatomy. Besides, as observed in the pilot test in Study 1, students who did not enrol in a plant anatomy course were likely to be less motivated to complete the instrument. Therefore, a subset of targeted students was invited to participate in this pilot study. While the PADI-I was pilot tested at the beginning of a semester, the pilot test of the PADI-II was conducted immediately after the topic of leaf anatomy had been taught. This time was selected to ensure that the participants' conceptual understanding of the content being tested were not interfered with irrelevant topics of plant anatomy.

Because the PADI-III relied on the results of both the first and second studies, the development of the first draft of the PADI-III required more time than was initially anticipated. As a result, the PADI-III could not be pilot tested because targeted students were at the end of a semester when the final draft of the PADI-III was completed. However, by combining the findings of the first and second studies, this instrument was predicted to have only minor problems during its administration to the main body of student participants.

Fundamentally, the purpose of these pilot studies was to detect any technical problems that might have occurred during administration of the instruments. Technical problems arising included the clarity of the test instructions; the comprehensibility of the test language; the clarity of the test format and pictures

provided; the adequacy of time allocated for completing the test; and the relevance of the test content to teaching materials. To obtain the intended information, an extra page has contained yes/no questions about those aspects was attached to the end of answer sheets of the PADI-I. The second pilot study used short interviews to gain the information because of the small number of the participants involved. In addition to the technical aspects, students' answers to each plant anatomy question in the diagnostic instruments were also taken into account. Based on the students' responses and further discussion with the researcher's supervisors, changes were made to inappropriate items of the validated diagnostic instruments. The revised Indonesian version of each diagnostic instrument was then ready to be administered as a tool for collecting intended information in the primary investigation.

### **3.3.3 Selection of Participants**

The three studies in this investigation were conducted in three consecutive semesters from September 2014 until December 2015. Each study involved all available plant anatomy classes provided by the Biology Department of the university under investigation. Overall, a total of 207 students participated in the three studies. The first study involved 79 biology education undergraduates studying plant anatomy who were distributed in three classes, with each class comprising 22-31 students. From the three classes, four students were excluded from Study 1 because they were absent during instrument administration. In contrast, only one plant anatomy class comprising 34 biology students was available to be invited to participate in the second study, but all 34 students participated in this investigation. In addition to the students, two in-service instructors of plant anatomy were involved in interview sessions for Study 2. Similar to Study 1, the third study was conducted by involving three plant anatomy classes, each class consisting of 17-42 biology education students. A total of 94 undergraduates was recorded as participants in Study 3. All participating students in the three studies were in the third or fourth semester at the undergraduate level. Their ages ranged from 19 to 23 years when this investigation was conducted.

### **3.3.4 Data Collection Methods**

To address the research questions given in Chapter 1, this case study collected information utilising four data collection methods, namely, classroom observations,



diagnostic tests, interviews, and document reviews. These various techniques were employed to improve the accuracy, validity, and reliability of the research findings (Fraenkel et al., 2012; Merriam, 2009; Yin, 2014). Besides, methodological triangulation enables the researcher to gain a more complete understanding of the phenomenon being investigated (Johnson & Christensen, 2012; Patton, 2002). In the following paragraphs, each data collection method that was employed in this investigation is described in detail.

#### *3.3.4.1 Classroom Observations*

The primary purpose of classroom observations in this investigation was to record those teaching and learning activities that were related to the use of visual representations in plant anatomy. Specifically, the observations focused on types of plant anatomy representations that were presented by lecturers, students' responses to the displayed representations during lecture sessions, and students' constructed drawings during laboratory activities. The results of observations were recorded using field notes only in order to not disturb students through the use of video recordings. Besides, the taking of field notes was found to be the most appropriate method for recording a five-hour teaching and learning activity.

In the first and second studies, classroom observations were conducted from the beginning of the plant anatomy lessons until the last topic of vegetative organs — leaf anatomy — was completed. After this topic, however, the students spent an additional two weeks learning the anatomy of generative organs. During a three-month period, the researcher visited each available plant anatomy class weekly and observed lectures and laboratory sessions for five hours. However, this data collection method could not be conducted in the third study because plant anatomy courses had commenced while the researcher was still analysing the findings of the second study and developing the first draft of the PADI-III. Besides, the geographical distance between the place of data analysis and the investigation site made it very difficult for the researcher to organise an appropriate research schedule.

During lecture sessions, the researcher acted as a nonparticipant observer who recorded activities from the back of the classroom. In contrast, as a participant observer during laboratory sessions, the researcher assisted students in identifying specimens under a microscope while observing their hands-on activities. On these

occasions, the intended information was also collected by informally questioning students about their interpretations of observed specimens and how they constructed their drawings of the objects. According to Creswell (2012), through a changing of observational roles, more complete information from subjective and objective perspectives can be obtained.

#### *3.3.4.2 Paper-and-Pencil Diagnostic Test*

In Studies 1, 2, and 3, the PADI-I, the PADI-II or the PADI-III was administered respectively, to undergraduates who were studying plant anatomy. The purpose of this paper-and-pencil based test was to gain a general picture of the participants' conceptual understanding of plant anatomy and their interpretation ability of visual representations in this discipline. In the first and second studies, the diagnostic test was conducted one week after the topic of leaf anatomy had been taught. To minimise disruptions to teaching and learning activities, the instrument was administered during a laboratory session and lasted for 30 minutes. In the third study, the participants completed the PADI-III one week after a summative test of plant anatomy. This time was selected because the final version of the PADI-III had been completed two weeks before the instructor-organised summative test being held. Furthermore, to avoid any language difficulties, the participants received only the translated version of the instrument. Appendices C2, D2, and E2 display Indonesian versions of the PADI-I, the PADI-II and the PADI-III, respectively.

Students' responses to each diagnostic test were assessed using different methods, as follows. For multiple-choice questions in Part 1 of the PADI-I, a correct item was determined by correctly selected responses for all four tiers. Each item was scored 0 or 1 respectively for incorrect and correct answers. The key answers, as symbolised with stars in Appendix C1, were utilised as a standard to determine the correctness of students' responses to the first part of the PADI-I. A 5-level point rubric was utilised to evaluate students' responses to short-answer and extended-answer questions in Part 1 of the PADI-II. The highest score was given to an item in which all three or four questions in this item were comprehensively answered. Detailed criteria for assessing students' responses to this part can be found in Appendix D3. To minimise subjectivity and increase reliability of the assessment, two reviewers were involved in the evaluation of students' responses to the PADI-II (see Section 3.3.5.1 for detailed information). Similar to Part 1 of the PADI-I, students' answers to multiple-

choice questions in the first part of the PADI-III were scored dichotomously as correct and incorrect responses. Scores 0 and 1 were awarded to incorrectly and correctly answered items, respectively. An item was correct only when the combination of the content and reason questions were correctly answered. Using star symbols, Appendix E1 points the correct response for each tier.

In contrast to Part 1, students' generated drawings and labelling in response to Part 2 of each instrument were evaluated using a rubric as shown in Appendices C3, D4, and E3 for the PADI-I, the PADI-II and the PADI-III, respectively. Table 3.1 shows an example of the rubric for the drawing test in the PADI-I. The rubrics used in the current research were developed by adapting the scoring categories for students' drawings which were proposed by Köse (2008) and Ilkorucu-Gocmencelebi and Tapan (2010). In contrast to Köse's categories in which labelling is considered as a part of drawing, students' drawings and labelling in the current research were assessed separately based on the assertion that the two activities are different (Brosi & Huish, 2014; Ilkorucu-Gocmencelebi & Tapan, 2010). For instance, a student may be able to draw a plant anatomical diagram from his or her memory, but labelling the diagram can be challenging without sufficient domain knowledge. The examples of students' drawing and labelling for each category in the rubrics are presented in Chapter 4.

**Table 3.1** *A Rubric for Drawing Test in the PADI-I*

<b>Assessment Aspects</b>	<b>Category</b>	<b>Criteria</b>	<b>Score</b>
Drawing	Comprehensive	The drawing includes all basic parts of the organ (see Appendix C3) with correct structure and position.	4
	Misconception	The drawing includes all basic parts of the organ, but the structure, shape, and/or position of one or some parts are incorrect; or there are unrelated tissues indicating misconception of the represented organ.	3
	Incomplete	The drawing shows the intended anatomical structure of the organ, but one basic part is missing.	2
	Incorrect	The drawing does not represent the intended anatomical structure of the organ because most of the basic parts are missing.	1

**Table 3.1** *Continued*

<b>Assessment Aspects</b>	<b>Category</b>	<b>Criteria</b>	<b>Score</b>
	No response	No response is provided in the answer sheet.	0
Labelling	Comprehensive	All parts of the drawing are correctly labelled as shown below.	3
	Partial	Some parts of the drawing are correctly labelled, but others are incorrectly or not labelled.	2
	Incorrect	All parts of the drawing are incorrectly labelled; or some parts of the drawing are incorrectly labelled, but others are not labelled; or only two parts are correctly labelled, but others are incorrectly or not labelled.	1
	No response	All parts of the drawing are not labelled.	0

Based on criteria in the rubric, each student's drawing was scored 0 to 4, whereas the labelling on each drawing was given a point of 0 to 3 (see Table 3.1). The highest score was awarded only to a comprehensive drawing or to comprehensive labelling. Because this type of assessment was highly subjective, two reviewers were involved in this evaluation to ensure the reliability of scoring. Further explanation about how these two reviewers worked together in evaluating students' generated drawings and labelling is presented in Section 3.3.5.1. The students' achieved scores in each instrument provided a general picture of the participants' level of understanding of plant anatomy concepts. This achievement was utilised as a basis for predicting students' ability to interpret visual representations in plant anatomy.

#### *3.3.4.3 Semi-structured Interviews*

Although the diagnostic tests provided initial prediction of students' interpretation skills, their actual ability to interpret visual representations in plant anatomy could not be justified solely from their responses to the tests. Therefore, several participants who completed a diagnostic instrument were invited to participate in semi-structured interviews. Through this method, the way the participants viewed, interpreted, and processed plant anatomy pictures could be further explored. Besides, respondents' answers to interview questions which were asked about particular items in a diagnostic instrument could be used to verify their previous responses to the

instrument. This cross-checking strategy increases the validity and reliability of findings in case study research (Fraenkel et al., 2012; Merriam, 2009).

In Study 1, interviews were conducted one week after the instrument's administration. A total of six semi-structured interviews were carried out in this study by involving 15 voluntary participating students. These interviews were conducted in a group of two, three, or four to minimise respondents' discomfort (see Tan, Goh, Chia, & Treagust, 2002) One week after a semester examination period, two of the 15 volunteers were re-invited to have in-depth interviews in order to gain more detailed information how these students interpreted individual photograph in the PAD-I. The two participants were selected as representatives of students who got the highest and the lowest scores of the PAD-I.

In contrast, no student voluntarily participated in an interview session for the second study because they were overloaded with assignments that must be completed before the university's final examinations. Therefore, the analysis of students' interpretation ability of visual representations in plant anatomy had relied heavily on their ideas conveyed in the PADI-II. However, in Study 2, two in-service instructors of plant anatomy in the university under investigation were invited to participate in interview sessions. These one-on-one interviews (Patton, 2002) were carried out to investigate the instructors' reflections on plant anatomy teaching and learning. Their views and perspectives about students' knowledge and understanding of plant anatomy concepts were also explored. The information collected from the lecturers was utilised to triangulate results of the PADI-II (Merriam, 2009). However, interviews with neither students nor instructors were carried out in Study 3. The administration of the PADI-III after a summative test of plant anatomy (see Section 3.3.4.2) made it difficult for the researcher to find volunteers for interviews. Most of the students went home directly after completing the PADI-III or just preferred to liberate their mind from any learning-related contents. In contrast to the students, the instructors were very busy at that time with marking and other activities.

Each interview was preserved using a voice recorder device and lasted approximately 30 minutes for normal interviews and 1 hour for in-depth conversations. Interview results were transcribed verbatim and translated into English for the purpose of analysis. An interview protocol was utilised to provide a track towards the focus of

this investigation. Adopting a format proposed by Creswell (2012), the interview protocol contained a header for recording necessary information from the interview session, an interview procedure, and a set of questions being posed (see Appendix F). Despite relying on the protocol, interview questions could be expanded depending on students' responses, which led these interviewing activities to become semi-structured interviews instead of structured queries (Merriam, 2009).

#### *3.3.4.4 Document Reviews*

In this investigation, documents and archives were reviewed and mined to supplement research findings. All written materials were obtained from in-service instructors of plant anatomy in the university under investigation. The documents included instructor-designed tests, instructors' PowerPoint slides about plant anatomy, and reports of students' achievement on plant anatomy for three different semesters across which this research was conducted. The reviews of the instructor-designed tests and PowerPoint slides focused on the learning contents and visual representations that were presented in the two documents.

### **3.3.5 Data Analysis Methods**

Using multiple research methods (see Section 3.3.4), the researcher obtained both quantitative and qualitative data. Because their inherent features were distinct, the quantitative and qualitative data were analysed separately and differently. However, in the discussions of research findings (see Chapters 4, 5, and 6), quantitative and qualitative information was combined and compiled to provide a holistic picture of the participants' interpretation ability of visual representations in plant anatomy. In the following paragraphs, each method that was utilised to analyse each type of data is described.

#### *3.3.5.1 Quantitative Data*

In this investigation, quantitative data were generated from participants' scores on plant anatomy diagnostic tests. Once an instrument administration was completed, participants' answers to the test were assessed manually based on a scoring rule as described in Section 3.3.4.2. For the first parts of the PADI-I and the PADI-III, students' scores on each item in the instruments were directly tabulated in Microsoft Excel spreadsheets. The tabulated raw data were then inputted into IBM SPSS Statistics 20 software for statistical analyses (Tsui & Treagust, 2010). The analyses

included frequencies, percentages, and Cronbach's alpha coefficient for internal consistency of the dichotomously scored tests (Downing, 2004; Streiner, 2003).

Subsequent evaluations were applied to students' responses to the first part of the PADI-II and drawing parts of the three instruments. Initially, all participants' answers and drawings were assessed independently by two reviewers who had extensive knowledge of plant anatomy. For the independent assessments, these two assessors relied on particular rubrics as shown in Appendices D3, C4, D4, and E4 for the first part of the PADI-II and the drawing part of the PADI-I, the PADI-II and the PADI-III, respectively. Then, the individual evaluation results were compared; and percentages of agreement were computed. If the minimum 80% of agreement was not reached (McHugh, 2012), the two reviewers either revised the rubrics or reassessed students' responses. When this minimum percentage of agreement had been met, any differences in an individual assessment were discussed by the two reviewers, and final decisions about the student's score were made. The final scores were then tabulated in Microsoft Excel spreadsheets to enable computations of frequencies and percentages.

In addition to students' performance on diagnostic tests, quantitative data also derived from instructors' reports of students' achievement on plant anatomy. The tabulated students' scores received from the instructors were then presented in pie charts for quick analysis. The aim of the inclusion of this document is to triangulate the findings of the diagnostic tests about the student participants' conceptual understanding of plant anatomy.

#### 3.3.5.2 *Qualitative Data*

Qualitative data in this research were derived from classroom observations, semi-structured interviews and document reviews. The qualitative database from the three methods, including field notes, interview transcripts and document analysis records were then analysed using qualitative content analysis. Adopting a definition proposed by Graneheim, Lindgren, and Lundman (2017), content analysis refers to a strategy for analysing text-based data in order to describe the visible component in the texts or to interpret the underlying abstract ideas of the qualitative evidence. This method of analysis was selected because the main goal of content analysis is to provide insights toward the phenomena being investigated (Fraenkel et al., 2012; Hsieh &

Shannon, 2005; Merriam, 2009), and thus is in line with the primary purpose of this investigation.

Referring to the three approaches to content analysis described by Graneheim et al. (2017), this investigation used the deductive approach to analyse the content of qualitative information being collected. Using this theory-driven strategy, the initial categories in each qualitative database were predetermined based on the research questions and theoretical framework of this study (Graneheim et al., 2017; Hsieh & Shannon, 2005). In so doing, this research has an opportunity to validate or expand the existing theory being relied on in this investigation (Cohen et al., 2011; Graneheim et al., 2017; Hsieh & Shannon, 2005).

The step-by-step process of qualitative data analysis in this research was carried out using a strategy described by Graneheim and Lundman (2004) as follows. Initially, the qualitative database was sorted into the predetermined categories which included the seven factors of the CRM model (see Section 2.4 for descriptions) and teaching strategies. Any content that was difficult to categorise under the predetermined categories was put under a new created category. Afterwards, the researcher read thoroughly and carefully through an item, for example one interview transcript, under a particular category to gain insights about the content of the information being collected. This text was then reread for the process of coding. At this stage, while reading the text, meaningful sentences or paragraphs were highlighted and condensed, then the meaning of these meaning units was coded by the researcher and recorded in the margins. This process is known as “open coding”, that is, “a process of segmenting and labelling text to form descriptions and broad themes in the data” (Creswell, 2012 p. 243). Once the entire passage had been coded, the emerging codes which had similarities were sorted into new categories. In the next step, the researcher moved to another item under a different initial category. This new information was treated using the same process as outlined above. Subsequently, all emerged categories in the whole qualitative database were interpreted and separated into themes.

### **3.4 Trustworthiness of the Research**

Trustworthiness is an essential aspect of any type of study. A trustworthy research study should produce valid and reliable information (Johnson & Christensen, 2012;



Merriam, 2009) that readers can rely on. To ensure the trustworthiness of this current investigation, several strategies were employed to increase the validity and reliability of research inferences. Despite involving qualitative information, the terms validity and reliability were preferred to be used as a standard to evaluate the quality of this research. The following sections discuss each strategy that had been adopted to improve research validity and reliability.

### **3.4.1 Research Validity**

Research validity refers to the correctness, appropriateness, and meaningfulness of research inferences that are drawn from collected information (Fraenkel et al., 2012; Johnson & Christensen, 2012). However, because of the inclusion of qualitative data, the current research defined validity as the extent to which research conclusions capture the reality being investigated (Merriam, 1998; Perakyla, 2016). Thus, the more congruent the inferences with reality, the more valid the investigation. To enhance the validity of the current research, the following strategies were employed during the investigation.

- a. Methodological triangulation. This research collected information using four different methods, namely observations, tests, interviews, and document reviews (see Section 3.3.4). By using multiple methods of data collection, the appropriateness of information obtained from a particular method can be checked by examining results of other data gathering strategies (Fraenkel et al., 2012; Merriam, 2009; Patton, 2002).
- b. Data triangulation. In this research, interview results were obtained from two different sources, namely, students and in-service instructors (see Section 3.3.4.3). To ensure the validity of findings, the collected information from both sets of respondents were compared and cross-checked (Fraenkel et al., 2012; Merriam, 2009).
- c. Member checking. In Study 1, interview respondents were required to confirm their answers to questions in the PADI-I. This member checking strategy enabled the researcher to evaluate the correctness of findings collected through interviews and tests (Creswell, 2013; Merriam, 2009).

- d. Peer review. As a part of the researcher's doctoral degree, all procedures, findings, interpretations, and conclusions in this report were reviewed and assessed by a panel of supervisors. Through this peer review strategy, the accuracy of research inferences that were drawn from collected data could be strengthened (Creswell, 2013; Merriam, 2009).
- e. Content validity. Each instrument in this investigation had been content validated by an expert panel before its administration (see Section 3.3.2, Step 5). This validation was conducted to ensure the accuracy of the test content being investigated (Cohen et al., 2011; Creswell, 2012; Fraenkel et al., 2012).

### **3.4.2 Research Reliability**

Instead of emphasising the replicability of research findings (Fraenkel et al., 2012; Johnson & Christensen, 2012), the current investigation defined reliability as the consistency of research inferences with collected data (Merriam, 2009). This definition was selected because replication of results in this social science research was problematic. Human behaviour and perspectives tended to dynamically change over time and circumstances (Merriam, 2009). However, to strengthen the reliability of this research, the following strategies were implemented.

- a. Multiple reviewers. In this research, two reviewers assessed students' answers to the PADI-II and drawing parts of the PADI-I and III. The use of multiple reviewers gives a measure of interrater reliability that will minimise any bias that one judge might bring to the assessment process (Creswell, 2012; Johnson & Christensen, 2012).
- b. Triangulation. Using multiple data collection methods and involving multiple data sources enable the researcher to cross-check the consistency of research findings (Cohen et al., 2011; Merriam, 2009).
- c. Internal consistency. To ensure the consistency of multiple choice items in the first part of the PADI-I and the PADI-III, Cronbach's alpha coefficients were calculated. The size of the alpha coefficient shows the correlation of each item with all other relevant items (Streiner, 2003). A high correlation among items indicates the high reliability of an instrument and vice versa (Johnson & Christensen, 2012).

## **3.5 Ethical Issues**

As a part of human-involvement studies, ethical issues were considered to be an essential aspect of this research. Although this investigation collected information that was not highly sensitive to political, social, physical, and psychological conditions of participants, the researcher gave full respect and consideration to every individual involved in this study. The following ethical considerations were addressed during this investigation.

### **3.5.1 Informed consent**

Before data collection activities were commenced, an ethics application for this study had been approved by the Curtin Human Research Ethics Committee (see Appendix G1). Afterward, formal letters were sent to the Dean of Faculty, the Head of Department, and the in-service instructors of plant anatomy at the university under investigation in order to gain their permission to access targeted participants. These letters detailed essential aspects of this research including its purpose, the methods, its potential significance, and any potential risks to participants. The letters that were sent to the Dean, the Head of Department, and the instructors are presented in Appendices G2, G3, and G4, respectively. Furthermore, prior to any instrument's administration or to an interview, all respondents received written material that described the purpose and methods of this research, the confidentiality of the data collected, and participants' rights (see Appendix G5). Participating students were also verbally informed that their participation, withdrawal, or exclusion during any stage of this research would not affect their final grade of the subject under investigation. All volunteers were also required to complete a consent form shown in Appendix G6 as evidence of their voluntary participation.

### **3.5.2 Consideration**

Data collection activities in this investigation resulted in a minimum disruption to regular teaching and learning processes. Each diagnostic instrument was administered once during a laboratory session and its administration took only 30 minutes. For interviewing activities, the place and time of interviews were negotiated with invited interviewees. During lecture sessions, moreover, the researcher played a

role as a nonparticipant observer who only recorded events and behaviours without any intervention to observed activities (Creswell, 2012; Fraenkel et al., 2012).

### **3.5.3 Anonymity and Confidentiality**

Anonymity and confidentiality of all volunteers participating in this investigation were guaranteed. Prior to the completion of a diagnostic instrument, all student participants were required to provide information only about their student number, age, and class. Detailed information of each volunteer can be found in a database that was restricted to the researcher, the instructors, and the administration staff of the university under investigation. Furthermore, both qualitative and quantitative data that were collected in this study were stored in a secure place. Any electronic research data were saved on the researcher's external hard drive with password protection, whereas the original data in the form of papers were stored in a locked filing cabinet in the School of Education at Curtin University. Access to the data was limited to the researcher and her supervisor. The electronic data will be retained for 7 (seven) years after which they will be destroyed, whereas the original data in the form of papers (such as completed diagnostic instruments, interview notes, and field notes) will be destroyed at the conclusion of this research.

## **3.6 Summary of the Chapter**

In this chapter, each aspect of the research methods that were employed in this investigation has been described in detail. Using multiple data collection methods and involving multiple sources of evidence, this case study research aimed to gain a holistic picture of the student participants' ability to interpret visual representations in plant anatomy. Despite several limitations, the three studies that had been conducted in this research are expected to provide a better understanding of the phenomenon being investigated. As an overview, a brief summary of the research methods that have been detailed in Chapter 3 is presented in Table 3.2. In the following chapters, research findings from the data that had been collected and analysed using strategies explained in Chapter 3 are discussed.

**Table 3.2** *Summary of Research Methods*

<b>Research Phase</b>	<b>Data Collection Method</b>	<b>Data Source</b>	<b>Types of Data</b>	<b>Data Analysis Technique</b>	<b>Quality Standard</b>
Study 1 Sept-Dec 2014	Observation	Biology education students Lecturers	Qualitative	Content Analysis	Triangulation Member checking
	Diagnostic Test (the PADI-I)	Biology education students	Quantitative	Statistical Analysis	Content validity Interrater reliability
	Semi-structured Interviews	Biology education students	Qualitative	Content Analysis	Internal consistency
	Document Review	A report of students' achievement	Quantitative	Statistical Analysis	Peer review
Study 2 Feb-June 2015	Observation	Biology students Lecturers	Qualitative	Content Analysis	Triangulation Content validity
	Diagnostic Test (the PADI-II)	Biology students	Quantitative	Statistical Analysis	Interrater reliability Peer review
	Semi-structured Interviews	Lecturers	Qualitative	Content Analysis	
	Document Review	A report of students' achievement	Quantitative	Statistical Analysis	
Study 3 Dec 2015	Diagnostic Test (the PADI-III)	Biology education students	Quantitative	Statistical Analysis	Triangulation Content validity
	Document Review	A report of students' achievement	Quantitative	Statistical Analysis	Interrater reliability Internal consistency Peer review

# **CHAPTER 4**

## **STUDENTS' CONCEPTUAL UNDERSTANDING OF PLANT ANATOMY**

### **4.1 Overview of the Chapter**

Students' ability to interpret visual representations is profoundly affected by their understanding of the concepts being represented (Chittleborough & Treagust, 2008; Schönborn & Anderson, 2009). In this chapter, therefore, the data related to the students' knowledge of plant anatomy is presented. This information is analyzed to address the first research question: What is the extent of undergraduates' conceptual understanding of plant anatomy concepts? Students' responses to each of the three instruments—the PADI-I, the PADI-II, and the PADI-III—are discussed sequentially for initial prediction of students' interpretation skills of visual representations. The results of interviews and document reviews are also included to triangulate the observable incidents in the outcomes of the instruments. Moreover, students' incorrect reasoning to the questions in the instruments are recorded to understand misconceptions held by the three groups of participants when interpreting visual representations in plant anatomy. To ensure the trustworthiness of this research, the validity and reliability measures of the data collected using the three instruments are also addressed in the last part of this Chapter.

### **4.2 Students' Performance on the PADI-I**

The PADI-I was the first researcher-developed diagnostic test that was administered in Study 1. This instrument contained two different parts. The first part comprised five items of four-tier multiple-choice questions. Each tier examined different students' abilities. While the first tier focused on the general concepts of plant anatomy, Tiers 2 and 3 assessed students' skills to recognise and annotate the components of illustrations being presented, respectively. Students' reasoning of the selected response to the first tier was then recorded in Tier 4. An example of the items in Part 1 of the PADI-I is shown in Figure 3.1, whereas the complete test is presented in Appendix C1. In contrast, the second part was a single item drawing test that required students to draw the anatomical structures of three different organs

based on the description and picture provided. This drawing test is illustrated in Figure 3.2.

#### 4.2.1 The Results of the PADI-I

After the administration of the PADI-I, students' responses to each question in this test were assessed using the method as described in Section 3.3.4.2. The undergraduates' performance on each tier of the first part of the PADI-I is tabulated in Table 4.1.

**Table 4.1** *Percentage of Students who correctly Answered Part 1 of the PADI-I (N = 79)*

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
<b>Average</b>	<b>54.4</b>	<b>47.1</b>	<b>38.0</b>	<b>35.4</b>	<b>18.0</b>

The data revealed that most participants struggled to successfully complete this instrument. Table 4.1 shows that the proportion of students who correctly responded to all tiers of the first part ranged from 11% to 27%. Furthermore, only 18% of all participants provided correct answers to all questions in Part 1. This means 82% of the students involved in Study 1 found this part difficult to complete. Students' drawings in Part 2 of the PADI-I in which the examples are presented in Table 4.2 demonstrated a similar outcome. Figure 4.1 shows that most students tended to create incomplete drawings with partial labeling (see incomplete drawings in Table 4.2) indicating their inadequate understanding of the anatomical structures of plants. As apparent in Figure 4.1, moreover, the percentage of students who provided no drawings exceeded that of students who drew complete diagrams, indicating the difficulties that students experienced when completing Part 2 of the PADI-I.

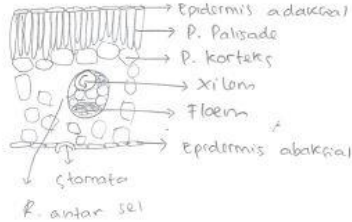
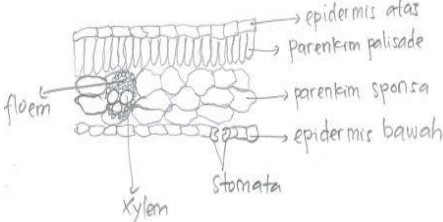
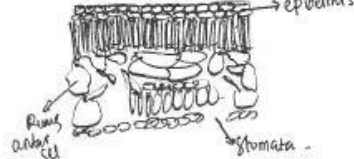
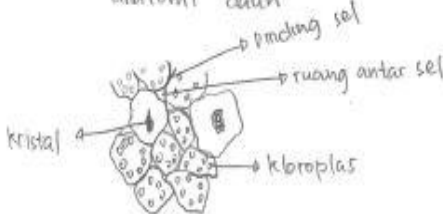
**Table 4.2** Examples of Students' Drawings in Part 2 of the PADI-I

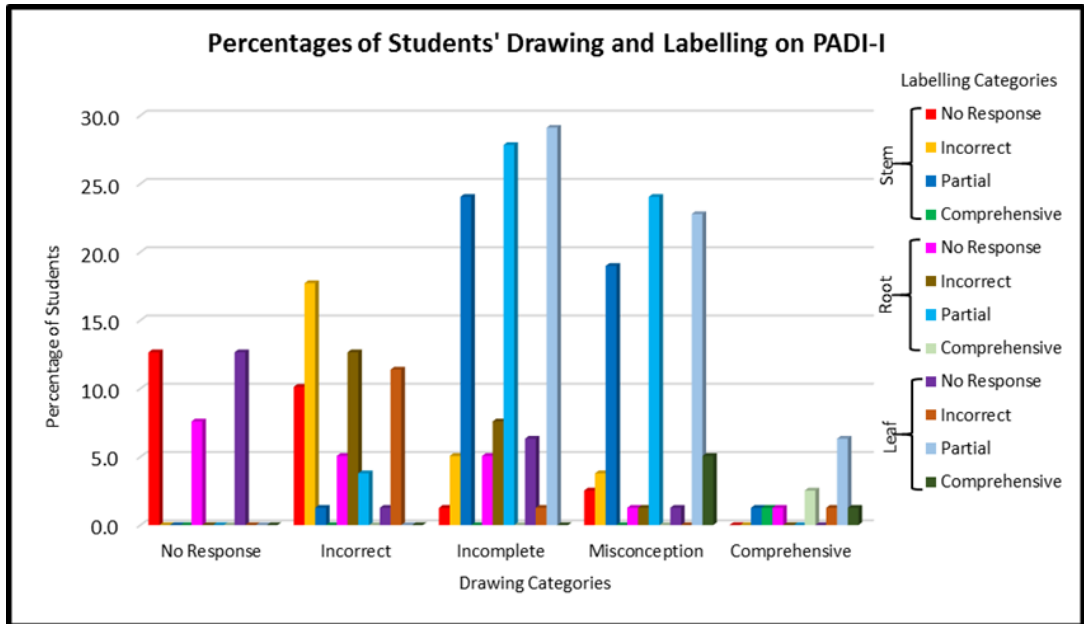
Organ	Example of Students' Drawings			
Comprehensive	Misconception	Incomplete	Incorrect	
Root				
Stem		<p>2. Struktur anatomi batang</p>	<p>batang</p>	<p>anatomi batang</p>

(Continued)



Table 4.2 Continued

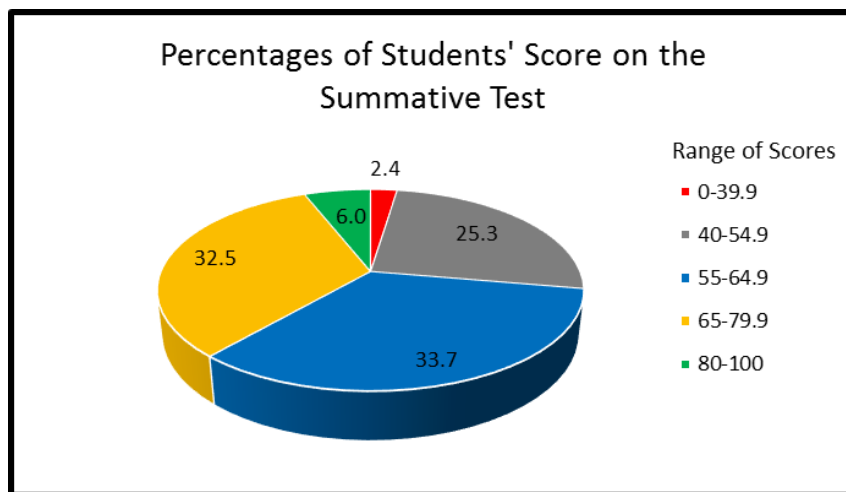
Organ	Example of Students' Drawings			
Comprehensive	Misconception	Incomplete	Incorrect	
Leaf	<p>* Daun</p> 	<p>3. Struktur anatomi daun</p> 	<p>Struktur Daun</p> 	<p>anatomi daun</p> 



**Figure 4.1** Students' performance on Part 2 of the PADI-I.

#### 4.2.2 Instructors' Assessment

In spite of the different test format, interestingly, similar findings were also recorded in the instructors' assessment report. As shown in Figure 4.2, only 6% of students achieved high scores (80-100) on the final examination of plant anatomy. The scores of the majority of students ranged from 55 to 64.9, meaning that almost 50% of students' answers to the questions in the instructor-designed test were incorrect. The results of both the PADI-I and the final examination illustrate that the undergraduates had difficulty learning plant anatomy to the expected level of proficiency.

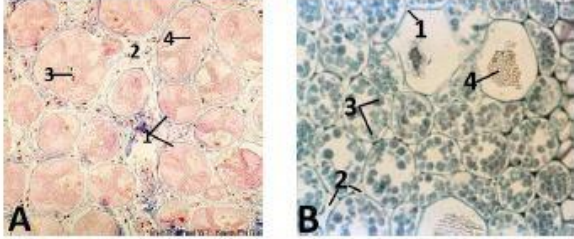


**Figure 4.2** Students' performance on the final examination of plant anatomy in Study 1.

### 4.2.3 Comparison of Quantitative and Qualitative Data

When inspecting the data in Table 4.1, it is evident that more than 70% of participants could correctly answer the first tiers of Items 1 and 3. These two items examined students' conceptual understanding of a plant cell and a leaf anatomy, respectively. Figures 4.3 and 3.1 show the questions being posed in Items 1 and 3, respectively .

1.1 Under a microscope, you see something similar to the following pictures.



Based on the characteristics, which picture shows the plant cells?

- a) A.
- ★ b) B.
- c) A and B.

1.2 Which parts of the pictures support your answer?

- a) 1 dan 2.
- b) 2 dan 4.
- ★ c) 3 dan 4.
- d) 1 dan 3.

1.3 What is the name of the parts?

- ★ a) Starch grains and crystals.
- b) Intercellular spaces and chromoplasts.
- c) Cell walls and nucleus.
- d) Cell walls and intercellular spaces.

1.4 The reason is...

- a) both pictures show rigid polyhedral cells with large intercellular spaces for gas exchange in plant.
- b) the cells contain plastids which bring the colour to the cells.
- c) the cells contain the major components of plant cells which are clearly seen.
- ★ d) the cells contain ergastic substances as the products of plant secondary metabolic processes.
- e) I do not know.
- f) other (Explanation: \_\_\_\_\_)

**Figure 4.2** Item 1 in Part 1 of the PADI-I.

The finding that the first tiers of Items 1 and 3 were easy to complete indicates that the students may have a better understanding of these topics than of the other topics. This argument, in particular for the latter concept, is also supported by the data on students' drawings presented in Figure 4.1, which show that more students comprehensively drew a leaf structure than those who could create a comprehensive schematic diagram of stem and root. In fact, students' interview responses, as apparent in the following conversation, confirmed these findings.

- 1 I : “Which one the easiest item for you?”
- 2 S13: “The easiest item was number 1...because it was about cells in general...”
- 3 S10: “The easiest item was 1.1...They (the pictures) could be distinguished from the colours...”
- 4 S6 : “Number 3.1...The structure was obvious...The structure, in my opinion between the stem and root are sometimes similar, but the leaf is different from the others.”
- 5 S8 : “The item about the leaf...The leaf tissues are apparent. Differently, roots and stems have similar structure and tissues...”

(Interview, 04 & 08/12/2014, I = Interviewer; S = Student)

Based on the quotes, these students seemed to have insufficient understanding of the plant anatomy concepts. However, the quotes above show that these participants were quite confident with their knowledge of anatomical structures of a plant cell and a leaf. Indeed, they expressed that identifying the pictures in Items 1 and 3 were not difficult. However, the students’ comprehension of the two concepts seemed to be weak. As highlighted in Quotation 3, Student S10 relied only on the colour to recognise the image leading to an incorrect interpretation of the object being depicted. This student failed to notice the relevant components in the illustrations indicating her limited understanding of plant cells. The other students seemed to have a similar experience. As apparent in Table 4.1, the proportion of students who provided correct responses to Tiers 2, 3, and 4 of item 1 progressively declines and drops dramatically compared to Tier 1. These facts imply that most of the students might develop only surface knowledge of this particular concept.

The undergraduates’ conceptual understanding of a leaf seemed to follow a similar pattern. As highlighted in Quotations 4 and 5, students S6 and S8 found that learning a flat organ (i.e., a leaf) was easier than learning a cylindrical part (i.e., a stem or a root). In fact, these three organs have a similar basic structure. The different distribution of vascular and ground tissues distinguishes one organ from the others (Esau, 1965). These students were unable to comprehend this underlying principle. Consequently, they struggled in identifying a distinctive characteristic of plant parts which have similar morphology, such as a stem and a root. The data in Table 4.1 for Item 3 provides supporting evidence. Despite the acceptable results for Tiers 1 and 4 which focused on the general understanding and reasoning, most of the students were unable to recognise and identify the most relevant features of the object being

depicted, as reflected in the percentages of Tiers 2 and 3. These findings show that participants' comprehension of leaf anatomy were limited.

The result of Part 1 of the PADI-I also exhibits students' difficulties providing correct reasons for their responses. Table 4.1 shows a progressive reduction in the average proportion of students who correctly chose responses in the subsequent tiers. This is most evident in the students' reasoning part (Tier 4) which gained the lowest percentage compared to others. This finding suggested that the students had difficulty in applying their acquired knowledge. This assertion, in fact, is supported by students' responses to the interview questions, as recorded in the following conversation.

6 I : "What did you think that the test?"

7 S3 : "The test was difficult because it [the test] was about case studies. The lecturers taught only theoretical background. So, perhaps it was hard to relate them [theory and the cases]."

8 S9 : "In my opinion, the test was difficult because it needed logical thinking and reasoning from the questions."

9 S1 : "In my opinion, the test was not really difficult if we really understood the content, but I did not really understand the content so the result is not maximum."

(Interview, 08/12/2014, I = Interviewer; S = Student)

The highlighted parts show that the knowledge application was the major problem that these students faced when completing the PADI-I. The plant anatomy concepts that they had learned seemed to remain inert and inaccessible to them when solving novel problems. As confirmed by Student S1, the students just learned abundant superficial principles without any depth of comprehension of their application. Those observable phenomena discussed throughout this section confirm the students' inadequate understanding of the underlying concepts of plant anatomy.

However, the students' poor performance on this instrument was not solely affected by the depth of their conceptual understanding. The design of the PADI-I seemed problematic to the students. The four-tier format employed in this diagnostic test raised another problem. Some undergraduates struggled to link the answer of each tier in one item. They articulated:

10 S14: "In my opinion, the test was difficult. My difficulty was at making the connection between the first and second questions."

11 S5 : “In my opinion, the test made me confused. For example, for number 1.1, I answered this then I had to match the answer with the next question, it made me confused. In my opinion the answer was this, then in the next question the options changed...”

(Interview, 08/12/2014, I = Interviewer; S = Student)

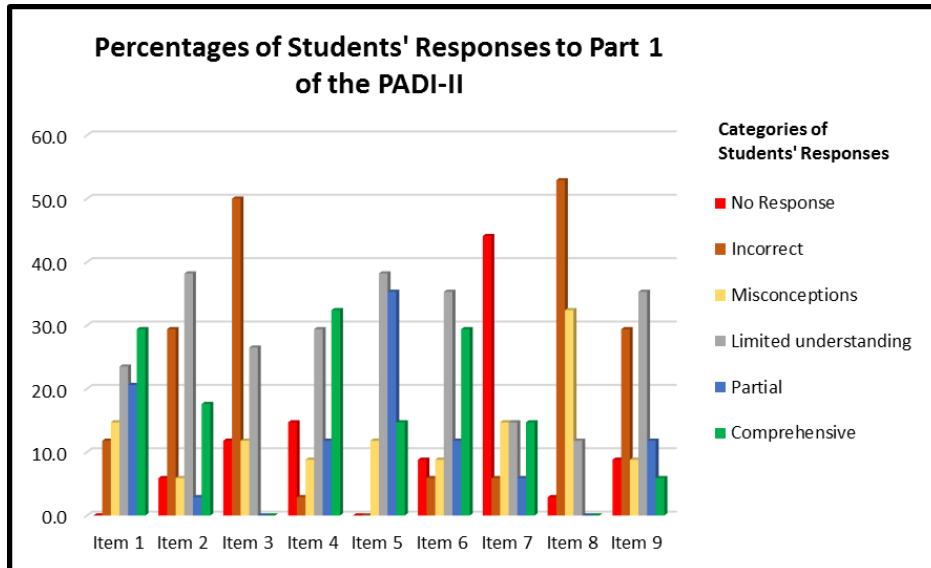
According to the respondents, completing the test was not as simple as the common one tier multiple choice questions. They needed to look back on their selected options to ensure the consistency of the answers. This format may have caused serious confusion when the expected responses could not be found in the following questions as expressed by Student S5 (see Quotation 11). Furthermore, the coloured pictures presented in the PADI-I attracted students’ attention and often trapped them to choose an incorrect answer as shown in Quotations 3. Because of these weaknesses of the PADI-I, therefore, the researcher developed the PADI-II to explore the students’ actual understanding of plant anatomy. The results of this second instrument are documented in the next section.

### **4.3 Students’ Performance on the PADI-II**

Similar to the first instrument, the PADI-II also was composed of two parts. Different from the PADI-I, however, Part 1 consisted of nine items of closed questions. Each item has three or four questions that examined students’ skills in recognising the depicted objects, their reasoning ability, and knowledge of the function of plant components. Figure 3.3 shows an example of items in Part 1 of the PADI-II. The complete version of this instrument is presented in Appendix D1. In contrast, Part 2 focused on the student making a drawing of a leaf’s anatomy (see Figure 3.4). Instead of using coloured pictures, moreover, the PADI-II presented only black and white visual representations. This presentation was selected because of the problem that was detected in the results of the PADI-I (see Section 4.2.3) which is also confirmed by Patrick et al. (2005). By employing these two formats, the PADI-II was expected to be able to investigate the extent to which the undergraduates comprehended the underlying concepts of plant anatomy.

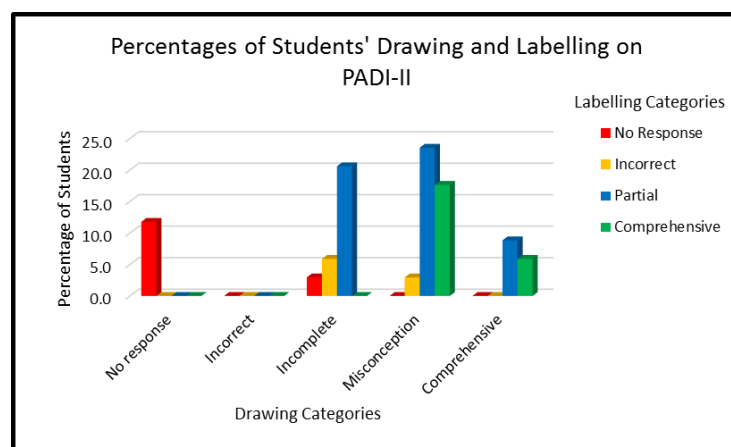
#### **4.3.1 The Results of the PADI-II**

Students’ responses to Parts 1 and 2 of the PADI-II were assessed using the rubrics in Appendices D3 and D4, respectively. Their performance on the first part of this second test is presented in Figure 4.4.



**Figure 4.3** Students' performance on Part 1 of the PADI-II.

Similar to the findings of the PADI-I, students' performance on the PADI-II reveals the difficulties that the participants experienced when completing this test. As apparent in Figure 4.4, the percentage of students who provided comprehensive responses is less than 50. Indeed, no correct responses were recorded in Items 3 and 8. Looking at the pattern of students' responses, furthermore, it is evident that misconceptions and limited understanding consistently occur in each item of Part 1. Similarly, as recorded in Figure 4.5 which shows students' performance on Part 2 of the PADI-II, most of the students drew either an incomplete or a misconception diagram of a leaf's anatomy. Examples of students' drawings in response to the question in Part 2 of the PADI-II are shown in Table 4.3. These findings suggest that both incorrect conceptions and insufficient comprehension of plant anatomy concepts were the primary sources of students' difficulties detected in Study 2.



**Figure 4.4** Students' performance on Part 2 of the PADI-II.

**Table 4.3** Examples of Students' Drawings in Part 2 of the PADI-II

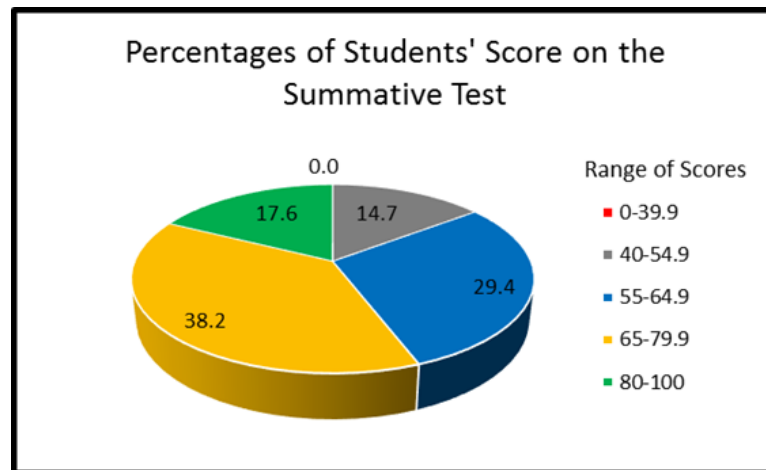
Drawing	Criteria		Example of Students' Drawings
	Labelling		
Comprehensive	Comprehensive		
Misconception	Partial		
Incomplete	Partial		
Incorrect	Incorrect		

### 4.3.2 Instructors' Assessment

To gain accurate information of the students' conceptual understanding of plant anatomy, the report of students' achievement on an instructor-designed summative test was evaluated. Figure 4.6 shows the distribution of scores that the students achieved after completing the final examination at the end of a semester when Study



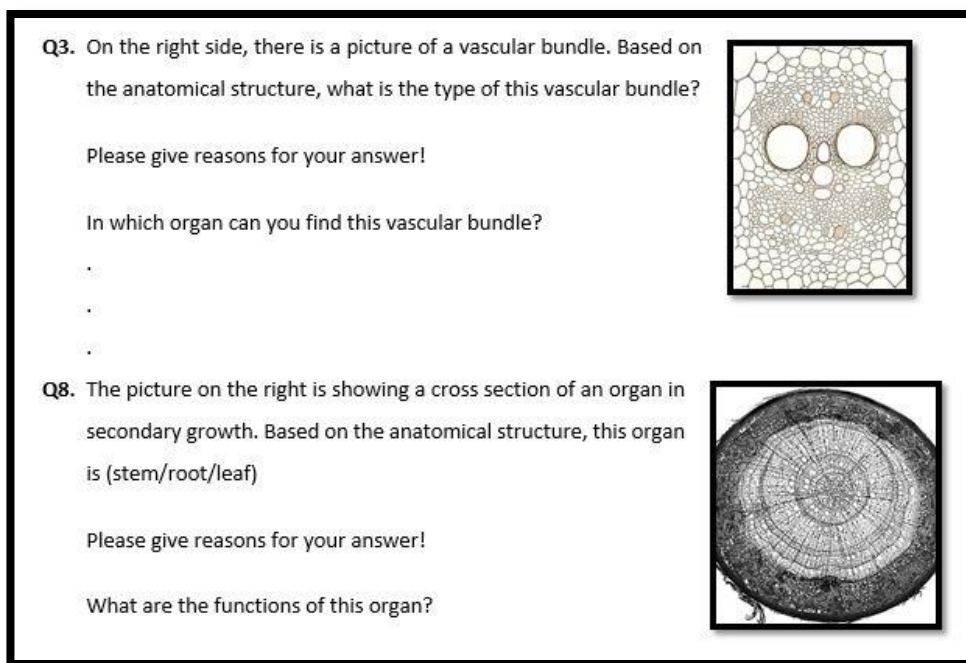
2 was conducted. As is apparent in Figure 4.6, only 14.7% of the undergraduates scored below 55. Indeed, the percentage of the students who gained scores above 64.9 was more than 50% indicating that the undergraduates' performance on this instructor-designed test was quite good. However, only 17% of the undergraduates scored above 79.9 (see Figure 4.6). This number indicates that most of the students have difficulties in understanding particular plant anatomy concepts which is in line with the findings of Study 2. This phenomenon is elaborated in the next section.



**Figure 4.5** Students' performance on the final examination of plant anatomy in Study 2.

### 4.3.3 Comparison of Quantitative and Qualitative Data

In addition to inadequate comprehension and misconception, another possible reason behind students' difficulties in completing the PADI-II was their lack of knowledge of particular plant anatomy concepts. The higher percentages of students with no and incorrect responses as shown in Figure 4.4 support this assertion. Moreover, Figure 4.4 shows that none of the students could correctly answer the questions in Items 3 and 8 which tested their understanding of two basic plant anatomy concepts, namely a type of vascular bundle and secondary root anatomy, respectively. The questions used in the first part of the PADI-II to probe students' understanding of the two concepts are presented respectively in Items 3 and 8 in Figure 4.7.



**Figure 4.6** Items 3 and 8 in part 1 of the PADI-II.

The fact that no students could correctly answer Items 3 and 8 indicates that the students' knowledge of plant anatomy was incomplete. According to the instructors, this finding seemed to be caused by either the infrequent exposure to the relevant objects or representations, or the unsupportive learning of the concepts. They articulated:

12 Mr. Akar : “They [the students] have never been trained to compare pictures of organs based on the patterns of vascular bundles...I had asked the students, why they had difficulty in comparing the secondary growth in a root and a stem...because they didn't observe the root and stem at the secondary stage.” (Interview, 28/05/2015)”

13 Mrs. Bunga : “I viewed that because unlike in the past [previous teaching strategy], I did not give the basic concepts firmly. They had not comprehended the core principles yet, but they saw a lot of variation...” (Interview, 28/05/2015)

From their responses, the lecturers seemed to realize that their students did not have sufficient knowledge of plant anatomy. The teaching method they had implemented did not facilitate the undergraduates' ability to cover the essential concepts of this subject. As clearly articulated by Mr. Akar (see highlighted statements in Quotations 12), the majority of students had a poor knowledge of vascular bundles and secondary growth because of the limited exposure to specimens or pictures representing the two topics. Indeed, as highlighted in Quotation 13, Mrs. Bunga

confirmed that the students' conceptual understanding of plant anatomy was limited because of the inadequate learning scaffolding.

In contrast, the students' comprehension of leaf anatomy seemed better than other topics. Figure 4.4 shows that the highest percentage of comprehensive responses is located in Item 4 (see Figure 3.3). This means that more than 30% of the students could correctly answer each question in this item which examined their knowledge of the anatomy of a particular leaf. Their sufficient understanding of a leaf's anatomy is also visible in the drawing they created to complete Part 2 of the PADI-II. As apparent in Figure 4.5, the majority of participants could draw an entire leaf anatomy either with some misconceptions or comprehensively. Besides, Figure 4.5 clearly shows that most of the students could provide either partial or comprehensive annotation on their drawing indicating their understanding of this particular topic. However, these findings are not surprising because the students had been sufficiently taught the basic concepts of leaf anatomy more than the other topics as confirmed by the comment of an instructor, Mrs. Bunga, as expressed in the following quote.

14 "...because for this [teaching leaf], I used a different method... Thus, students' basic concepts were strengthened at the beginning [of the lesson]...as you will see in the lesson plan, the steps when [teaching] stem were different from this [teaching leaf]. There was a change here [teaching leaf]..." (Interview, 28/05/2015)

The instructor's response above indicates that an instructional aspect had contributed to the students' learning. According to this instructor, the scaffolding at the beginning of the lesson had a positive impact on students' conceptual understanding. However, the change of teaching strategies (see Quotation 14) was implemented only for the last topic, the leaf anatomy. As discussed in Section 4.2.3, the leaf anatomy was considered as the easiest material to be understood compared to others. Therefore, it was hard to justify whether this achievement was influenced by the selected teaching method or the content per se.

As discussed throughout this section, it is evident that the undergraduates' acquired knowledge of plant anatomy was insufficient. This finding demonstrates the capability of the PADI-II in exploring the students' actual comprehension of plant anatomy. However, there were two primary reasons, as explained by Johnson and Johnson (2002) why this conclusion could not be directly drawn from the data.

Firstly, the assessment of students' responses to this instrument was complicated and highly subjective (see Section 3.3.4.2). Secondly, students who had writing difficulties were disadvantaged by this format. Therefore, the researcher developed the PADI-III by modifying the design of the PADI-II. How students performed on this new instrument is discussed in the following section.

#### **4.4 Students' Performance on the PADI-III**

Following the pattern of the PADI-I and the PADI-II, the PADI-III consisted of two different parts. The content of Part 1 of the PADI-III was derived directly from the second instrument. By excluding one or two questions in each item, the closed-question format of the PADI-II was transformed into two-tier multiple choice items in the third instrument. The first tiers assessed students' general knowledge of plant anatomy, whereas their reasoning ability was examined in the second tiers. Item 3 of the PADI-III is presented in Figure 3.5 as an example. The complete instrument is given in Appendix E1. Using the same pictures, moreover, the questions in the PADI-II were slightly changed into case study problems in the PADI-III to assess the transferability of students' knowledge of plant anatomy. Similarly, the drawing test in Part 2 of the PADI-III was constructed by changing the textbook-based question in the PADI-II to a problem that requires students to apply their knowledge of plant anatomy (see Figure 3.6).

##### **4.4.1 The Results of the PADI-III**

Using the rule as described in Section 3.3.4.2, students' response to each question in the PADI-III was assessed. Table 4.4 shows the undergraduates' performances on the multiple choice questions of the PADI-III.

**Table 4.4** *Percentage of Students who correctly Answered Part I of the PADI-III*  
(*N = 94*)

Item	Percentage of students who provided correct responses		
	Tier 1	Tier 2	Both Tiers
1	81.9	43.6	42.6
2	96.8	37.2	37.2
3	47.9	39.4	23.4
4	45.7	2.1	2.1
5	80.9	42.6	38.3
6	57.4	28.7	20.2
7	84.0	29.8	26.6
8	77.7	40.4	38.3
9	60.6	52.1	42.6
<b>Average</b>	<b>70.3</b>	<b>35.1</b>	<b>30.1</b>

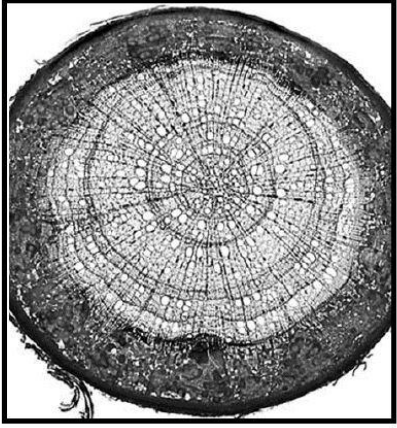
The results of the PADI-III revealed that the majority of the participants had not developed a comprehensive understanding of the basic concepts of plant anatomy. Table 4.4 shows that the correct answer combinations were still selected by fewer than 50% of the participants showing the difficulties that most of the students had when completing this instrument. This phenomenon is obvious from a drastic reduction of the percentages of Tier 1 to Tier 2. As is apparent in Table 4.4, on average, 70% of students could correctly respond to the first tier which questioned about their general understanding of plant anatomy. However, only half of these students could determine the correct reasons for the answers they selected previously. This fact demonstrates that most of the participants struggle to apply their acquired knowledge for solving novel problems. Furthermore, only 2% of the students successfully completed Item 4 (see Figure 4.8) which focused on a secondary root. In fact, a similar phenomenon was also observed in the PADI-II, most likely indicating the difficulty level of this topic for the participants.

**Item 4**  
 The picture on the right is a cross section of a plant organ. The organ functions to anchor the plant into the substrate, provide a physical support for the plant, and transport water. What is the organ?

(A) A young stem  
 (B) A young root  
 (C) An old stem  
 ★ (D) An old root

The reason is:

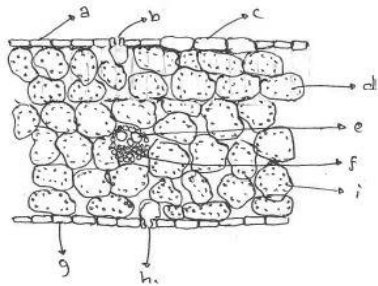
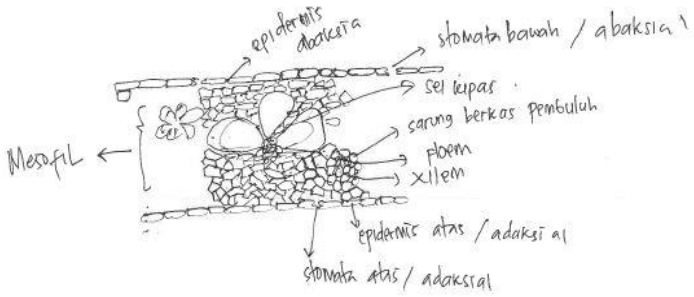
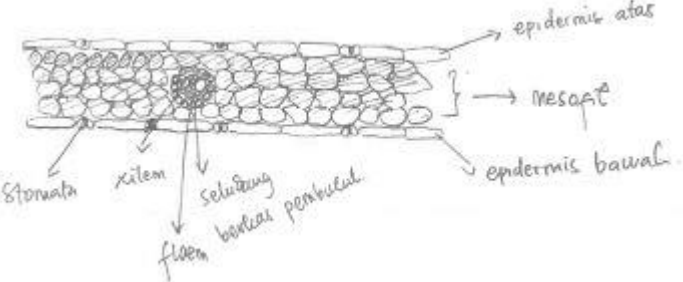
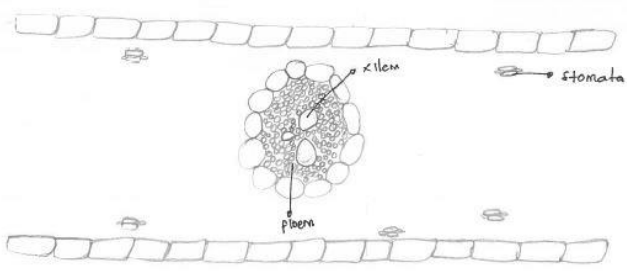
(1) The vascular bundles are radial.  
 (2) The vascular bundles are collateral.  
 ★ (3) The primary xylem is retained.  
 (4) There are several annual rings.  
 (5) The pith is retained in the centre.  
 (6) The epidermis is replaced by the periderm.  
 (7) I have my own answer.

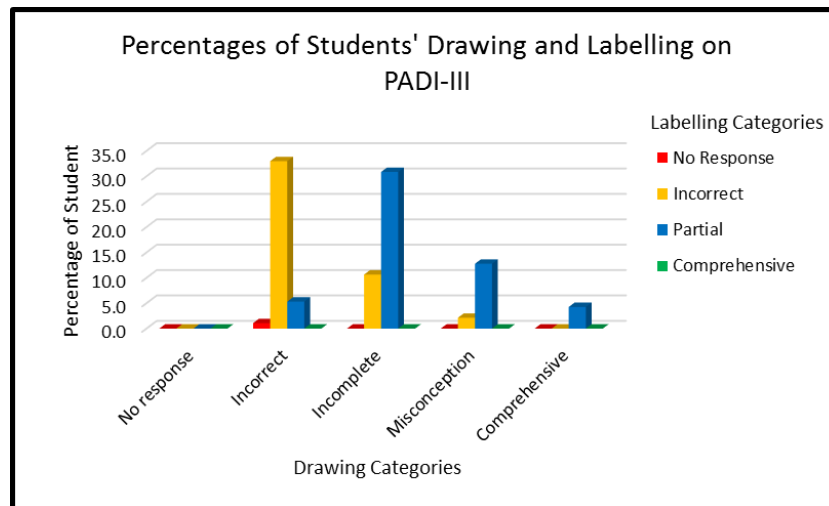


**Figure 4.7** Item 4 in part 1 of the PADI-III.

Students' performance on the second part of the PADI-III seems to follow a similar pattern. To be able to complete this part, the students were required to draw a leaf's anatomy based on the picture and description provided (see Figure 3.6). Examples of the students' drawing in response to Part 2 of the PADI-III are presented in Table 4.5. The assessment result of the students' drawing is presented in the form of a bar chart in Figure 4.9. Figure 4.9 shows that more than 30% of the students created an incorrect drawing and labeled the diagram incorrectly. In contrast, fewer than 5% of the participants drew a comprehensive anatomical structure of the leaf with partial labelling. In fact, all elements requested in Part 2 had been taught by the instructor and also were presented in the students' handbook. These findings suggest that the majority of these students acquired superficial information without sufficient comprehension of the knowledge being studied. Consequently, they struggled to find and use relevant knowledge to solve a problem being presented that in turn resulted in incorrect solutions as reflected in their drawing and labelling. Thus, the result of the second part of PADI-III provides further supporting evidence of the students' inability to correctly apply their knowledge.

**Table 4.5** Examples of Students' Drawing in Part 2 of the PADI-III

Criteria		Example of Students' Drawings
Drawing	Labelling	
Comprehensive	Partial	 <p>Keterangan :</p> <ul style="list-style-type: none"> <li>a = Epidermis atas.</li> <li>b = stomata.</li> <li>c = sel kipas.</li> <li>d = jaringan spongy.</li> <li>e = Xilem.</li> <li>f = floem.</li> <li>g = Epidermis bawah.</li> <li>h = stomata.</li> <li>i = kloroplas / klorofil.</li> </ul>
Misconception	Partial	
Incomplete	Partial	
Incorrect	Incorrect	



**Figure 4.8** Students' performance on Part 2 of the PADI-III.

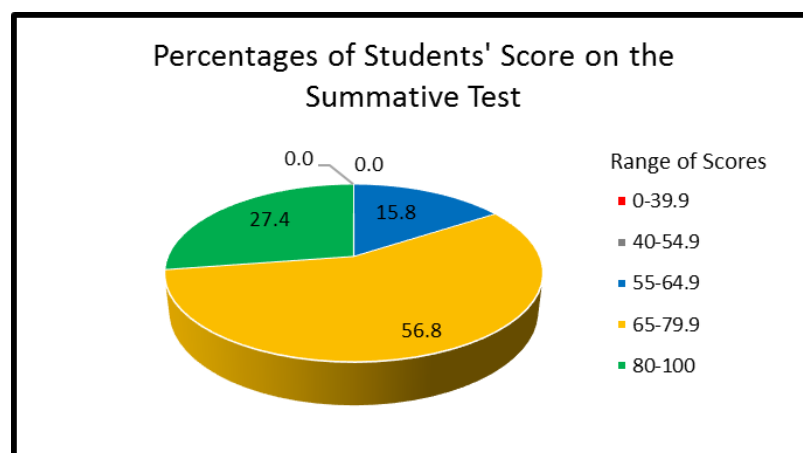
When comparing the results of Part 1 of the PADI-II and the PADI-III in which the same pictures were used in these two instruments, it is evident that more students could provide correct responses on each item of the PADI-III than those who completed the second instrument. As shown in Table 4.4, the percentage of students with correct answers ranged from 2% to 42% which is higher than the proportions of comprehensive responses to the PADI-II which ranged between 0% and less than 40% (see Figure 4.4). Besides, except for Item 4, all items in this test could be correctly completed by more than 20% of students (see Table 4.4). This result is better than that produced from using the PADI-II in which the percentages of correct answers above 20% was presented only in three of nine items (see Figure 4.4). The different formats of the instruments might potentially influence the students' performances on the two tests, as it has been widely understood that multiple choice questions are easier to complete than closed-ended items (Rauch & Hartig, 2010). However, the questions in Part 1 of the PADI-III were beyond the textbook-based questions as presented in the first part of the PADI-II. Besides, the distractors in each item in Part 1 of the PADI-III were selected from the students' responses to the PADI-I, the PADI-II, and interviews.

#### 4.4.2 Instructors' Assessment

Interestingly, the improvement of student's achievement in the two semesters when Study 2 and 3 were carried out was also apparent in the instructors' reports of students' performance on the summative tests of plant anatomy. Comparing the data



in Figures 4.6 and 4.10, it is obvious that there is an increase in the proportion of students who gained the higher scores in these two different semesters. Figure 4.10 also clearly shows that none of the students achieved scores below 55, whereas 14% of the students in Study 2 scored between 40 and 54.9 (see Figure 4.6). Furthermore, a wider range of students with scores 65-79.9 is apparent in Figure 4.10 compared to that which was documented in the instructor's document when the PADI-II was administered (see Figure 4.6). These facts indicate the improvement of the undergraduates' conceptions of plant anatomy which is also observed in the current investigation.



**Figure 4.9** Students' performance on the final examination of plant anatomy in Study 3.

#### **4.5 Predicting Students' Ability to Interpret Visual Representations in Plant Anatomy**

Despite the different formats, the results of the three PADIs revealed similar findings. As discussed earlier in this chapter, each group of students who were involved in each of the three studies struggled to complete the instrument being administered. The primary source of this difficulty was their insufficient comprehension of the basic concepts of plant anatomy. As a result, the participants found it difficult to access the most relevant information in their memory to solve problems being presented. This condition potentially affected their ability to interpret pictures in plant anatomy because conceptual understanding, including knowledge and reasoning ability (Konicek-Moran & Keeley, 2015), is a critical component for a successful interpretation of visual representations (see Cook et al., 2008; Schönborn

& Anderson, 2009; Won et al., 2014). Based on the aforementioned findings, it can be predicted that these participant students would also have difficulties when interpreting the visual representations of plant anatomy being displayed in the tests. Students' actual abilities to interpret visual representations in plant anatomy are described in Chapter 5.

Students' inadequate conceptual understanding had also led to the inappropriate application of their acquired knowledge that have resulted in misconceptions as reflected in their responses to the diagnostic tests. In order to understand the misconceptions that these students hold when completing the diagnostic instruments and the reasons behind this incorrect conceptions, therefore, their selected or provided reasons across the three PADIs are discussed in detail in the next section.

#### **4.6 Students' Misconceptions in Plant Anatomy**

As discussed in the preceding sections, the students' poor performances on the three diagnostic instruments were mainly caused by their insufficient comprehension of basic concepts of plant anatomy that may have resulted in their misinterpretations of the facts and principles being taught. In this section, therefore, the major incorrect but consistent responses that the participants selected or provided in the three PADIs will be compared, classified, and analysed. By doing so, students' misconceptions of plant anatomy can be examined. A list of students' misconceptions captured in each instrument is tabulated in Table 4.6. However, only incorrect responses that were provided by 10% or more students are presented (Lin, 2004; Wang, 2004). Using this criterion, a general picture of the participants' incorrect conceptions can be determined. The identified misconceptions are then classified under the order of topics being taught in the course, namely plant cell, tissues, stem, root, leaf, and secondary growth. This classification enables the researcher to identify the most challenging topic of plant anatomy for these participants. A detailed analysis of the students' misconceptions is presented in the following paragraphs.

**Table 4.6** *Students' Misconceptions across Three Types of Diagnostic Instruments*

Students' Misconceptions	Students' Responses to the Instruments			Percentage of Students (%)		
	PADI-I	PADI-II	PADI-III	Cohort 1	Cohort 2	Cohort 3
<b>A. Plant Cells</b>						
1. Cell walls and intercellular spaces are the most visible features of a plant cell.	I1 (B)(A)(D)(C)	-	-	10.1	-	-
2. Chloroplasts are a distinctive characteristic of a plant cell.	I1 (B)(D)(B)(C)	-	-	11.4	-	-
3. Starch grains contain amyllum.	-	-	I7 (B)(3)	-	-	51.1
<b>B. Plant Tissues</b>						
4. Aerenchyma functions to store water.	I4 (B)(C)(C)(C)	-	-	13.9	-	-
5. Multilayers of palisade prevent a plant from excessive transpiration.	I3 (A)(C)(B)(B)	-	-	11.4	-	-
6. Aerenchyma prevents absorption of excess water.	-	-	I2 (C)(5)	-	-	20.2
7. Phloem is represented by thick and hollow cells.	-	I4	I3 (A)(5)	-	11.8	16.0
8. Stomata can catch the light.	-	I5	-	-	11.8	-
9. During the photosynthesis, stomata function to regulate transpiration rates.	-	-	I8 (C)(6)	-	-	25.5
10. Endodermis is characterised by thick and strong cells.	-	-	I6 (E)(1)	-	-	26.6
11. Endodermis prevents outward leakage in a plant through its compact cells.	-	I2	-	-	14.7	-
12. Tracheas' cavity can prevent outward leakage in a plant.	-	I2	-	-	14.7	-
13. Scattered vascular bundles are arranged in one line at the periphery	-	I9	I5 (B)(3)	-	11.8	10.6
<b>C. Root</b>						
14. A primary root develops only the polyarch xylem.	-	-	I1 (B)(1)	-	-	18.1
15. A wide cortex is a distinctive characteristic of a primary root.	-	I1	I1 (B)(3)	-	11.8	10.6

**Note:** I = Item

*(Continued)*

**Table 4.6 Continued**

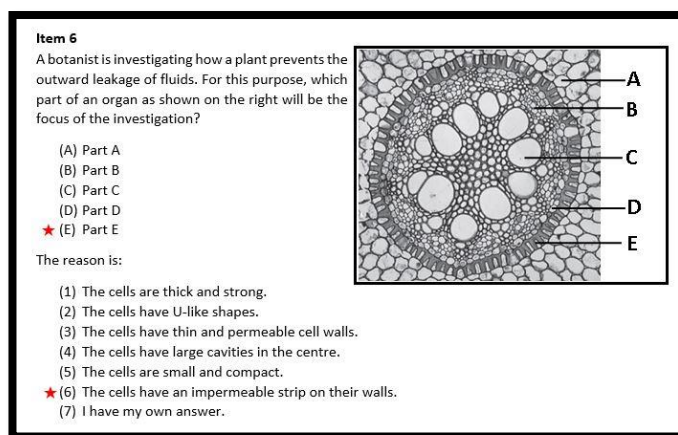
Students' Misconceptions	Students' Responses on the Instruments			Percentage of Students (%)		
	PADI-I	PADI-II	PADI-III	Cohort 1	Cohort 2	Cohort 3
<b>D. Stem</b>						
16. The stem of <i>Cucurbitaceae</i> has radial vascular bundles and develops root hairs at the outmost layer.	I2 (B)(A)(B)(A)	-	-	25.3	-	-
17. Collateral vascular bundles are characteristic of a dicotyledonous stem.	-	-	I5 (A)(1)	-	-	19.2
18. Vascular bundles in a dicotyledonous stem are commonly scattered at the periphery.	-	-	I5 (A)(3)	-	-	11.7
19. A monocotyledonous stem has pith in the centre.	-	I9	-	-	35.3	-
20. A monocotyledonous stem is characterized by the concentric vascular bundles.	-	I9	-	-	17.6	-
<b>E. Leaf</b>						
21. In an area with high sunlight intensity, the leaves capture sunlight as much as possible.	I3 (A)(C)(B)(A)	-	-	13.9	-	-
22. The adaxial side of a leaf is characterised by thick and compact cells.	-	-	I3 (A)(1)	-	-	18.1
23. The presence of trichomes indicates the adaxial surface of a leaf.	-	-	I3 (B)(3)	-	-	18.1
24. A monocotyledonous leaf has scattered vascular bundles.	-	I4	-	-	14.7	-
<b>F. Secondary Growth</b>						
25. Periderm is a distinctive characteristic of a secondary stem.	I5 I(D)I(B)	I8		12.7	14.7	
26. Annual rings are a primary marker to recognise a secondary stem.	-	-	I4 (C)(4)	-	-	41.5
27. Periderm is a unique feature of a secondary root.	-	-	I4 (D)(6)	-	-	21.3

**Note:** I = Item

When analysing the students' combined responses to the three PADIs, the researcher recognised five categories of the reasons behind students' incorrect conceptions. They include surface-level reasoning, inappropriate transfer, narrow understanding, incorrect application of concepts and superimposing concepts. Each of these categories is described as follows:

a) Surface-level reasoning

When completing the diagnostic test, some students seemed to engage in surface-level reasoning. They relied heavily on the perceptual information in the displays without any connection to the underlying concept represented by the depictions. As an illustration, Table 4.6 shows that 26.6% of the participants in Cohort 3 thought that “Endodermis is characterised by thick and strong cells” (see Number 10). When looking at the picture in Item 6 of the PADI-III (see Figure 4.11), this statement seemed correct. In fact, the thickness of endodermis is caused by Casparian bands that are deposited in the tangential and radial walls of the cells (Beck, 2010). This fact indicates that these participants focused only on the visual clues but failed to apply a relevant concept. A similar mechanism was employed when the students selected responses as shown in Table 4.6 for numbers 11, 15, 16, 22. This phenomenon was also observable in some studies of external representations (e.g., Chittleborough & Treagust, 2008; Cook et al., 2008; Kozma, 2003; Schönborn & Anderson, 2009). According to the authors, a possible source of this incorrect conception was students' superficial understanding of the underlying ideas being represented.



**Figure 4.10** Item 6 in Part 1 of the PADI-III.

#### b) Inappropriate transfer

To explain phenomena in the PADI, several undergraduates employed an erroneous transfer of a particular concept from one context to another. Students' misconceptions number 19 (see Table 4.6) provide a clear illustration of this incident. In this example, the participants seemed to inappropriately transfer the anatomical principles of monocotyledonous roots to stems of monocotyledons. Contrary to most monocotyledonous roots in which a pith is commonly present, this component is difficult to determine in the stems of many dicotyledons (Rudall, 2007). Instead of relying on this fact, however, the participants simply equalise the structures of these two different plant organs because they belong to the same group of a plant. Other illustrations of this phenomenon are presented in students' responses numbers 5, 13, and 24 (see Table 4.6). These four examples of inappropriate transfer indicate that the students had insufficient understanding of plant anatomy concepts. These students seemed to rely on salient clues, such as the words, multilayers, periphery, monocotyledonous, and monocotyledonous, respectively for numbers 5, 13, 19, and 24 in Table 4.6. These clues might direct the students to remember other concepts that have the same clues and were frequently discussed in the classroom. Schönborn and Anderson (2009) and Pugh, Koskey, and Linnenbrink-Garcia (2014) also identified this type of incorrect conceptions in their educational studies. Based on their findings, furthermore, Pugh et al. (2014) concluded that the students' failure to transfer concepts was primarily caused by their surface conceptual understanding and less organised knowledge, thus supporting the findings of the current study.

#### c) Narrow understanding

The other misconceptions that the students provided in the diagnostic tests reflected their narrow understanding of plant anatomy concepts. Basically, their explanations for the phenomena being presented were scientifically accepted but too limited, leading to inappropriate interpretations of the depicted object. When recognising a picture in Item 5 in the PADI-III (see Figure 4.12), for instance, 19.2 % of the participants focused only on the type of individual vascular bundle instead of the whole structure of the organ displayed (see Table 4.6, number 17). Although their limited conception was scientifically correct, their responses to this question were incorrect because this kind of vascular bundle is also present in another group of

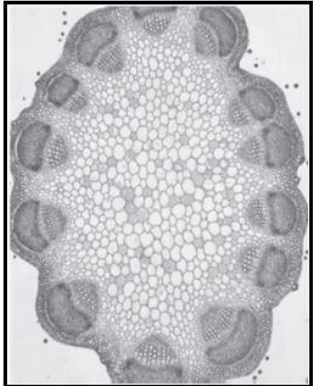
plants—monocotyledons (Rudall, 2007). This example indicates the students' limited understanding of this particular organ's anatomy. The students' misconceptions because of narrow understanding are also visible in Table 4.6 numbers 1, 2, 3, 9, 14, 20, 23, 25, 26, 27. These phenomena of narrow understanding show that the students were unable to build a comprehensive understanding of plant anatomy concepts, instead they placed emphasis on particular elements of the concepts. When analysing students' responses in Numbers 1 and 2 (see Table 4.6), thus, it is understandable that different students in Cohort 1 focused on different parts, namely cell walls and chloroplasts, respectively for the same pictures. In addition to plant anatomy, students' limited understanding has also been evidenced for concepts of the gene (Dikmenli, Cardak, & Kiray, 2011), plant growth and development (Lin, 2004), and ecology (Moseley et al., 2010). According to (Lin, 2004), the students' narrow conceptual understanding can be best treated using appropriate instructional strategies, such as integrating different concepts.

**Item 5**  
 A florist asks for your help to find a plant in which the stem anatomy is similar to the picture on the right. As a biology student, what is the plant group you recommend to help the florist?

★ (A) Dicotyledon  
 (B) Monocotyledon

The reason is:

- (1) The vascular bundles are collateral.
- (2) The vascular bundles are radial.
- (3) The vascular bundles are scattered at the periphery.
- ★ (4) The vascular bundles are arranged in one ring.
- (5) The pith is wide.
- (6) The cortex is narrow.
- (7) I have my own answer.



**Figure 4.11** Item 5 in Part 1 of the PADI-III.

d) Incorrect application of concepts

In some cases, students' responses to the diagnostic instruments indicated their incorrect application of plant anatomy concepts. These incidents frequently occurred when a plant anatomy concept has a binary division. The participants tended to misuse a particular principle to its corresponding concept. To illustrate, 11.8% of cohort 1 and 16% of cohort 2 responded that phloem is represented by thick and hollow cells (see Table 4.6, number 7). In fact, non-living cells with thickened cell walls and canal-like shape are characteristic of xylem tissue, whereas phloem is

characterised by sieve tube elements that are still alive and have thin cell walls (Beck, 2010; Dickison, 2000). It is obvious that the students confused the principles of both xylem and phloem structure and inappropriately stored this information in their memory. It is unsurprising because both elements spatially correlate and are present together throughout the plant body forming vascular bundles. Students' misconception in number 18 (see Table 4.6) also seemed to be generated using a similar thought pathway. A possible source of these incorrect applications of plant anatomy concepts is students' infrequent exposure to the real objects. As contended by Gallagher (2000), the use of practical experiences as a basis for knowledge application has the potential to deepen students' understanding of the concepts being considered. Thus, observing and interpreting specimens is the best way to understand plant anatomy materials.

e) Superimposing concepts

Another source of the undergraduates' misconceptions was superimposing concepts. Firstly used by Schönborn and Anderson (2009), this term refers to students' reasoning that is constructed by combining two different principles into a single inaccurate explanation. In this study, this incident is apparent in the participants' responses in Table 4.6 numbers 4, 6, 8, 12, and 21. In the last case, as an illustration, 13.9% of cohort 1 indicated that in an area with high sunlight intensity, the leaves capture sunlight as much as possible. In this example, the students seemed to fuse the fact that some plants develop multilayers of palisade as an adaptation to a condition of high sunlight intensity with the function of palisade as a photosynthetic tissue. Although the individual concepts are scientifically correct, the combination of the two has resulted in an unacceptable explanation. Instead of absorbing as much sunlight as possible, the plants which live in this extreme environment tend to develop distinctive components to diminish the destructive effect of high sunlight intensity (Rudall, 2007). In line with this finding, Wang (2004) also found that many students across educational levels misconnected the concepts of photosynthesis and internal transport in a plant. Focusing on a biochemistry field, similarly, Schönborn and Anderson (2009) documented that a participant was superimposing the ideas of a lock and key model and an antigen-antibody binding. This kind of misconception may reflect the students' confusion of the two concepts (Schönborn & Anderson, 2009).



Based on the discussion of misconceptions, it is apparent that the primary reason behind the students' incorrect conceptions is their weak comprehension of the basic principles of plant anatomy. These misconceptions seemed to affect the way students interpret pictures in the tests, as described along with the explanations of the five categories. As shown in Table 4.6, furthermore, most of the participants' misconceptions are related to plant tissues. As explained by Beck (2010), each plant organ such as a stem, a root, and a leaf comprises various plant tissues that play different roles to support the function of the organ they have formed. In other words, an understanding of the nature of individual plant tissue will help students to gain insights toward the characteristics of each plant organ. Thus, it is understandable that the students in this study constructed inappropriate conceptions of plant organs because their understanding of the plant tissues was inadequate.

To ensure that these inferences are correct, the researcher also describes the validity and reliability of the three diagnostic instruments. By doing so, the readers can determine whether the collected information is sufficiently valid and reliable to be drawn as research-based conclusions. The information of the validity and reliability of the PADIs is available in the next section.

#### **4.7 Validity and Reliability Measures of the Diagnostic Instruments**

The quality of research instruments is critical for any type of study. Trustworthy research conclusion can be drawn when the data are collected using valid and reliable instruments (Creswell, 2012; Fraenkel et al., 2012). In this section, therefore, an attempt that had been made to increase the validity and reliability of the three PADIs is described.

Relying on the content validity, the researcher-developed diagnostic instruments were expected to cover the basic underlying concepts of plant anatomy that had been taught by the instructors (Cohen et al., 2011). As outlined in Section 3.3.2 (Step 5), the three instruments had been content validated by three in-service instructors of plant anatomy and one biology expert from Curtin University. Despite some minor revisions, overall, the panel of the four experts indicated that the three PADIs were valid in terms of the content coverage.

To ensure that the three instruments were reliable, two methods of reliability—internal consistency and interrater reliability were employed. These two different approaches were applied because of the distinctive formats of the tests in the diagnostic instruments. The first parts of the PADI-I and III were designed using multiple-choice questions, whereas the close-answered and drawing tests were apparent in the first part of the PADI-II and the second part of the three PADIIs, respectively. The Cronbach’s alpha coefficient (Cronbach, 1951) was calculated to examine the internal consistency of students’ responses to the objective test—the multiple-choice questions. Table 4.7 shows the results of this calculation. In contrast, the interrater reliability procedure (see Section 3.3.5.1) was applied to evaluate students’ subjective answers to the close-answered questions and drawing tests. The percentages of agreement for these two formats of the tests are presented in Table 4.7.

**Table 4.7 Reliability of the Three Diagnostic Instruments**

Instrument	Format	Reliability	
		Determinant	Value
PADI-I	Multiple-choice questions	Alpha coefficient	0.52
	Stem Drawing	Percentage of agreement	100%
	Stem Labelling	Percentage of agreement	100%
	Root Drawing	Percentage of agreement	87.5%
	Root Labelling	Percentage of agreement	100%
	Leaf Drawing	Percentage of agreement	100%
	Leaf Labelling	Percentage of agreement	100%
PADI-II	Close-answered questions	Percentage of agreement	89.5%
	Drawing	Percentage of agreement	87.5%
	Labelling	Percentage of agreement	87.5%
PADI-III	Multiple-choice questions	Alpha coefficient	0.59
	Drawing	Percentage of agreement	100%
	Labelling	Percentage of agreement	100%

The data indicate that the three PADIIs were reliable as research instruments. As shown in Table 4.7, the percentages of agreement for both close-answered and drawing tests ranged from 87.5-100%. This means that the disagreement between the two reviewers who were involved in the assessment occurred no more than 12.5% of the students’ responses to the tests. These values well exceed the minimum acceptable percentage of interrater reliability, that is, 80% (McHugh, 2012). In

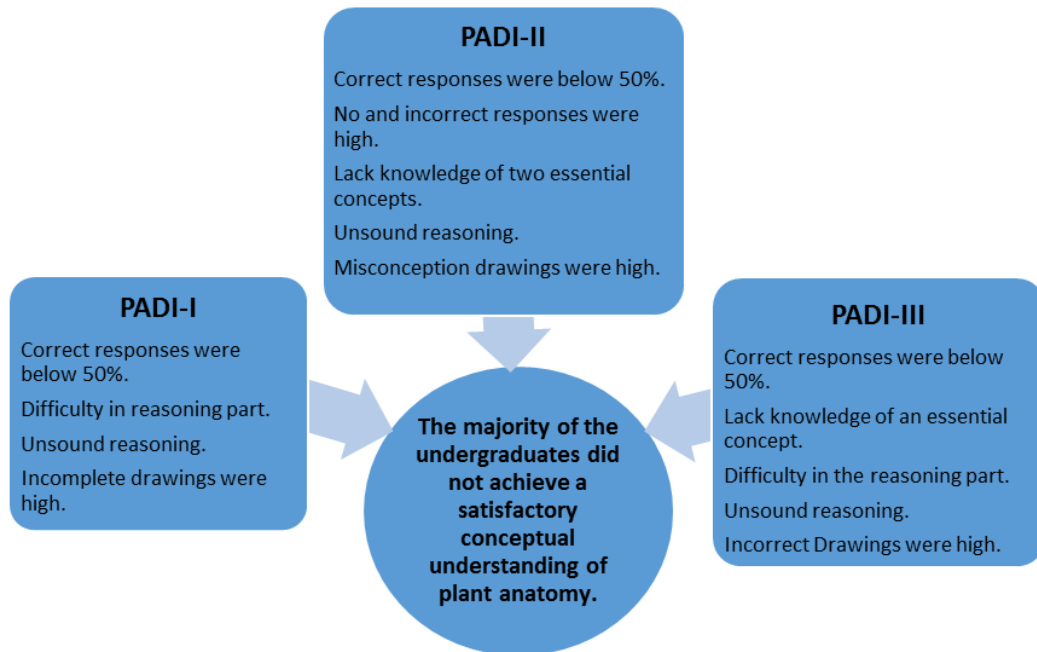
contrast, the alpha coefficients for the multiple choice questions are relatively low, that is about 0.5 (see Table 4.7). This value implies the weak correlation among items within a test (Nunnally & Bernstein, 1994). Two possible factors were identified as sources of the tests' heterogeneity including the diverse content of the test and the small number of items (Nunnally & Bernstein, 1994). As apparent in Appendix A, each of the PADIs covers five different topics of plant anatomy, namely, plant cells, tissues, roots, stems, and leaves instead of one particular concept or topic. These heterogeneous items influence the alpha coefficient which reflects the degree of item correlation. Moreover, the number of questions in Section 1 of both the PADI-I and III are fewer than 30 items. This small number of items will decrease the test reliability because the alpha coefficient is a function of the number of items (Nunnally & Bernstein, 1994; Streiner, 2003). Despite these facts, the alpha coefficient at the point of 0.5 is an absolute threshold (Nunnally & Bernstein, 1994) and classified as moderate (Salvucci, Walter, Conley, Fink, & Saba, 1997). Furthermore, Roszkowski and Spreat (2011) contend that for research such as the current investigation which aims to characterise the level of the participants' conceptual understanding of plant anatomy, the lower reliability values are acceptable.

Based on the above information, it is suggested that the three PADIs were sufficiently valid and reliable as research instruments. This fact implies that any conclusion that is drawn from the data collected using these instruments is warranted, thereby, ensuring the trustworthiness of this investigation.

#### **4.8 Summary of the Chapter**

In this chapter, the participants' performance on the three diagnostic instruments has been presented and analysed in response to the first research question. Supporting one another, as briefly schematised in Figure 4.13, the results from the three PADIs suggested that the majority of the students who enrolled in the three different semesters did not achieve a satisfactory conceptual understanding of plant anatomy. This insufficient comprehension of the basic concepts had led to difficulties in knowledge application leading to the construction of students' misconceptions. Five mechanisms of the undergraduates' incorrect conceptions that were identified in this study include surface-level reasoning, inappropriate transfer, narrow understanding,

incorrect application of concepts and superimposing concepts. The possible sources of this learning problem were the students' insufficient understanding of the basic components of plant structures, such as tissues, and limited learning scaffolding. These inferences can be justified because the three PADIs were shown to be sufficiently valid and reliable as research instruments.



**Figure 4.12** Students' performances on the three diagnostic instruments.

Students' ability to interpret visual representations is prominently affected by their existing knowledge (Schnotz & Bannert, 2003; Schönborn & Anderson, 2009). Thus, based on the fact of students' insufficient conceptual understanding and misconception as described in this chapter, it can be predicted that students would have difficulties when interpreting pictures in the tests. To clarify this assumption, several student volunteers were interviewed. Their responses to the interviews will give insights of the undergraduates' actual ability to interpret visual representations of plant anatomy being presented. This information is presented in Chapter 5.

# **CHAPTER 5**

## **STUDENTS' INTERPRETATIONS OF PLANT ANATOMY PICTURES**

### **5.1 Overview of the Chapter**

As initially predicted in Chapter 4, the undergraduates seemed to develop insufficient interpretation skills of visual representations in plant anatomy. To clarify this initial prediction, in this chapter, the collected information related to students' interpretations of plant anatomy representations is analysed using the CRM model. According to this model, students' ability to interpret visual representations is affected by seven factors, namely, conceptual knowledge (C), reasoning ability (R) which is divided into reasoning ability related to underlying concepts of representations (R-C) and reasoning ability related to external features of representations (R-M), graphical features of representations (M), the scientific information communicated by representations (C-M), and ability to involve all factors in this model (C-R-M).

The relevant factors of the CRM model are discussed in this chapter while describing students' interpretations of plant anatomical pictures to provide answers to Research Question 2: How do undergraduates interpret visual representations in plant anatomy?. For this purpose, students' interview responses to the given images are analysed deeply. The results of the PADI-I, observations, and document reviews are also discussed to provide a more complete information of the phenomena being captured. The focus of Chapter 5, however, is only on students' interpretations of the photographs in the PADI-I because no students' interviews were carried out when the PADI-II and the PADI-III were administered.

### **5.2 Students' Interpretation of the Pictures in Item 1**

The first item of the PADI-I was designed to assess the undergraduates' understanding of the components of a plant cell (see Figure 5.1). By comparing the images of animal and plant cells, the researcher aimed to communicate that unlike animals, which maintain minerals at a required level, plants typically deposit those inorganic substances, such as in the form of crystals, in their body (Esau, 1965)(C-

M). As mentioned by Evert (2006), the crystal deposits in plants function as a protection against predators, detoxification, and for mechanical support. Similar explanations as well as photographs and diagrams of plant crystals were also presented in the lecturer's PowerPoint slides during a lecture session (Observation, 29/09/2014) and students' handbook of plant anatomy on pages 8-9 (Santoso et al., 2007). These facts indicate that the students had had opportunities to study the scientific concept being conveyed by the pictures in Item 1.

1.1 Under a microscope, you see something similar to the following pictures.

Based on the characteristics, which picture shows the plant cells?

- A.
- B.
- A and B.

1.2 Which parts of the pictures support your answer?

- 1 dan 2.
- 2 dan 4.
- 3 dan 4.
- 1 dan 3.

1.3 What is the name of the parts?

- Starch grains and crystals.
- Intercellular spaces and chromoplasts.
- Cell walls and nucleus.
- Cell walls and intercellular spaces.

1.4 The reason is...

- both pictures show rigid polyhedral cells with large intercellular spaces for gas exchange in plant.
- the cells contain plastids which bring the colour to the cells.
- the cells contain the major components of plant cells which are clearly seen.
- the cells contain ergastic substances as the products of plant secondary metabolic processes.
- I do not know.
- other (Explanation: \_\_\_\_\_)

**Figure 5.1** Item 1 in Part 1 of the PADI-I.

However, only a few students could capture the intended message represented by pictures in Item 1. Although 14 of 15 interviewees expressed their familiarity with the micrograph showing plant cells (M), less than 15% of the participants could answer Item 1 of the PADI-I correctly (see Table 4.1). From the interviews, it was obvious that this small group of students who correctly responded Item 1 could recognise the presence of a distinctive component — crystals — in one of the micrographs. Relying on this particular characteristic, these students selected the most appropriate answers. The following quotes illustrate this phenomenon.

- 1 S3 : “...we know that this [pointed Picture B] was a plant cell because there were crystals and starch grains...*I identified them [crystals and starch grains] based on the shapes...*”
- 2 S4 : “...*The differences were in the number 3 and 4 (see Picture B in Figure 5.1). For the number 4, I knew that it was a crystal, and I could find the word crystal in the provided options. For the number 3, I thought it was a chloroplast, but in the multiple choices, it was a starch grain. So, I chose them [crystal and starch grain]...Crystals belong to ergastic substances that are essential for metabolic process in a plant.*”

(Interview, 08/12/2014, S = Student)

As shown by Arial font in Quotation 1, Student S3 relied on the major characteristics of a plant cell — crystals and starch grains — to identify the presented micrographs. This response indicated that this student was able to apply her sufficient knowledge of a plant cell to solve the problem in this item (R-C). The italicised response in Quotation 1 also shows that the student could focus on and decode the relevant elements in the micrographs (R-M) by relying on their distinctive shapes (M). This finding provides an example how a student could successfully interpret the presented micrographs by involving both sufficient skills in reasoning related to concepts and representations (C-R-M).

Similar to Student S3, Student S4 could recognised the distinctive elements in the micrographs by pointing to Numbers 3 and 4 in Picture B of Item 1 (R-M), as italicised in Quotation 2. However, the student’ identification of the two elements was correct only for the crystals because Student S4 seemed to have sufficient knowledge of this particular component, as shown by Arial font in Quotation 2 (C). This finding indicates that the student’s observational skills were inadequate. However, Students S4 could correctly select the answers to Item 1 of the PADI-I because she was able to determine the relevant component in the pictures (R-M), thus contrary to Student S3 who had comprehensive understanding of a plant cell. The result is understandable because Item 1 is a simple question about picture identification.

In addition to these two examples, the researcher identified that the words of “special features/unique parts/characteristics” frequently occurred in interviewees’ responses. These facts imply the saliency of distinctive components in visual representations and identification skills for students’ sense-making processes of plant anatomy

visualisations. Students' insufficient skills in identifying components of visual representations in plant anatomy may lead to incorrect interpretations of the object being depicted, as illustrated in the following paragraphs.

A major reason behind the undergraduates' poor performance on Item 1 may be the incorrect identification of the cell parts being represented. Some students focused on the conspicuous aspect of the image resulting in the inappropriate explanations of the depicted object as demonstrated below.

3 I : "...why did you predict that Picture A did not represent plant cells?"

4 S5 : "One of the key features of a plant is the green colour because of chlorophyll. This part is the main component of plant cell which cannot be found in other creatures' cells. *Thus, based on the colour of the pictures, I chose B.*"

5 I : "...Why did you select Parts 1 and 3 for Question 1.2?"

6 S5 : "...I chose *Part 1* because it was *aerenchyma*. The *aerenchyma* functions for gas exchange. Then, *Part 3* was *chloroplast*. The chloroplast is an element which presents in a plant cell."

7 I : "Did your answer to Question 1.2 match with the answer to Question 1.3?"

8 S5 : "Eee, nope."

9 I : "So, why did you choose the option?"

10 S5 : "Eee, in Part 3, *besides the green colour there was a red colour*. In my understanding, besides the chlorophyll, a plant cell may contain other pigments. Thus, I selected the *chromoplasts*. Then, for the intercellular spaces, within the *aerenchyma* tissue, the *aerenchyma* cells are connected by *cavities*."

(Interview, 27/02/2015, I = Interviewer; S = Student)

The quotes above show that the respondent considered the colour (M) as a diagnostic feature in identifying the presented images. As shown in Quotation 4, the student associated plants with green colour (R-C) based on the understanding that chloroplasts are present only in plant cells, a misconception (C). By relying only on this characteristic, this respondent was unable to recognise other important parts in the illustration. As a result, the student misidentified the cell components (R-M), as italicised in Quotation 6 —actually, Parts 1 and 3 are intercellular spaces and starch grains, respectively— leading to the inconsistent responses for the following questions (see Conversation 7-8). However, the student's explanations of those misidentified components as coded by Arial font in Quotation 6 were accurate (C). Using a broad comprehension of plant cells, interestingly, this student could provide a convincing reason for the selected incorrect responses. Focusing again on the



colour (see italicised statement in Quotation 10), the student substituted the chloroplasts with chromoplasts using the fact, as explained by Esau (1965), that plants may also develop a coloured component which contains a pigment other than green (R-C). Moreover, the student's conceptual reasoning about aerenchyma shown in Quotation 10 was also correct (R-C). According to Beck (2010), the aerenchyma tissue is characterised by large intercellular spaces that function to facilitate gas exchange. This finding demonstrates that external features, such as colour, of a realistic representation could distract students' attention from the relevant information being represented (Dwyer, 1969; Patrick et al., 2005). The decision to use coloured pictures in Item 1 was based on the fact that most of visual representations of plant cells in the lecturer's PowerPoint presentations and test were presented in colours. However, the frequent occurrences of the word "conspicuous features" were apparent in students' interview transcripts. Despite the distraction effect, these graphical properties were considered by the students as essential clues for interpreting plant anatomy pictures.

In contrast, other participants showed an over-reliance on a characteristic that is difficult to be seen in the representation. In this case, the students' answers to Item 1 seemed to be merely driven by a theory without any accurate observation of the micrographs. As an illustration, the conversations between the researcher and a respondent are presented below.

11 S6 : "...if the cells seem to be rigid, it means it is a plant cell because of the cell walls. However, if the cell is irregular, it is an animal cell."

12 I : "Do you think the cells in Figure A are not regular?"

13 S6 : "*They are regular, but they are not rigid.*"

14 I : "How do you know that?"

15 S6 : "Because for this picture (Picture B), *the cell walls are apparent, but for this (Figure A)[the boundary] is unclear because of the other parts.*"

(Interview, 08/12/2014, I = Interviewer; S = Student)

Those quotes clearly indicate that this student paid too much attention to the cell walls as a distinctive feature of a plant cell (M). Although the student's explanation about the rigidity of plant cells (see Quotation 11) was correct (C), in fact, the location of cell walls in Figure B was hard to pinpoint, thus, contrasting the student's identification which is italicised in Quotation 15 (R-M). As informed by Beck (2010), the outer line of each plant cell cannot be simply labelled as the cell wall

because it also contains the plasma membrane and cytoskeleton. Furthermore, the way the student analysed the visual representations as italicised in Quotes 13 and 15 was also unconvincing. Instead of focusing on the flexibility of cells, the student relied only on the cell boundaries (R-M) leading to a surface level reasoning. This student seemed unable to apply her conceptual understanding, as presented in Quotation 11, for identifying the pictures. Furthermore, the students' over-reliance on cell walls implies her insufficient knowledge of plant cells. This limited conceptual understanding seems to prevent the respondent from recognising other relevant components in the depictions. This phenomenon shows the importance of conceptual knowledge in students' interpretations of visualisations.

### **5.3 Students' Interpretation of the Pictures in Item 2**

As shown in Figure 5.2, Item 2 of the PADI-I examined students' knowledge of the anatomical structure of plant stems. For this purpose, the researcher presented both anatomical and morphological photographs of a stem. By showing a close-up of the vascular bundles, the researcher intended to inform the students that this part was essential for distinguishing a stem from a root (C-M). Although the two organs are morphologically similar, vascular bundles of a stem are arranged in the form of collateral, bicollateral, or concentric, whereas a root maintains the xylem and phloem in different radii (Cutler et al., 2007). This description was in the students' handbook of plant anatomy on pages 43-44 and 66 (Santoso et al., 2007) and the real specimen was observed by students during a laboratory session (Observation, 18/11/2014).

2.1 A botanist observes a transverse section of an unknown plant organ as shown by picture A. He sees something similar to the picture B under a light microscope. Based on its anatomical structure, he concludes that the organ serves to...

- ★ a) transport water and photosynthesis products.
- b) absorb minerals and water from the soil.
- c) store nutrient.
- d) support the plant body.

2.2 Which part of the picture supports your answer?

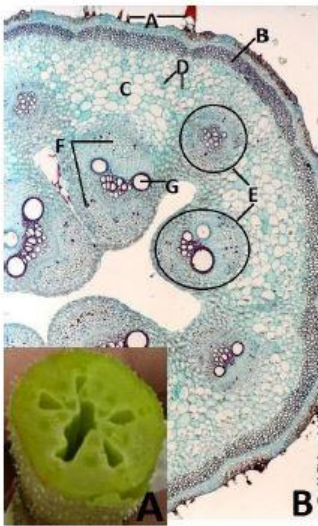
- a) A dan E.
- b) B dan G.
- c) C dan D.
- ★ d) F dan G.

2.3 What is the name of the part?

- a) Sclerenchyma and xylem.
- b) Root hair and vascular bundles.
- ★ c) Phloem and xylem.
- d) Parenchyma and starch grains.

2.4 The reason is...

- a) the organ has well-developed vascular bundles in which the xylem and phloem are arranged alternately and develops root hairs at the outermost layer.
- b) the organ has abundant ground tissues which contain starch grains.
- c) the organ is surrounded by supportive tissues which contain lignin.
- ★ d) the organ has well-developed vascular bundles in which the xylem is located in between the outer and inner phloem.
- e) I do not know.
- f) other (Explanation: \_\_\_\_\_)



**Figure 5.2** Item 2 in Part 1 of the PADI-I.

In fact, the majority of the undergraduates gave attention to the desired part of the images. Indeed, 10 of 14 respondents articulated that the images had been known well (M). However, the students' inadequate understanding of the stem anatomy seemed to lead them to interpret the presented images incorrectly. The following conversation illustrates this phenomenon.

16 I : "Why did you think that the organ was a root?"

17 S4 : "*Because of the root hairs...and the vascular bundles...*"

18 S7 : "*...because it has a lot of vascular bundles...and root hairs...*"

19 I : "What was characteristic of the vascular bundles that you used to recognise this organ as a root?"

20 S4 : (quite), **I did not know, but I thought it was a root.**"

21 I : "Based on the structure of vascular bundles, do you agree that it was a root?"

22 S7 : "It looked like a root, but when I identify the structure it looks like a stem of a plant that I have observed during the laboratory session. Now, **I become confused**...it seemed to be hair roots but root hairs come from pericycle. Why are they here [pointing the margin of the organ]..."

(Interview, 08/12/2014, I = Interviewer; S = Student)

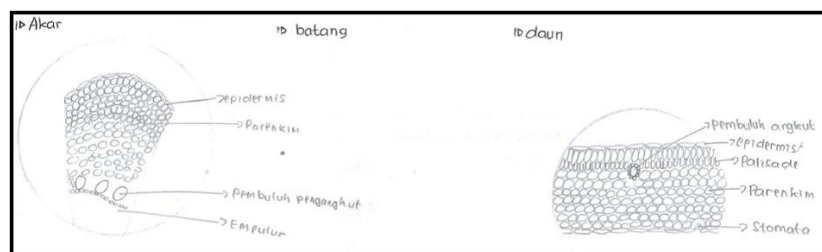
As expected by the researcher, the two participants focused on the enlarged part (M) of the picture — the vascular bundles — to recognise the plant organ (R-M) (see Quotations 17 and 18). However, the students failed to further explain the characteristic of the component to support their answer. Student S4 seemed to rely on intuitive awareness (see Quotation 20), whereas student S7 struggled to match her perceptual-based memories (see Quotation 22) indicating their poor conceptual understanding of this topic (C). Because of the lack of understanding, those students also gave attention to an irrelevant component of the micrograph leading to a misinterpretation of the depicted organ. As shown in Quotations 17 and 22, both participants also focused on the outer appendages (M) and identified them simply as root hairs (R-M) without careful observations. In fact, these projecting parts are also apparent in other organs. Furthermore, Arial font in Quotation 22 shows that Student S7 had incorrect conception about root hairs. The student thought that root hairs are developed from the pericycle (R-C) instead of the epidermis in a root (Santoso et al., 2007). This student seemed to inappropriately transfer a concept of lateral roots to root hairs because both plant components look similar, a phenomenon that is also recorded in Chapter 4 (see Section 4.6b). These findings showed that the students' lack of conceptual knowledge had a great impact on their identification and interpretation skills of the plant anatomy representation.

Interestingly, a similar problem was evident in a response provided by a participant who correctly identified the pictures. Although the student's answer was correct, the reasoning that the student provided was driven only by a visual memory without any connection to the underlying concept, as shown below.

23 S8 : “I used an analogy without a theoretical basis. If it was a leaf, I have never seen a leaf with a hole in the centre like this. Then, if it was a root, I have never seen a root like this. But, if it was a stem, actually there is a stem with a hole in the centre. *So, it might be a stem.*” (Interview, 08/12/2014, I = Interviewer; S = Student)

As coded by Arial font in Quotation 23, instead of observing the anatomical structure, the respondent relied on visual memories to recognise the represented organ. Focusing on a unique component in the depictions — a hole (M) — this student tried to compare the photographs with other plant structures she had seen before (R-M). This unsound deductive reasoning indicates the student's lack of knowledge of stem anatomy. In fact, this argument seems to be also supported by

the student's drawings which were blank only for the stem part (see Figure 5.3). However, the student could accurately identify the object (R-M) because the anatomical structures represented by the micrograph were similar to the specimen that the respondent observed during a laboratory session. Another participant confirmed this fact, "It looks like, I know, *Dracaena* when I dissected it. Oh pumpkin, not *Dracaena*..." (Interview, 08/12/2014). This phenomenon demonstrates that the ability to recall images compromised students' poor knowledge for identifying visual representations in plant anatomy. In fact, the students' dependence on visual memories when reading plant anatomy illustrations is also evident in their interview transcripts. The word "remember" occurs many times in students' responses to interview questions related to plant anatomy pictures. As also observed by Brewer (1974), these findings indicate the crucial role of the visual memory for students in interpreting plant anatomical structures. However, without sufficient conceptual understanding, students' visual memory-based interpretations of plant anatomy representations remained superficial, as is apparent in this phenomenon.



**Figure 5.3** Student's plant anatomical drawings. Akar means a root; batang means a stem; and daun means a leaf.

#### 5.4 Students' Interpretation of the Picture in Item 3

The researcher created this item to investigate to what extent the undergraduates were able to apply their knowledge of leaf anatomy. For this purpose, a well-known leaf micrograph was selected to complement a question which was designed to go beyond a typical textbook problem (see Figure 5.4). In so doing, the researcher could measure the depth of students' conceptualisation of the familiar picture which was presented in the instructor's power point presentation (Observation, 21/10/2014) and students' handbook of plant anatomy on page 97 (Santoso et al., 2007), and observed in a laboratory session (Observation, 21/10/2014). Fundamentally, the micrograph represented the leaf anatomy of a plant which lives in an area with high sunlight

intensity (C-M). The plant has two distinctive features, namely a hypodermis and stomatal crypts, to minimise water loss (Rudall, 2007).

A young woman is found killed in a location. During the investigation, police found a piece of leaf attached to her clothes. Under the microscope, the leaf shows an anatomical structure as shown in the picture. Based on the anatomical structure of the leaf, where do you predict the location of the crime?

- ★ a) Area with high sunlight intensity.
- b) Area with high salinity.
- c) Submerged area.
- d) Shaded area.

Which parts of the picture support your answer?

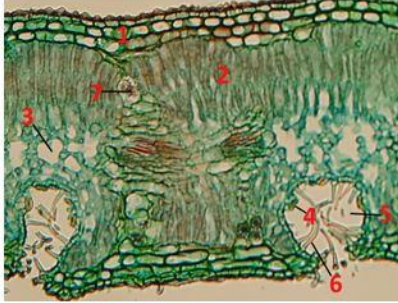
- a) 3 and 4.
- ★ b) 1 and 5.
- c) 1 and 2.
- d) 6 and 7.

What is the name of the parts?

- a) Intercellular space and stomata.
- b) Multiple epidermis and palisade parenchyma.
- c) Trichomes and salt gland.
- ★ d) Multiple epidermis and substomatal chamber.

The reason is...

- a) the structure facilitates the leaves to capture light as much as possible.
- ★ b) the structure prevents the plant from excessive transpiration.
- c) the structure helps the plant excluding salt deposit.
- d) the structure facilitates a faster gas exchange.
- e) I do not know.
- f) other (Explanation:\_\_\_\_\_)



**Figure 5.4** Item 3 in Part 1 of the PADI-I.

However, it is evident that only a quarter of the participants (see Table 4.1) could complete Item 3 successfully. Based on the interviews, a primary reason behind this finding was the undergraduates' inability to apply their content knowledge. Although the students had been taught the concept during the lessons, their knowledge was insufficient to solve the novel problem given in this item. The following responses explicitly demonstrate that the students struggled to explain the presented anatomical micrograph.

24 S1: "...Actually, Item 3 based on the picture was the easiest one, but I did not know why it was hard to complete the questions although the image was easy to be understood..."

25 S2: "I was very familiar with the graphic, but I lacked reasoning ability here..."

26 S9: "Yes, it was difficult to make an analogy, to integrate, shhh I thought it [Item 3] was hard to be completed."

(Interview, 08/12/2014, I = Interviewer; S = Student)

It is obvious from those quotes that the students were familiar with the picture shown in Item 3 (M). Indeed, all other participants expressed their agreement with this statement showing the lesser impact of the graphical factor on the students' incorrect answers. As highlighted above, however, those students had a problem in accessing

relevant knowledge necessary for explaining the underlying concept of the image. This finding indicates that those three respondents had learned the anatomical details intensively without acquiring an in-depth understanding of the roles of the leaf parts.

The following illustration provides more convincing evidence for this phenomenon. As recorded below, an undergraduate whose responses to Item 3 were correct identified the image precisely but had difficulty in the reasoning section.

27 I : “...wonderful, you can identify each tissue correctly...For the last question in Item 3 [reasoning part], why did you choose the option B?”

28 S4 : “I did not know. At that time, I just decided this [option B] because I did not know the reason...This plant lives in an area with high sunlight intensity because of the characteristics, I saw this picture often...I know this is a stomatal chamber but I was not sure whether this is a feature of the plant lives in an area with high sunlight intensity or a submerged area...”

(Interview, 27/02/2015, I = Interviewer; S = Student)

The highlighted part in Quotation 27 shows that Student S4 could correctly decode each graphical elements in the micrograph (R-M) indicating that this student might had a comprehensive understanding of the anatomical structure of the organ being depicted or good visual memory because of the frequent exposure to the image (see italicised part in Quotation 28). In addition, a diagram version of the same picture was also presented in the instructor-designed test. In contrast to the PADI-I where problem-solving question was applied, the instructor’s test was required students only to identify the parts of the represented specimen. Thus, it was understandable that the student was able to correctly recognise each part of the displayed organ (see Quotation 27).

Despite the correct selection of the answers to Item 3, in fact, the student experienced difficulty in applying her content knowledge for explaining the idea behind each anatomical element of the organ (see the highlighted part in Quotation 28). As shown by Arial font in in Quotation 28, the student could correctly interpret that the plant lives in an area with high sunlight intensity after observing the features in the micrograph. However, this understanding seemed superficial because the student still had difficulty to determine the correct function of the plant component (i.e., stomatal chamber) (R-C). This confusion might occur because an anatomical structure that is similar to the stomatal chamber exists in aquatic plants. This phenomenon is evident



in the following example (see Quotation 29). This finding implies that the student's comprehension was limited to the anatomical structure without a sufficient understanding of the functions of the anatomical components. Besides, this instance clearly shows that the participant had difficulty with reasoning related to the concept, which is categorised as the R-C factor in the CRM model. However, this finding also demonstrates the importance of identification skills in plant anatomy learning. As illustrated in Quotations 27-28, the thorough understanding of the anatomical structure seemed to direct the student to select the most reasonable answer.

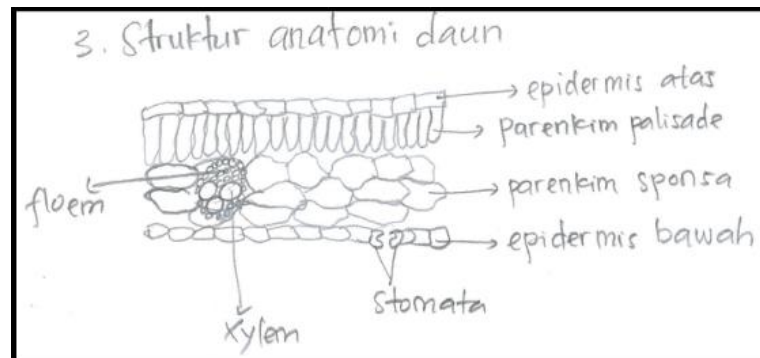
The saliency of students' ability in recognising the internal structures for interpreting plant components is also evident in the following example. As recorded in the quote below, a respondent misinterpreted the object being presented because of the incorrect identification of a plant component.

29 S5 : *"...I saw this (pointed the stomatal chamber) just as a hole, an intercellular space.* Thus, the plant lives in a submerged area so that it has many large intercellular spaces which facilitate gas exchange in the water." (Interview, 27/02/2015, S = Student)

The italicised statement shows that this participant focused only on a particular part (i.e., the hole) (M) instead of the whole structure of the plant tissue (the stomatal chamber) leading to incorrect identification of this plant element. Student S5 recognised this plant tissue as another tissue which has a similar appearance—large air spaces (R-M). Although both structures look quite similar, unlike the intercellular spaces, the stomatal chambers are developed on the outer layer of the organ (Dickison, 2000). The student failed to realise this principle resulting in an inaccurate observation of the micrograph. As a result, the student misinterpreted the plant as an aquatic species instead of one which lives in high sunlight intensity (R-C). Moreover, the italicised part in Quotation 29 indicates that the student focused only on the unique element in the micrograph — the stomatal chamber (M) — rather than view the micrograph in its entirety (R-M) that had resulted in incorrect interpretation of the plant's habitat (R-C). In fact, the anatomical structure of plants which occupy arid land will be quite different from those living in water (Dickison, 2000). However, the student's reasoning indicated by Arial font in Quotation 29 was fundamentally correct for aquatic plants (R-C) showing that the participant may have an adequate knowledge of leaf anatomy (C). A leaf anatomical diagram which was



generated by the student supports this argument. As shown in Figure 5.5, the student represented a leaf anatomy appropriately, except in the incorrect positioning of the vascular bundles—xylem and phloem (C). Thus, different from the previous finding, the student’s misinterpretation of the picture is mainly affected by the reasoning factor which relates to the graphical features of the representation, referred to as the R-M.



**Figure 5.5** A student's anatomical drawing of a dicotyledonous leaf.

### 5.5 Students’ Interpretation of the Pictures in Item 4

Fundamentally, Item 4 of the PADI-I focused on the primary function of aerenchyma (see Figure 5.6). By comparing the micrographs of a root with and without this tissue, the researcher intended to show that the aerenchyma is a plant adaptive feature for an unfavourable condition (C-M). According to Evert (2006), the continuous air channels in the aerenchyma facilitate gas exchange in waterlogged roots, thus, preventing them from suffering of oxygen deficiency. The functions of aerenchyma had been explained by Mrs. Bunga when teaching the topic of plant tissues (Observation, 06/10/2014) and Mr. Akar when guiding the lesson about plant roots (Observation, 04/11/2014). The brief explanation of this function is also available in students’ handbook on pages 19 and 69 (Santoso et al., 2007). These learning opportunities were expected to have had a positive impact on students’ conceptual understanding of this particular plant components (i.e., aerenchyma).

4.1 An agronomist finds a difference of plant productivity in two different areas. Area A produces a greater dry weight than area B. In order to understand the cause of the difference, he observes and compares the anatomical structure of the plant organ collected from the two areas. Under the microscope, he sees something similar to the picture A from the plant in area A and the picture B from the plant in area B. Based on the observation, what should he have been done to improve the plant productivity of area B?

a) Fertilizing the plant with organic fertilizers.  
 b) Watering the plant regularly.  
 ★c) Aerating the soil mechanically or biologically.  
 d) Reducing the salt level of the soil.

4.2 Which parts of the picture supports your answer?

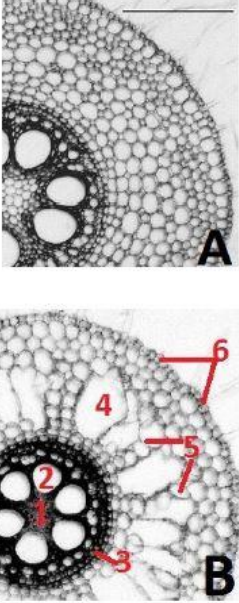
a) 1 and 2.  
 b) 3 and 4.  
 ★c) 4 and 5.  
 d) 3 and 6.

4.3 What is the name of the parts?

a) Pith and vessels.  
 b) Endodermis and intercellular space.  
 ★c) Intercellular space and aerenchyma.  
 d) Endodermis and salt glands.

4.4 The reason is...

★a) the tissues are formed by the plant to tolerate an oxygen deficiency.  
 b) the tissues are formed by the plant to tolerate a nutrient deficiency.  
 c) the tissues are formed by the plant to tolerate a water deficit.  
 d) the tissues are formed by the plant to tolerate a salt stress.  
 e) I do not know.  
 f) other (Explanation: \_\_\_\_\_)



**Figure 5.6** Item 4 in Part 1 of the PADI-I.

The results of interviews show that 12 of 15 respondents expressed their familiarity with the presented images (M). Indeed, most of the participants easily noticed the presence of aerenchyma in one of the micrographs, as demonstrated below.

30 S4 : “E..because it [pointed Figure B] had aerenchyma, I thought the plant lived in a submerged area.”

31 S9 : “These are roots with [pointed Figure B] and without aerenchyma [pointed Figure A]...we can clearly see the different here, the cells in this organ [pointing Picture A] are compact, but here [pointing Picture B] the cells are loose because of the aerenchyma...”

(Interview, 08/12/2014, S = Student)

Those quotes show that the two participants focused on the intended component in the representations when observing the micrographs. It is understandable because the difference between the two representations is obvious (see Figure 5.6), as is also confirmed by Student S9 indicating the effectiveness of the selected representations (M). However, these students could correctly identify the distinct feature in Picture B (see Figure 5.6) as aerenchyma. As utilised in Quotation 31, Student S9, for example, relied on the compactness of the cells (M) to recognise the presence of

aerenchyma (R-M). This finding indicates that the students had no problem in identifying the given micrographs. Indeed, as coded by Arial font in Quotation 31, Student S4 precisely associated this distinctive tissue with the plant's habitat showing the sufficient knowledge that the student possessed (C). The result is understandable because the students had been exposed to both anatomical images and real specimens of a root with aerenchyma during lecture and laboratory sessions, respectively. Furthermore, one short-answered question of the lecturer-designed test focused on the function of aerenchyma.

However, Student S4's understanding of the role of aerenchyma seemed limited. The following conversation illustrates that this student did not understand the function of this plant tissue.

32 I: "Why did you think that the plant with the root anatomical structure shown in Picture B needs organic fertiliser?"

33 S4: "*Because of the presence of aerenchyma*, the root may be submerged. Terrestrial plants get much more nutrition than those in a flooded area so that the plant needs organic fertiliser."

(Interview, 27/02/2015, I = Interviewer; S = Student)

Based on the student's response in Quotation 33, it is evident that the respondent did not know why the plant has this distinctive feature. As indicated by Arial font, the student's explanation focused on the environmental differences rather than the role of aerenchyma for the plant (R-C). The student might view this component only as a plant identity without any connection to the plant's physiology showing that the student's comprehension was limited to its anatomical structure. In other words, the student's understanding of the role of aerenchyma was quite superficial. As a result, this respondent struggled to reason the problem in Item 4 (see Quotation 30). This finding implies that the primary source behind this student's low performance on Item 4 was the R-C factor.

This assertion is, in fact, supported by the interview responses of another respondent. In contrast to S4 who lacked an understanding of aerenchyma's function, this student held an alternative conception of the role of this tissue. As illustrated in the following conversation, the way this student explained this distinctive feature deviated from the instructors' explanation.

34 I : "...did you think the tissue [aerenchyma] were the evidence that the plant was in a water shortage condition?"

35 S5 : "Yes. Because of the high evaporation...because it has large intercellular spaces, the evaporation is high..."

(Interview, 27/02/2015, I = Interviewer; S = Student)

As indicated by Arial font in Quotation 35, the participant associated the presence of aerenchyma with droughts condition (R-C). In fact, it was contrary to the common concept taught by the lecturers that aerenchyma is a characteristic of most aquatic plant (see Section 6.3.2, Quotations 4 and 5). Interestingly, the finding of research conducted by Zhu, Brown, and Lynch (2010) supported the student's alternative conception indicating the broad knowledge that the student possessed in this subject. However, contradicting the student's idea, Zhu et al. (2010) elaborated that the transformation of root cells into intercellular spaces within aerenchyma reduces metabolic processes, thereby much more energy can be allocated for water absorption (C-M). This additional fact shows the student's superficial understanding of the role of aerenchyma. Based on her reasoning (see Arial font in Quotation 35), indeed, the student seemed to inappropriately transfer the function of stomata to the aerenchyma (R-C). Although both these elements have the same function, in fact, the location of the two structures is completely different. Whereas the stomata are located on the surface of a plant body, the aerenchyma occupies the inner layer of an organ, thus, less likely contributes to the plant transpiration. This evidence, therefore, confirms the fact that students' reasoning ability related to the underlying concept of the representations (R-C) was the element contributing most to their difficulties in completing Item 4.

## **5.6 Students' Interpretation of the Pictures in Item 5**

To measure the level of students' understanding of the concept of secondary growth, the researcher developed Item 5 of the PADI-I (see Figure 5.7). The three coloured pictures presented in this item were selected to investigate the students' ability to recognise a fundamental difference between secondary stems and roots, and in counting the number of annual rings (C-M). As explained by Beck (2010), the annual rings refer to the layers of secondary xylem which are formed once every year during the secondary growth process. Commonly, this cambial activity has no impact on the

parts inside the secondary xylem; therefore, an old stem retains the pith, whereas the primary xylem still exists in an old root (Beck, 2010).

5.1 To make a high-quality handicraft, a craftsman has decided to use a 5-year-old trunk of Basswood (*Tilia*). The tree is commonly found in temperate regions and forms a growth ring every year. Based on the description, which picture shows the trunk that the craftsman will choose when buying online?

a) A.  
 b) B.  
 \*c) C.

5.2 Which parts of the picture support your answer?  
 \*a) 1 and 2.  
 b) 2 and 3.  
 c) 3 and 4.  
 d) 2 and 4.

5.3 What is the name of the parts?  
 a) Secondary xylem and secondary phloem.  
 \*b) Pith and secondary xylem.  
 c) Secondary xylem and periderm.  
 d) Primary xylem and secondary xylem.

5.4 The reason is...  
 a) the wood shows 5 rings of secondary phloem and an existence of primary xylem as a characteristic of old trunk.  
 b) the wood shows 5 rings of secondary xylem and an existence of periderm as a characteristic of old trunk.  
 \*c) the wood shows 5 rings of secondary xylem and an existence of pith as a characteristic of old trunk.  
 d) the wood shows 5 rings of secondary phloem and an existence of periderm as a characteristic of old trunk.  
 e) I do not know...

**Figure 5.7** Item 5 in Part 1 of the PADI-I.

These two aspects of secondary growth had been taught by Mr. Akar (Observation, 14/11/2014) and Mrs. Bunga (Observation, 18/11/2014). Indeed, the images similar to those shown in this item were presented in the students' handbook on page 63 and 80, respectively for secondary stems and secondary roots (Santoso et al., 2007) and a lecturer's PowerPoint slide. Thus, it is unsurprising that 12 of 15 respondents articulated their familiarity of the depictions (M). However, only 11% of the participants completed Item 5 correctly (see Table 4.1). According to the interview results, the primary reason behind this finding was the students' lack of understanding of the secondary growth concept. A quote below confirms this assertion.

36 S11: "Because I did not understand the concepts of a woody plant. Thus, I could not complete this item [Item 5] well." (Interview, 08/12/2014, S = Student)

This conceptualisation problem led another respondent to develop an alternative conception of the secondary growth resulting in the incorrect interpretation of the depicted objects. This phenomenon is apparent in the following interview between the researcher and a female student.

37 I : “Why did you think all of them were stem?”

38 S5 : “Eee *there was a part which similar to the [secondary] stem’s tissue...the annual rings*”

39 I : “Do you think an old root has no annual rings?”

40 S5 : “Based on my knowledge, it has not.”

41 I : “...Why did you choose Picture B?”

42 S5 : “Because *it had the smallest pith*...It means the pith had been compressed by the secondary growth of vascular bundles so that it becomes smaller [than the pith in the primary stem]...later the primary xylem, during the secondary growth, will be pushed into the centre and will replace the pith. Next, the secondary xylem will grow outward.”

(Interview, 27/02/2015, I = Interviewer; S = Student)

The italicised response in Quotation 38 demonstrates that this participant recognised all micrographs in Item 5 as secondary stems (R-M) by relying on the presence of annual rings in each micrograph (M). The student failed to notice the representation of an old root among the three micrographs because of the alternative conception that the student held. As recorded in Conversation 39-40, this student erroneously thought that the annual rings were present only in old stems (C). She was not aware that dicot roots also develop this structure during the secondary growth stages (Beck, 2010). This incorrect conception seemed to be caused by an infrequent exposure to the relevant specimens during the lessons (see Quotation 12 in Section 4.3.3).

The student’s conceptual framework may be appropriately categorised as an alternative conception rather than a lack of knowledge. The student’s explanation coded by Arial font in Quotation 42 shows that basically the respondent understood the process occurred during cambial activities (C). However, the student failed to understand the fact that the secondary growth less likely affects the tissues in the inner layers of secondary xylem, such as the pith and primary xylem (Beck, 2010), thus, contradicting the student’s reasoning (R-C). This alternative conception may have led the student to incorrectly interpret the central element as the affected tissue rather than to the organ’s identity (R-C). However, the design of the selected

representations seemed also to contribute to the student's misinterpretation of the represented organs. As italicised in Quotation 42, the student focused on the size of centre of each micrographs (M) to select the picture (R-M) because the three representations show a reduction in diameter of the central components. In this case, thus, the graphical format of the visual representations has an impact on the student's ability to interpret visual representations in plant anatomy.

In fact, a similar phenomenon is also captured in the responses of another respondent who answered all questions in Item 5 correctly. In line with Student S5, this participant relied on the graphical characteristics of the micrographs. However, different from Student S5 who held an alternative conception, this respondent engaged in superficial reasoning because of a lack of knowledge. These facts are apparent in the following conversation.

- 43 I : "Thus, in your opinion, Pictures A, B, and C were old stems, weren't they?"  
44 S4 : "Yes."  
45 I : "So, what are the differences?"  
46 S4 : "The colour, the [size of] pith, and the [number of] annual rings...*Picture A has the biggest pith but the fewest annual rings than others.*"  
47 I : "How many are the annual rings in this image (Picture A)?"  
48 S4 : "Three."  
49 I : "How about this ring [the outer ring]? Do you include it or not?"  
50 S4 : "Four maybe."  
51 I : "Why did you choose the pith as the main characteristic of an old stem rather than the periderm, for example?"  
52 S4 : "...*Em, because the pith is more dominant than other parts...In my opinion, the wider the pith, the older the organ.*"  
53 I : "This image (picture A) is four years old, but the pith is larger than Picture C [the student recognised it as a five-year-old stem], right?"  
54 S4 : "Yes, haha...I do not know."

(Interview, 27/02/2015, I = Interviewer; S = Student)

Despite providing correct responses to Item 5, this respondent identified the micrographs in Item 5 inappropriately. Conversation 43-46 demonstrates that this student was unable to recognise the different structure presented by Picture B. The student viewed that all micrographs represented the same organ (R-M) because Students S4 relied on the colours, sizes, and annual rings (M) for identification rather than the structure of the organs indicating the student's inadequate observational

skills. This problem with identification (R-M) is also evident in the student's inconsistent responses to the number of annual rings (see Conversation 47-50).


A possible source of this incorrect identification is the participant's insufficient conceptual knowledge of secondary growth. As italicised in Quotation 52, this student determined the pith as the key feature of a secondary stem (R-C) just because it was a conspicuous part (M) of the representation rather than the theoretical judgement. As a result, the student's reasoning was inappropriate and superficial. As indicated by Arial font in Quotation 52, the student relied on an external graphical attribute — the size of the pith (M) — to interpret the micrographs without any connection to the underlying principles of secondary growth (R-C). Although the depictions' design may influence the student's interpretation of the objects as seen in Student S5's response, in fact, the respondent's inadequate knowledge seems to contribute much to this erroneous thought. This argument is supported by the student's uncertain response (see Quotation 54) and inconsistent statements which are highlighted in Quotations 46 and 52 (C). Despite those described problems, in fact, this student could respond to the four interrelated questions in Item 5 correctly implying that the student's responses to this item might be not genuine. It means the student might have been in collusion with other participants when completing the test. Although the students were required to provide their own answers to the test, the collusion among students was possible to occur because during the test each of three students were sat together on a long laboratory desk without a clear separation.

## **5.7 Students' Interpretation of the Picture in Drawing Section**


In contrast to the other items, the researcher deliberately chose an unknown photograph for the drawing section to examine the level of students' comprehension of plant morphology and anatomy concepts (see Figure 5.8). In so doing, students' ability to integrate knowledge of the two interrelated concepts can be determined. By showing a photograph of a potted plant with leaves and flowers, the researcher intended to demonstrate the common morphological characteristics of dicotyledonous plants (C-M). As indicated by Esau (1965), generally, the dicotyledons can be recognised from the palmately or pinnately veined leaves and multiple of three of the floral leaf-like parts. Through this drawing section, thus,



students who have a deep comprehension of plant morphology and plant anatomy are expected to be able to construct anatomical drawings of dicotyledonous organs.

A Plant Anatomy Diagnostic Instrument I (PADI-I)  Curtin University

Section 2: Drawing test  
Direction: Below is a picture of a plant native to Brazil. As a tropical plant, it needs adequate amount of water to grow perfectly. Based on the plant's characteristic shown in the picture, you are asked to draw then provide anatomical descriptions of the plant organs including root, stem, and leaf.



**Figure 5.8** Drawing test in the PADI-I.

The results of students' interviews indicates that the majority of the undergraduates struggled to integrate their knowledge of plant morphology and anatomy. As illustrated below, most of the participants created the drawings merely from their memory and prior knowledge without any relation to the presented photograph.

55 S4 : "...I did not know the anatomical characteristics because I did not know what the plant was...So, when I drew these stem, root, and leaf, I could not predict what the anatomical of those organs look like. Thus, they [the drawings] were just the general anatomical structure."

56 S5 : "...I did not know the plant so I had no idea about the characteristics."

57 S6 : "...I confused, if the morphological structure like this, what would be the anatomical structure because the anatomical structure of different plants is different although not all, but there are some different structures...That's why I drew the general anatomical structure of the organs that I knew."

(Interview, 08/12/2014, I = Interviewer; S = Student)

The quotes show that those three participants had difficulty in applying their knowledge of plant morphology to solve the novel problem. As highlighted in Quotations 55-57, the three students struggled to determine the anatomy of the plant organs just because they were not familiar with the plant being depicted. It indicates that the students' knowledge of plant morphology seemed non-transferable and

inaccessible to enable them to interpret the features of an uncommon specimen. Consequently, to complete the drawing section, those students relied heavily on their prior knowledge of plant anatomy and visual memory (see Quotations 55 and 57) without involving any morphological information from the photograph being presented. This finding provides a possible reason why the majority of students created incomplete drawings, as reported in Figure 4.1.

In contrast, the unknown plant in the photograph had no impact on a participant who was able to integrate knowledge of plant morphology and plant anatomy. The student could easily capture and extract the salient visual information from the image despite her unfamiliarity with the species of plant depicted. This phenomenon is apparent in the following conversation.

58 I : “So the plant belongs to what group?”

59 S7 : “*Dicot because the leaves’ venation is palmate no no no pinnate*, it is easy to recognise plants from the leaf structure.”

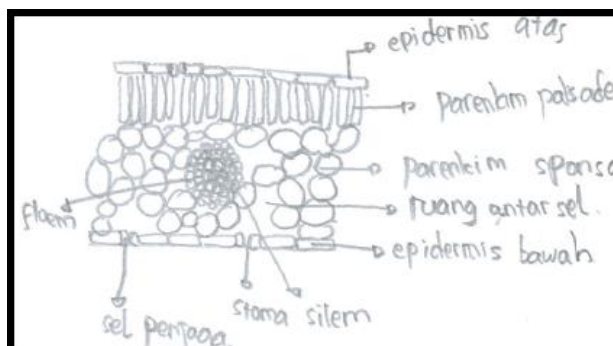
60 I : “I mentioned in the test that the plant did not come from Indonesia. Did you have difficulty to draw the anatomical structure?”

61 S7 : “...it does not matter where the plant from if there are clues, it will be easy to draw the plant anatomical structure. We just have to know the differences of anatomical structure between monocots and dicots...”

(Interview, 08/12/2014, I = Interviewer; S = Student)

The italicised reasoning in Quotation 59 shows that this student could recognise a relevant component in the photograph — leaves’ venation (M) — and correctly identify it as pinnate style (R-M), a leaf’s venation pattern that is commonly found in dycotyledoneous plants (Foster, 1974). Quotation 59 also indicates the student’s sufficient understanding of a concept in plant morphology because the student could correctly interpret the photograph as a representation of a dicot plant by referring a common characteristic of this group of plants (R-C). Because of this fact, it is understandable that the student’s interpretation of the picture (R-C) was not distracted by the fact that the plant species was not known to her (M), as recorded in Conversation 60-61. Moreover, this student could smoothly integrate the visual morphological information into the anatomical drawings indicating the student’s well-organised knowledge. As shown in Figure 5.9, this participant constructed an anatomical diagram of a dicotyledonous leaf (R-M) which was consistent with the student’s interview response in Quotation 59 (R-C). Inspecting the drawing and

labelling shown in Figure 5.9, it is obvious that Student S7 had a comprehensive understanding of the dicotyledonous leaf anatomy. The student represented each anatomical component of the leaf precisely and labelled it correctly (C). In this case, thus, this student involved all factors of the CRM model leading to a correct generation of plant anatomy representation.

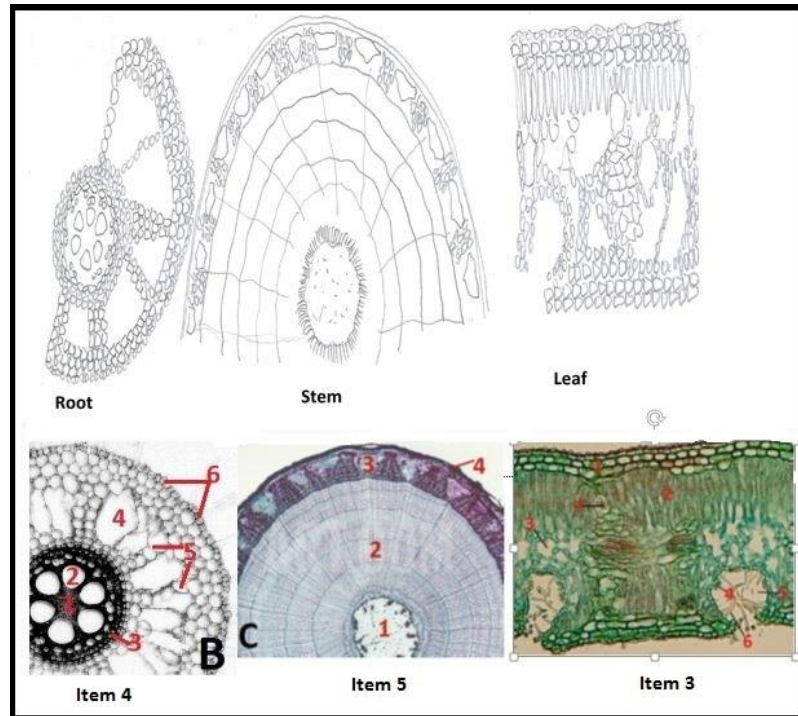


**Figure 5.9** A student's comprehensive anatomical drawing and labelling of a dicotyledonous leaf.

However, some other students only imitated the images shown in the preceding part of the PADI-I (the multiple choice questions) indicating a neglect of the provided photograph. An example of this phenomenon is presented in the following conversation and Figure 5.10.

- 62 I : “Why did you draw an old stem [see the stem drawing in Figure 5.2]?”  
 63 S4 : “Because I remembered that. There were annual rings.”  
 64 I : “So, you didn’t relate this drawing with the picture, right?”  
 65 S4 : “Yes.”  
 66 I : “Why did you draw a root with aerenchyma [see the root drawing in Figure 5.2]?”  
 67 S4 : “Because it was submerged, oh, but the picture do not show that.”  
 68 I : “Did you imitate these pictures (pointed Picture C in Item 5 and Picture B in Item 4)?”  
 69 S4 : “Yes (laughing).”  
 70 I : “How about the leaf drawing? Did you also imitate the picture in Item 3?”  
 71 S4 : “The drawing looks like this [see the leaf drawing in Figure 5.2]. Some parts came from the picture (a micrograph in Item 3), but others were from memory.”  
 72 I : “Why did you think that the plant lives in an area with high sunlight intensity?”  
 73 S4 : “It can been seen from the chlorophyll, eh, the green colour. It looks bright...The plant does photosynthesis actively...there are abundant chloroplasts’ pigment, chlorophyll.”

(Interview, 27/02/2015, I = Interviewer; S = Student)



**Figure 5.10** Comparison between student's drawings and micrographs. The upper images are Student S4's drawings, whereas the micrographs of multiple choice section are shown by the lower images.

It is apparent from the student's responses and drawings that this respondent tried to replicate the micrographs displayed in another part of the test. As shown in Figure 5.10, all of the student's generated diagrams show great similarities with the micrographs presented in Items 3, 4, and 5 (R-M). Indeed, this fact had been honestly confirmed by the student as indicated in Conversation 68-71. Furthermore, this student apparently did not use any information represented by the photograph in Part 2 of the PADI-I and indeed ignored it. As demonstrated in Figure 5.10 and Quotations 63, 67, and 71, the student generated anatomical drawings of the plant organs that were completely different from the facts represented by the photograph. Indeed, Quotation 67 shows that this participant had recently noticed the mismatch between the created diagram and the displayed plant indicating a neglect of the visual information during the drawing construction.

One possible reason behind this fact is the student's lack of knowledge of both plant morphology and plant anatomy. As italicised in Quotation 73, the student focused on the leaves' colour (M) instead of other identifiable morphological features, such as leaf venation, leading to misinterpretation of the representation that was reflected in

the student's incorrect drawings (R-M). It shows that the student was easily distracted by the superficial characteristic of the image indicating a weak comprehension of morphological principles (C). This fact also implies that the student engaged in surface level reasoning by simply associating the plant's habitat with the leaves' colour without considering the other features of the plant (R-C). Contradicting the student's opinion as indicated by Arial font, in fact, leaves which are exposed to full sun tend to have a lower density of green pigment than those growing in shade (Beck, 2010; Dickison, 2000). Besides, the photograph shows thin and large leaves which commonly characterise a plant growing in a shady environment (Beck, 2010; Dickison, 2000), thus, contrasting the student's interpretation of the plant's habitat (R-C). These facts indicate the student's poor conceptualisation of plant anatomy (C). The unlabelled drawings which are shown in Figure 5.10 also seemed to support this assertion (C).

Interestingly, a similar phenomenon is also apparent in participants who observed the photograph being presented. Because of the limited knowledge of plant morphology, the students focused on a fuzzy morphological feature to determine the group of the depicted plant. A student's response is presented below to illustrate this phenomenon.

74 I : "Why did you think that the plant was monocot?"

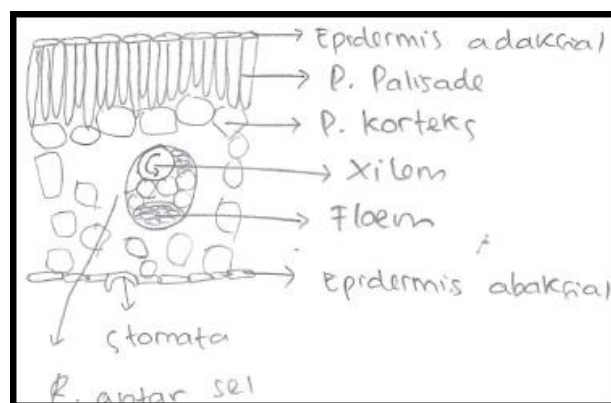
75 S1 : "...*I thought that it [the stem] was soft, the plant was a herb, not a tree. It looked like a monocot...Actually, I just remembered a picture of a leaf when Mr. Daun taught this topic...*"

(Interview, 08/12/2014, I = Interviewer; S = Student)

As italicised in Quotation 75, the student relied on the stem's texture (M) to recognise the plant. Although this respondent correctly identified the plant as a herb (R-M), in fact, the student's focused feature is not a characteristic which will distinguish monocotyledons and dicotyledons (Foster, 1974), because soft non-woody stems can be observed in members of both of the two groups of the plants. As reported by Takhtadzhian (2009), furthermore, dicotyledons include both woody and herbaceous plants, thus, contradicting the student's understanding of monocotyledons (C). This finding shows that the student's knowledge of plant morphology was limited leading to incorrect deductive reasoning, as indicated by the Arial font statement in Quotation 75. In this quote, the student' inappropriate

conception — all herbs are monocotyledon (C) — directed the student to focus only to the texture of the stem in the photograph (M) rather than other more visible features. Because the picture shows the intended characteristic — the stem looks like soft (R-M), the student then applied the conception that she thought to be true to interpret the photograph. However, the student’s interpretation of the photograph was incorrect because the conception that she relied on when interpreting the representation was inappropriate (R-C). The incidents of students’ reliance on a plant’s texture were also observed in interview transcripts. These facts demonstrate the saliency of this graphical characteristic for students in recognising visual representations in plant anatomy.

Unexpectedly, the student’s anatomical drawing communicated different information. As shown in Figure 5.11, this student drew a diagram of a dicotyledonous leaf (R-M), which is inconsistent with the student’s identification during the interview session (see Quotation 75). The discrepancy between the student’s response and drawing demonstrates that this student might be unable to integrate the concepts of plant morphology and anatomy (R-C). As a result, the student just drew an anatomical drawing by relying on visual memory, as is confirmed by the student (see Quotation 75). In fact, the student created a comprehensive drawing with the partial labelling of a dicotyledonous leaf anatomy showing an adequate conceptualisation of this material. Thus, this finding suggests that the primary source of this participant’s difficulty in completing Part 2 of the PADI-I was the student’ inability to integrate knowledge of plant morphology and anatomy.

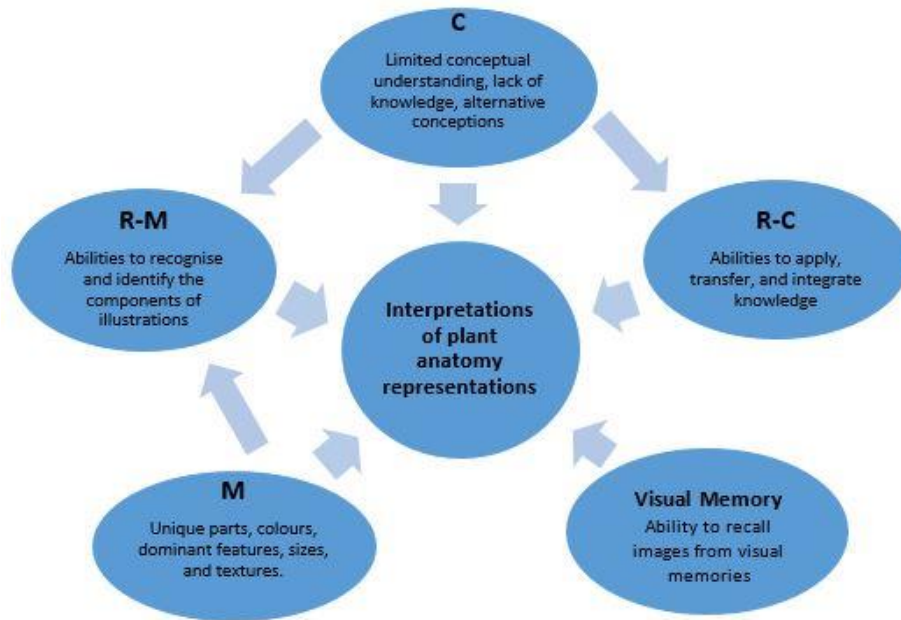


**Figure 5.11** A student's drawing and labelling of a dicotyledonous leaf.

## 5.8 Summary of the Chapter

In response to the second research question, this chapter discussed the way the participants interpreted the photographs in the PADI-I. Based on the analysis, it is recognised that most of the students relied on five graphical features to identify the photographs in this instrument. These components, which are categorised as M-factor, includes distinctive parts, colours, conspicuous aspects, size, and texture. Furthermore, the analysis suggested that the majority of the participants had problems in interpreting the represented objects. As documented in this chapter, the students misidentified the components in the photographs, used unsound deductive reasoning, relied on intuitive awareness and visual memories, guessed the visual representations, and reasoned the depictions superficially.

The primary sources of students' difficulties in interpreting the object being depicted include insufficient identification skills (R-M), limited conceptual understandings (C), lack of knowledge (C), alternative conceptions (C), and inability to apply, transfer, and integrate knowledge (R-C). Each of these factors interact with and affect one another. For example, students' incorrect recognition of a depiction (R-M) leads to the selection of an inappropriate concept (C) resulting in an unsound conceptual reasoning (R-C). However, in most cases, the level of students' conceptual understanding had a great impact on their ability to interpret photographs in plant anatomy. In addition to a direct influence on students' interpretations, this factor affected students' reasoning ability related to concepts (R-C) as well as their ability to reason about the graphical aspects (R-M). Surprisingly, in some cases, these affecting factors can be compromised when students have good visual memories of anatomical structures. In other words, the students' interpretations of photographs in plant anatomy were influenced by not only the CRM factors but also their ability to memorise visual information. Therefore, the findings described in this chapter confirm the initial prediction that the students would have difficulties when interpreting pictures in the test, as stated in Chapter 4. As a brief summary, the content of Chapter 5 is concisely presented in Figure 5.12.



**Figure 5.12** Diagram representing the factors affecting the students' interpretations of the plant anatomy pictures. The directions of arrows show the influence of one factor on another factor.

As recorded in this chapter, the student participants in the current investigation had inadequate ability to interpret visual representation in plant anatomy. According to Eilam (2012), students' difficulties in learning from visual representations may be influenced by instructional aspects. In the following chapter, therefore, the instructors' perspectives of teaching and learning of plant anatomy are discussed to understand to what extent the instructional strategies contribute to students' ability to interpret visual representations in plant anatomy.



# **CHAPTER 6**

## **REFLECTIONS ON PLANT ANATOMY TEACHING AND LEARNING**

### **6.1 Overview of the Chapter**

In order to gain deep insights about students' learning of plant anatomy, two instructors were interviewed, namely, Mrs. Bunga and Mr. Akar (pseudonyms). In these interviews only two instructors were involved because Mr. Daun was very busy when Study 2 was conducted. Their reflections on the plant anatomy teaching and learning are elaborated in this chapter in response to Research Question 3: How do the instructors perceive the teaching of plant anatomy to support undergraduates' ability to interpret visual representations in plant anatomy? Combining instructors' reflections with the researcher's analysis and experiences provides possible explanations of students' difficulties in interpreting visual representations in plant anatomy as reported in the preceding chapters. Beginning with their profiles, in this chapter, the instructors' perspectives of plant anatomy, their teaching practices, and the possible sources of students' difficulties in learning plant anatomy are discussed respectively.

### **6.2 Profiles of Plant Anatomy Instructors**

#### **6.2.1 Profile of Mrs. Bunga**

In 1991, Mrs. Bunga began her career as an instructor in the Biology Department at the state university under investigation. For the first two years, however, she had not concentrated on any particular biology subject because of the university's policy of apprenticeship. As a new instructor, she had to be an apprentice to the senior biology instructors for various subjects, including plant anatomy, plant physiology, mycology, ecology, genetics, and research methodology. In 1993, Mrs. Bunga pursued her master's degree that focussed on plant development because of the home university's request. This demand, fortunately, did not raise any problems for her because she has been interested in botany since the beginning of her career.

Since 1997, Mrs. Bunga has taught plant anatomy with two other senior instructors as a teaching team. She is a good-humoured instructor who often creates jokes to make a two-hour lecture session enjoyable for the students. She also patiently assists students who have difficulties in identifying plant structures under a microscope. The way Mrs. Bunga elaborates a plant structure often generates students' curiosity and enthusiasm towards the object being observed. Following the established teaching approach, she previously had used a teacher-centred model to deliver information to the students. She often combined analogies, gestures, and drawings to improve students' understanding of the concepts being taught. A variety of visual representations, such as line drawings, photographs, and diagrams were also presented to make the lesson understandable.

When Study 2 was conducted, however, Mrs. Bunga has been implementing problem-based learning (PBL) as an alternative strategy to teach plant anatomy courses. The change of teaching strategies was made because she realised that there was no improvement in students' achievement in plant anatomy every semester when the conventional teaching method was implemented. This fact is reflected in the instructors' report (see Figure 4.2) and the results of the PADI-I (see Section 4.2.1). After 17 years of teaching, Mrs. Bunga finally had an opportunity to change the instructional strategy because the two senior instructors had recently retired. As a junior instructor, previously, she had no power to make a change to the established instructional strategy.

### **6.2.2 Profile of Mr. Akar**

In contrast to Mrs. Bunga, Mr. Akar began his teaching career working at a private university for four years. During this period, he concentrated on teaching plant morphology and biotechnology. He was recruited as a new instructor in the state university under investigation in 2014. When he moved to this new environment, he perceived that in the two institutions students' conceptual knowledge were slightly different. According to him, students in the state university were better selected than at the private university. Thus, unsurprisingly, the students' general knowledge was better than their counterparts in the private university. Moreover, he thought that the teaching team strategy in this new environment worked better than that implemented in the previous workplace. Thus, different from the prior teaching experiences, Mr.

Akar received much more support and guidance in this new workplace which significantly improved his teaching practices.

Although he was a new instructor, Mr. Akar could clearly communicate information in front of the class and was confident in doing so. Similar to Mrs. Bunga, he also uses different visual representations including 2D and 3D diagrams, photographs, and line drawings to support students' learning. However, the way he explained plant structures sometimes left questions in the students' minds. His way of explaining might be because of his limited experiences in teaching plant anatomy in the previous workplace where he taught plant morphology and biotechnology.

As a member of a teaching team of plant anatomy, Mr. Akar teaches a particular topic in this unit using a strategy that the team has implemented. Thus, when Study 1 was carried out, Mr. Akar together with Mrs. Bunga and Mr. Daun has been implementing a conventional teaching method to guide the lessons. In Study 2, Mr. Akar then uses PBL approach to follow the change that Mrs. Bunga had been made to the teaching strategy (see Section 6.2.1).

### **6.3 Instructors' Perspectives of Plant Anatomy**

#### **6.3.1 Features of Plant Anatomy**

Plant Anatomy is a botanical discipline that deals with the internal structures of the plant body. The variations of plant anatomical structures can appeal to aesthetic senses of some people, such as botanists (Beck, 2010; Fahn, 1990) and the instructor, as is apparent in the following Mrs. Bunga's expression.

- 1 "...We [the instructor] was so excited with the variation and uniqueness [of plant anatomy] that they [the students] found [during the observation of plant anatomical structure under a microscope]..." (Interview, 28/05/2015).

The quote above shows that Mrs. Bunga could see the aesthetic value of plant anatomy that many people cannot appreciate it (Balding & Williams, 2016; Wandersee & Schussler, 1999). This fact is understandable because she had been working with plant anatomy for more than 17 years and naturally was interested in botany. The extensive experiences with plant anatomy gave the instructor a thorough understanding of this discipline. Based on her understanding, she concluded that plants have simple anatomical structures when she reticulated "...in my opinion,

basically, the structure is one, similar...so the plant is so simple...” (Interview, 28/05/2015). Mrs. Bunga’s statement indicates that learning plant anatomy is not difficult if students can comprehensively understand the fundamental structures of plant organs.

In contrast, Mr. Akar perceived that the variation in plant anatomy can be a source of students’ difficulties in learning this discipline. He explained:

- 2 “...the condition of the specimen was sometimes inconsistent with or did not support the theories...Thus, this was the main challenge in the plant anatomy subject...” (Interview, 28/05/2015).

According to Mr. Akar, learning plant anatomy can be challenging because students’ understanding of plant anatomy that derives from instructions may be distracted by the anatomical variants that students found when observing a real specimen (see Quotation 2). The impact of the variations in plant anatomy on students’ learning is further discussed in Section 6.5.1. When compared to Mrs. Bunga’s perspective of plant anatomy, Mr. Akar’s consent about the variation in plant structures seemed to be caused by his limited knowledge and experiences in teaching this discipline (see Section 6.2.2). In fact, the variation in anatomical structures because of developmental and environmental factors are presented and discussed in many plant anatomy textbooks (e.g., Cutler et al., 2007; Dickison, 2000; Esau, 1965).

### **6.3.2 The Assumption of Plant Anatomy Knowledge**

It is commonly believed that plant anatomy is static knowledge. The anatomical structures of plants are considered to be stable and well understood (Beck, 2010; Cutter, 1978). As explained by Esau (1965), for example, the orientation of primary xylem maturation is a distinctive feature to distinguish an anatomical structure of a stem from a root’s anatomy. In fact, this concept is still accepted and indeed reproduced in recent plant anatomy textbooks (see Beck, 2010; Cutler et al., 2007). This phenomenon is also confirmed by Mrs. Bunga’ which is apparent in her interview responses, as follows:

- 3 “...you can see in the current textbooks; they did not raise any new concepts. The main ideas are the Esau’s [concepts]...So, the basic principles have not changed since the twenties...” (Interview, 28/05/2015).

It is obvious from the instructor's explanation that the details of plant anatomy are commonly accepted to have been well established and that no further investigations are required to re-examine the accuracy of the existing concepts. In fact, recent experiments on plant anatomy have revealed new facts that slightly deviate from the existing theories. Jung et al. (2008), for example, observed that aerenchyma can be found in both aquatic and non-aquatic plants of the same genus. This finding is contrary to the common understanding that this structure is a unique characteristic of aquatic plants (Esau, 1965). The two instructors' explanations during the lecture sessions (see Quotations 4 and 5) also showed that the instructors still relied on the existing Esau's (1965) concept of aerenchyma.

- 4 Mrs. Bunga : "...this unique structure—aerenchyma—can be found in plants living in water. Lotus and Water Hyacinth will have this structure, although the shape [of aerenchyma] may be different..." (Observation, 06/10/2014).
- 5 Mr. Akar : "Sometimes, in submerged roots, we can find aerenchyma...This [structure] is a characteristic of aquatic plants..." (Observation, 04/11/2014).

From the results of observations, it is apparent that the instructors associated aerenchyma with aquatic plant species. This information may result in students' misinterpretation of the function of this structure. Rather than facilitating internal gas exchange, students may erroneously think that the aerenchyma functions to store water, as was evident in their responses to the PADI-I (see Table 4.6, Number 4). In fact, this tissue is also developed in terrestrial plants and has a great importance in drought tolerance (Zhu et al., 2010).

The assumption that the knowledge of plant anatomy is static seems to direct teaching toward a conservative mode. Consequently, plant anatomy is regarded by students as a dry and boring subject (see Quotations 10 and 11 in Section 6.4.1). To overcome this problem, inquiry learning has been highly recommended by many botanists as an alternative teaching strategy. Further explanations about the plant anatomy teaching approaches that the instructors have implemented and the consequences are discussed in the next section.

## 6.4 Teaching Strategies for Plant Anatomy

### 6.4.1 Conventional Teaching Strategy

For a long time, plant anatomy has been traditionally taught using a traditional, didactic approach. This teaching emphasises extracting basic concepts and principles, without mentioning any application of the concepts being taught (Brosi & Huish, 2014; Cutler et al., 2007; Troughton & Donaldson, 1972). This strategy, as reported by Timmerman et al. (2008), is considered to be sufficient to develop students' understanding of plant structures. A similar situation has also occurred at the university under investigation. Based on the researcher's experience as a biology student, the plant anatomy courses had adopted the teacher-centred strategy for many years. This discipline was designed to focus on content without any connection to function and adaptations to habitat. This fact is reflected in an instructor's opinion of the diagnostic instrument:

6 "...when constructing a test about the understanding of plant structure in relation to pictures, I suggest you ask only about the structure. Do not ask the function because **the plant anatomy does not teach about the function, especially, how the organs work...**"

(Written comment received on 21/04/2015).

The highlighted part of Quotation 6 clearly shows that the instructor separates plant anatomy and physiology although the two aspects are intimately interrelated to each other. The instructor, in the researcher's view, tended to teach basic principles of plant anatomy by only cataloguing and demonstrating the general plant structures. Consequently, as evidenced in Sections 5.4 and 5.5, the students could identify the depicted object accurately but struggled to explain the roles of the represented plant components. This finding indicates that the students' knowledge was limited only to the plant's internal structural arrangement. Moreover, during laboratory sessions, students were required only to repeat the content that had been studied by observing the actual plant structure under a microscope. The students were not involved in any activity which encouraged them to think about the relationship between habitat and anatomy, for example.

In fact, these didactic approaches to teaching were confirmed by Mrs. Bunga when she articulated,

7 “...from what I was learning until what I was teaching [plant anatomy], the pattern was the same...the basic concepts needed to be memorised... There was no explanation related to other things. Besides, during the practicums, students were asked to find this and this [plant components]. Thus, they just looked for them [the plant components], but they did not know why they [the components] were there... *I actually did not like to see that* [the way the plant anatomy was taught] as a fixed thing” (Interview, 28/05/2015).

Concurring with the researcher's perceptions, Mrs. Bunga reflected that the established teaching strategy which she and the two other instructors had implemented tended to centre on rote learning (see the highlighted part in Quotation 7). The lesson relied heavily on memorisation of content without any further elaboration. The hands-on activities were also constructed under a similar approach. The students identified plant components by matching the appearances of specimens to those shown in textbooks without understanding the roles of the observed components.

As italicised in Quotation 7, in fact, Mrs. Bunga was dissatisfied when observing these situations. She tried to apply a new method of teaching because she perceived that the previous conventional strategy was no longer relevant to plant anatomy teaching. Instead of increasing students' understanding, the didactic approach had hindered students' learning, as she revealed below.

8 “Previously, most students saw the plant anatomy as a “scary subject”... Many students failed to complete this subject because I saw students studied the content as a fixed price. **It means these [the concepts] had to be memorised without any elaboration, thus, it [the subject] was difficult for them.**... Students were required to memorise phenomena [of plant structures] that depend on many aspects. Consequently, students did not understand [the material], they were confused. It [this condition] was fatal...” (Interview, 28/05/2015).

From Mrs. Bunga's comment to the interview, it is evident that the primary factor leading to students' difficulties in learning plant anatomy was the implemented rote learning strategy. As highlighted in Quotation 8, Mrs. Bunga argued that memorising information was hard for students without a sufficient understanding of the context. Indeed, the anatomical facts were highly contextual which means the anatomy of closely-related plant species may be dissimilar because of the different habitats they occupy. In other words, without a solid conceptual knowledge, students will struggle to memorise and understand the variety of plant structures. It is understandable, as warned by Brosi and Huish (2014), that the memorisation-based learning caused

students' long-term memory of the learned information to be weak and easily forgotten. This condition had resulted in the students' low performance on plant anatomy, as communicated by Mrs. Bunga (see Quotation 8) and reflected in the results of the PADI-I in Section 4.2.1.

In addition to poor conceptualisation, Mrs. Bunga added that this traditional instructional method might lead the students to incorrectly memorise the learned information. She explained this phenomenon in the following quote.

- 9 “I often saw, for example, on the topic of stem development taught by another lecturer, there was a term of metamorphosis. The students were asked to answer a question [related to the metamorphosis]. They had already known that it [the question] was related to the plant morphology, but they provided an explanation about animals' metamorphosis. This [fact] was a sign that the students could not sort [the information], then confused to put [the information] in their memory because they just memorised [the information], there was no elaboration. So, the scores were too bad. Thus, the additional explanation is critical to support [understanding of] the concepts...” (Interview, 28/05/2015).

The quote demonstrates another shortcoming of rote learning. As illustrated by Mrs. Bunga, the over-reliance on memorisation paved the way for disorganised information in the students' memory. As a result, the students may have inappropriately used a concept from one phenomenon to another which has similar attributes. In addition to the fact shown in Quotation 9, the similar incidents were reported in Chapter 4 (see Section 4.6b) and Chapter 5 (see Sections 5.5). This condition seemed to contribute to the students' unsatisfactory achievements in plant anatomy, as expressed by Mrs. Bunga (see Quotation 9) and also shown in the two preceding chapters of this thesis.

Unsurprisingly, the criticism of the teacher-centred approach to the teaching of botany has been very clearly expressed (Hershey, 1996; Quave, 2014). In addition to its adverse impact on students' memory and knowledge, this teaching style has compromised students' learning enthusiasm toward this discipline (Brosi & Huish, 2014; Hershey, 1996; Uno, 2009). A similar situation was also perceived by the instructors as shown by the following expressions:

- 10 Mrs. Bunga: “...students thought that there was no story behind the plant anatomy... Anatomy was static, consequently, it [the subject] was not interesting [for



the students]. They [the students] did not know what the function of learning this [plant anatomy]” (Interview, 28/05/2015).

- 11 Mr. Akar : “...When they [students] were required to learn the theories by only comparing the pictures of the secondary and primary growths, a root and a stem, they seemed bored” (Interview, 28/05/2015).

Those quotes demonstrate the fact that most students had low motivation to learn plant anatomy because of the didactic instructional method. As expressed by Mrs. Bunga, the absence of a connection between theories and real-life contexts made the students struggle to find a future application of the learned information leading to the students’ lack of curiosity about this subject (see Quotation 10). Indeed, the students thought that plant anatomy was a dull and uninteresting course because of the uninspiring learning tasks they were required to complete (see Quotation 11). These facts were also observed by Cutler (1978) and Hershey (1996) showing that this problem was recognised a long time ago.

#### **6.4.2 Inquiry Learning**

To generate students’ interests toward learning plant anatomy, the use of inquiry-based instruction is highly recommended (Brosi & Huish, 2014; Uno, 2009). Different from the conventional strategy that emphasises the lower levels of Bloom’s Taxonomy, this approach provides students with opportunities to develop critical thinking while gaining understanding of basic concepts (Brosi & Huish, 2014). Through student-centred activities, students are expected to be self-motivated and independent learners who can gain experiences that are beneficial for their future life (Uno, 2009). Using the similar reasons, as seen in the following quotation, Mrs. Bunga decided to implement problem-based learning (PBL) as an alternative approach to teach plant anatomy at the same time when Study 2 was conducted (see Section 6.2.1).

- 12 “...[Previously, the teaching] did not connect to the phenomena, did not require logical thinking. When [the teaching] was related to [those aspects], it will be useful and improve students’ memory. Thus, it was the underlying reason [for implementing the PBL strategy]. Besides, I viewed that students need modelling for their future. When they are working related to it [plant], it [the information about plants] can be extracted fast from their [students’] experiences [PBL activities]...” (Interview, 28/05/2015).

Based on Quotation 12, Mrs. Bunga expected that the students' would receive at least two major benefits from the implementation of the PBL method. The first was an increase of students' retention of the learned concepts. It was understandable because the nature of a PBL activity which focused on authentic problems would encourage students to understand the material more deeply to find a solution to the problem, leading in turn to a better conceptual memory (Albanese & Mitchell, 1993). The second was giving the students experiences that would be useful in their future life. In line with Mrs. Bunga's explanation, Herrington et al. (2010) contended that students' involvement with real-life related tasks would provide meaningful and accessible knowledge when the students face a problem within a similar context.

Mrs. Bunga's decision to implement the PBL approach was appropriate. As reported by Yoon, Woo, Treagust, and Chandrasegaran (2014), this instructional strategy had successfully developed students' life skills including creative thinking, self-regulated learning, and self-evaluation. By contextualising learning, moreover, students have opportunities to build a sound understanding of concepts being learned (Chu & Treagust, 2014). Chu and Treagust (2014) further explained that each challenge that students face in different contexts contributes to the development of consistent conceptions. Supporting Mrs. Bunga's assertion, thus, such context-based teaching is promising to improve students' future learning of plant anatomy.

In addition to the expected advantages of the PBL strategy, Mrs. Bunga anticipated that students' appreciation of plant structure, which was previously absent, can be generated. She identified this aspect by evaluating the level of students' curiosity of plant anatomy as expressed in plant anatomical problems that the students created. After the implementation of PBL, Mrs. Bunga observed that many students were now better able to appreciate the significance of the fine details of plant anatomy. She reported:

13 "...So far, approximately 60-70% of students can appreciate what they have done... It means they [students] understood the uniqueness [of plant structures under observation] and were able to emerge new ideas [related to the phenomena] for their advance studies [projects or thesis]..." (Interview, 28/05/2015)

The students' capability to construct advanced ideas, as highlighted in Quotation 13, indicated their curiosity and interest in the details of plant anatomy. Despite being a

part of the learning task, in fact, the students would have difficulty to create these ideas without having an increased motivation to learn (Brosi & Huish, 2014). Thus, according to Mrs. Bunga, the newly implemented instructional approach had successfully increased the students' desire to learn this subject (see Quotation 13). This assertion was confirmed by Mr. Akar who has also implemented this new teaching method to the topic he taught (see Section 6.2.2). He expressed:

14 "...when they [the students] just observed primary roots, secondary roots, and the differences between both [the primary and secondary roots], they looked so exhausted...But when it was changed, they faced the real-life problems, were trained to analyse and diagnose the cause [of the problems], and viewed the real condition, they become more interested and enthusiastic. I observed that the learning times were not enough, they asked more..." (Interview, 28/05/2015)

It is evident from Mr. Akar's reflection that PBL was able to generate students' learning enthusiasm towards plant anatomy when compared to the traditional teaching strategy that was previously implemented. As highlighted in Quotation 14, indeed, the provided authentic problem maintained the students' engagement with the task beyond the allocated time. This finding indicates the students' enhanced levels of curiosity and interest generated by their participation in the PBL activities. A similar finding was also reported by Brownell, Kloser, Fukami, and Shavelson (2012) when comparing the cookbook-style and authentic research-based biology laboratory tasks.

Although this new approach has successfully facilitated the instructors to be able to reach their main goal — increasing students' motivation to learn plant anatomy — the PBL approach was not free from weaknesses. The following quote illustrates a problem that Mrs. Bunga identified during the initial implementation of the PBL method.

15 "The result of the authentic [phenomena-based test] was good, they [students] could explain [the phenomena], but when they [student] were asked about the basic concepts, it was silly, they [students] were silent. I was surprised. [For example], they [students] could explain [the reason behind] the various colours [in plants], [the colours were present] because of the difference of pigments inside the plastids. However, when they were asked, what plastid was. They did not know. Thus, they had difficulty defining the basic concepts..." (Interview, 28/05/2015).

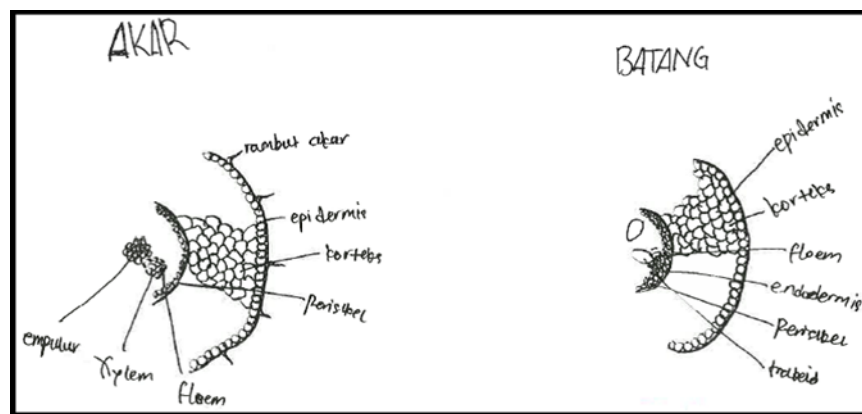
Starting with the pure and unguided PBL, Mrs. Bunga found that many students struggled to comprehend the basic principles of plant anatomy. The highlighted part of Quotation 15 shows that the students were unable to extract the underlying ideas from the contextual information of the phenomena. This finding certainly contradicts with the primary purpose of the PBL. Barrows (1985), a pioneer of PBL, argued that by solving real-life problems students will learn both the problem-solving skills and basic science knowledge at the same time.

Interestingly, a similar phenomenon was also reported in the researcher's previous investigation (Susiyawati et al., 2015). The researcher observed that most students performed well on the authentic tasks, but their mastery of basic plant anatomy concepts was low. Albanese and Mitchell (1993) in their review of PBL in medical education also revealed the same finding. They found that PBL students outperformed on clinical evaluations but were less prepared for basic science examinations than their counterparts who were taught using the conventional method. According to Albanese and Mitchell (1993), the result was understandable because the PBL students were highly exposed to clinical problems but less exposed to the content. Concurring with this explanation, the researcher observed that the students tended to focus only on a particular plant component during the PBL activities, while the time spent on content knowledge was limited. Consequently, their understanding seemed to be highly context dependent. In fact, this shortcoming was also realised by Mrs. Bunga, she expressed:

16 *"They were confused between the root and stem. It was apparent from the way they put [the terms]...but they could identify each tissue which supported an organ...unlike previously, I did not give the basic concepts firmly...they searched everything by themselves, solving the problem [by themselves]. They had not comprehended the core principles yet, but they saw a lot of variation [of plant structures], so [their difficulties] became double... It was the first [reason]. The second [reason] was the lecture dynamic. Students seemed not to have enough time, so I thought it was necessary that there was a point in which they [students] contemplated all information they received... After that, they move to the new concepts. They missed this opportunity..."* (Interview, 28/05/2015).

Concurring with the researcher's perspective, Mrs. Bunga also observed the students' weaknesses in comprehending the underlying principles of plant anatomy. As italicised in Quotation 16, she found that the students incorrectly recognised the parts of a root as the stem's components. This phenomenon was also captured in the

students' drawing in response to Part 1 of the PADI-I. As shown in Figure 6.1, the student erroneously labelled some components of a stem as tissues that typically occur in a root, namely, endodermis and pericycle; but the endodermis which should be present in the root was absent in the diagram of a root. Section 4.6b also illustrated the other phenomena of students' errors that were constructed using the similar mechanism. For example, students incorrectly memorised a concept of monocotyledonous roots when interpreting a dicotyledonous stem. These mistakes indicate the students' disorganised knowledge which was also apparent when the instructors implemented the didactic instructional approach (see Quotation 9).



**Figure 6.1** Students' plant anatomical drawings. Akar means a root, whereas batang means a stem.

In contrast to the traditional method of teaching which led to students making errors because of the limited elaboration, Mrs. Bunga identified two primary reasons behind the students' incorrect understanding of plant anatomy concepts (see Quotation 16). Firstly, the limited scaffolding of content knowledge at the beginning of the lesson made the students struggle to extract the underlying principles of the phenomena which varied from one to another. Secondly, the students had not enough time to build sufficient understanding of the information they received during the PBL activities, leading to the construction of ill-organised knowledge.

To overcome this problem, in the next topic Mrs. Bunga used a modelling strategy as a cognitive scaffold for improving students' comprehension of the underlying concepts. This change is illustrated in detail in the following quotation.

- 17 "Since the first topic, we let students free [to create their own problems], so, there were a lot of variations [of students' understanding]. Consequently, only a few students could

complete the task. After [the activities were] too broad several times, finally, I slightly changed [the lesson plan]. I tried to control the first sessions... I asked the students to bring the dicots-monocots. **When they came [to the class], in fact, their dicots-monocots also varied each other.** Thus, *I concluded that the starter specimen needed to be mentioned specifically, plant A, plant B. Then, they were required to analyse and compare [the structures of dicots-monocots]... Thus, in the beginning, they also observed, identified, and presented [their observations] in front of the class.* In other words, the basic concepts [were received] by self-observation. They [the concepts] were not only theories. If they [the students] relied only on [general] theories, **they would be confused because [the general theories] were different from the facts...** I just want to change so that anatomy is not just rote learning” (Interview, 28/05/2015).

The quote above describes the change that Mrs. Bunga had made to improve students’ understanding of plant anatomy. The unsatisfactory results seen from the use of the pure and unguided PBL (see Quotation 16) encouraged Mrs. Bunga to make a significant change to this current approach. As italicised in Quotation 17, rather than exposing the students to authentic problems, Mrs. Bunga directed them to learn the general anatomical structure through observation at the beginning of the lesson. In fact, this modification was contrary to the basic outline of the PBL which emphasised the problem as being the starting point (Barrows, 1985). However, Mrs. Bunga’s decision to slightly modify the application of PBL instructional approach was understandable. Instead of sacrificing students’ conceptual understanding, a small amount of guidance in advance of a lesson may provide a valuable direction for students (Srinivasan, Wilkes, Stevenson, Nguyen, & Slavin, 2007) to learn plants’ body which has variations in anatomical structures. As highlighted in Quotation 17, Mrs. Bunga communicated that sometimes the real specimens revealed facts that deviated from common concepts in plant anatomy leading to misinterpretation of the objects being observed. These facts indicate Mrs. Bunga’s passion for providing students with meaningful learning experiences of plant anatomy.

From the instructor’s reflection, the complexity and complication of the implementation of the PBL can be seen clearly. A lot of effort and time has been devoted by the instructors to support and improve students’ learning. However, the implementation of new teaching approach was not working smoothly as evidenced by students who still experiencing difficulties when learning plant anatomy using this alternative teaching strategy. Based on the instructors’ interview responses, the

possible sources of students' learning difficulties in plant anatomy are discussed in the next section.

## **6.5 The Possible Sources of Students' Difficulties in Plant Anatomy Learning**

### **6.5.1 The Variation of Plant Anatomical Structures**

Plants are highly variable in anatomical structure, even within an individual. Those variations result from growth processes, environmental changes, or evolutionary developments (Dickison, 2000; Schweingruber, Říha, & Doležal, 2014). The variability in plant structure provides substantial justification for studying plant systematics, evolution, physiology, and ecology (Dickison, 2000), in addition to generating an aesthetic sense (Fahn, 1990).

For novice students, in contrast, the variety of anatomical structures may be problematic. Students may observe that real specimens possess anatomical structures that were different from common concepts they have been studied, leading to misinterpretation of the object being observed. This fact was confirmed by the instructor and student, as shown in the following expressions:

18 Mr. Akar : "... The condition of the plant anatomy subject that frequently became the source of students' difficulty...was that the theories were sometimes different from the facts in a real situation...when we let students choose their own specimen, the condition of **the specimen was sometimes inconsistent with or did not support the theories**. Moreover, when the plant anatomy was connected to the environmental issues, then, there were many things [variations] that can be found by the students. Thus, this was the main challenge in the plant anatomy subject..." (Interview, 28/05/2015).

19 Student : "...usually the conceptual understanding received during the lecture session was slightly unstable when it was applied to the laboratory sessions. I was still confused. I could understand the material during the lecture session, but **when I did an observation of real specimen sometimes the appearance was different and not as pretty as shown in the lecture session**" (Interview, 08/12/2014).

It was obvious from the responses that the variation of plant structures was one of the sources inhibiting students' learning of plant anatomy. As highlighted in Quotations 18 and 19, both the instructor and student found that real specimens often showed

anatomical structures which deviated from those that had been taught in the classroom. As mentioned by Mr. Akar, the environmental changes seemed to be the primary source of the variation in plant structures. It is understandable because plants cannot escape from the unfavorable conditions, thus, structural adaptations play an important role in the plant's survival (Dickison, 2000). However, this fact had led to students' confusion in understanding plant anatomy concepts (see Quotation 19).

Students' misinterpretation of the photograph showing the variation of plant anatomical structures in Item 2 of Part 1 of the PADI-I (see Figure 5.2) provided supporting evidence of the aforementioned finding. The percentages of students who selected each option in Tier 4 of Item 2 of the PADI-I are presented in Table 6.1. As shown in Table 6.1, 45% of the participants, which exceeds the percentage of students who correctly selected the answer, misinterpreted the images in Item 2 as a root instead of a stem. This incorrect interpretation seemed to result from the unusual structure of vascular bundles in the depicted plant. Different from the majority of dicotyledonous group of plants which possess only one cylinder of vascular bundles in the stems, this plant develops vascular bundles which are arranged within two different rings resembling the radial pattern of vascular bundles in a root. As explained by Beck (2010), this structural variation is common in tropical climbing plants.

**Table 6.1** *Students' Responses to Tier 4 in Item 2 of PADI-I*

<b>Option</b>	<b>Statement</b>	<b>Percentage of students</b>
A	The organ has well-developed vascular bundles in which the xylem and phloem are arranged alternately and develops root hairs at the outermost layer.	45.6
B	The organ has abundant ground tissues which contain starch grains.	5.1
C	The organ is surrounded by supportive tissues which contain lignin.	5.1
★ D	The organ has well-developed vascular bundles in which the xylem is located in between the outer and inner phloem.	43.0
E	I do not know.	1.3

Note: The star symbol [★] indicates the correct answer.



Contrary to the aforementioned facts, six decades ago Eames and MacDaniels (1947) suggested exposing students as much as possible to the variation of plant anatomical structures. According to these botanists, observation and interpretation practices facilitate students to acquire a thorough understanding of plant anatomy. Thus, the detrimental effect of the variations in plant structure seems to be only experienced by novice students. As students' knowledge has been established, the variation in plant structure may be seen as an interesting feature to be investigated further. This fact was clearly articulated by Mrs. Bunga.

20 "...the emphasis on the basic principles, I felt it was not enough. I had already let students go too far to surf, find the variations...students' [comprehension] was not yet stable and strong. For the lecturers, [in contrast], the more variations, the more interesting...but for them... [for example], there are bulliform cells. It is a variation because it [the leaf] need to be able to roll so the cells are differentiated, their turgor pressures are changed, so there are bulliform cells. It is just a variation." (Interview, 28/05/2015).

From the quote, it was apparent that the students' inadequate conceptual understanding was the primary reason behind their difficulties in learning plant anatomy. As expressed by Mrs. Bunga, the limited scaffolding at the beginning of the lesson resulted in the students' lack of knowledge of basic plant anatomy. Consequently, the students struggled to interpret the unusual anatomy that they found during their observations. The students were unable to understand that the presence of distinctive components was only an adaptive variation to support the plants in particular circumstances (see Quotation 20).

The student's concern about the variety of anatomical structure might result from the lack of appreciation of the fact that all parts of a plant are intricately interconnected. The students' lack of understanding about this fact may be caused by the way the instructors taught the plant components. Instead of emphasising the interrelationship between plant elements, the instructors tended to explain each plant part separately. The impact of the division of plant parts on students' conceptual understanding of plant anatomy are a focus of the next section.

### **6.5.2 The Division of Plant Organs**

Mrs. Bunga argued that fundamentally the basic anatomical structure of any plant is similar (see Quotation 21). Each organ has similar structures from the outer toward

the inner layers—a view based on the theory communicated by Esau (1965) in which she mentioned that the vascular plant body is only composed of the dermal, ground, and vascular tissue systems. However, most students saw the arrangement of plant parts differently. As recorded in Quotations 4 and 5 (Section 4.2.3), the students thought that recognising the anatomy of a leaf was easier than identifying the components of a stem or a root which look similar. Responding to the students' perspectives, Mrs. Bunga explained:

21 "...in my opinion, basically, the structure is one, similar... they [students] thought that leaf is different because the structure, the shape is flat, whereas the root and stem are cylindrical... [The organs are] different because of the location, but the basic structure is same... When the students can understand and conclude [toward this principle]... [it will be] easy... so the plant is so simple. Students had difficulty [to understand the content] because [they were not] able to connect and integrate the structures of the root, stem, and leaf, where the connection point is, they did not know..." (Interview, 28/05/2015).

The instructor's response in Quotation 21 implies that the possible source of students' difficulties in understanding the underlying concepts of plant anatomy was the division of the plant body into root, stem, and leaf. As communicated by Mrs. Bunga, this separation made the students view the plant organs as three separate components rather than as interrelated parts which are distinct because of their different positions in a plant's body. This finding seemed to provide a convincing reason behind the fact that the two different teaching strategies still resulted in the students' insufficient conceptual understanding. In fact, during the implementation of the two instructional approaches, the instructors still taught plant organs separately. This condition made the students struggle to capture the simplicity of basic plant structure (see Quotation 21). Thus, in spite of its useful purpose for research and in-depth discussion (Esau, 1965), such division of plant anatomy into the separate components of root, stem, and leaf leads to the detriment of students' understanding that the plant elements are actually intimately interconnected (Troughton & Donaldson, 1972). To direct students toward this conclusion, it is necessary to emphasise from the beginning of the lesson that a plant is a highly integrated organism. To the researcher's knowledge, there is no educational research that has focused on the use of this teaching strategy. Further research is necessary to investigate this assertion.

As has been discussed in the preceding section, the variation of plant structure and the division of plant organs had contributed to students' difficulties in understanding the basic principles of plant anatomy. Students' problems with conceptualisation had adverse impact on their ability to interpret visual representations in plant anatomy as reported in Chapters 4 and 5. In fact, the interpretation of visual representations is affected not only by an individual's existing knowledge, but also the object being interpreted. In plant anatomy, specimens are commonly used as objects of interpretation. To what extent the complexity of specimen of plant anatomy influences students' interpretation skills are discussed in the next section based on the instructor's perspectives.

### 6.5.3 The Complexity of Specimen of Plant Anatomy

For learning plant anatomy, students are commonly exposed to two-dimensional (2D) specimens either in cross or longitudinal sections that are derived from three-dimensional (3D) plants' components. According to Eilam (2013), constructing understanding of 3D structures from 2D objects or representations may be problematic for students, especially for those who do not have sufficient skills and knowledge about graphic conventions (Gilbert, 2005). This issue is also mentioned by Mrs. Bunga during the interview. She articulated:

22 "...when looking at specimen [of plant anatomy], we see three-dimensional phenomena in two-dimensional forms so students need to be able to predict if the position [of a plant component] looks like this [in 2D form], how it [the plant component] should look in a 3D intact plant..." (Interview, 28/05/2015).

The quotation in 22 indicates that interpreting specimens in plant anatomy may be complex. Unlike interpreting an intact plant which relies only on perceptions, the interpretation of plant anatomical specimen requires ability to translate from 2D to 3D forms. Therefore, Mrs. Bunga suggested the importance of ability to construct 3D mental model from 2D specimen for learning plant anatomy (see the highlighted part in Quotation 22). Without this ability, students may incorrectly interpret plant components being observed because 3D structures appear differently in different 2D dissection orientations. In fact, a student participant in the current investigation found that such activity was difficult, as is evident in the following quote:

23 “I cannot identify this plant [the photograph in drawing test of the PADI-I] because it is a two-dimensional image. It will be different if it [the plant] in a three-dimensional [form], I will be able to recognise [the plant] because I can see the real stem...” (Interview, 08/12/2014).

Quotation 23 clearly shows that this student was unable to imagine the real plant based on the flat visual representation being presented (see Figure 5.8). Consequently, the student struggled to interpret the plant being represented, although the plant’s features are obvious for other students (see Section 5.7). This finding supports Mrs. Bunga’s assertion in Quotation 22.

In addition to the dimensional aspect, interpreting specimens of plant anatomy may be difficult without adequate skills in using a microscope because observations of these specimens rely on this device. This argument is supported and elaborated by Mrs. Bunga in the following quote.

24 “...it will be more complex because it is impossible to get specimens with one layer thickness using hand dissections. Consequently, students need to be competent in using a microscope to find a correct focus of observation. Without these skills, they [students] will misinterpret the objects...they [students] saw the cell walls are double, in onion cells the nucleus was in a vacuole. It [the nucleus] is just a shadow from cells in the lower layers...” (Interview, 28/05/2015).

Mrs. Bunga’s explanation in Quotation 24 shows that the thickness of specimens in plant anatomy can cause a problem for observation practices. It is understandable because an optical microscope that is commonly used in plant anatomy courses relies on lights for its function. Therefore, only transparent and thin specimens can be clearly seen under this device; a thick specimen will appear as a dark object because it blocks the lights. In fact, making one layer transparent specimens of plant anatomy is difficult using only hand dissection (see Quotation 24), a special tool, such as a microtome, is required for this purpose (Cutler et al., 2007). Specimens with few layers of tissues can still be observed under a light microscope by adjusting a microscope’s contrast, focus, and resolution indicating the importance of these skills for plant anatomy learning (see Quotation 24).

However, observing multilayers specimens of plant anatomy may be problematic for students with an inadequate ability to use a microscope leading to incorrect interpretation of the object being observed. As illustrated by Mrs. Bunga (see the

highlighted part in Quotation 24), students misinterpreted that cell walls are double and the location of a nucleus was in a vacuole because of the overlapping tissues in multilayers specimens. A corresponding phenomenon is also evident in a student's response to the interview (see Quotation 19) implying that this student might not be able to use a microscope appropriately. This finding indicates that students' skills in using a microscope needs to be strengthened before learning plant anatomy.

## **6.6 Summary of the Chapter**

Based on the reflections of the instructors, the researcher, and the students, it is suggested that insufficient understanding of basic plant anatomical concepts was the primary source of students' difficulty in learning plant anatomy. This finding, thus, supports the facts recorded in Chapters 4 and 5. Although the change of instructional strategy had significantly increased students' learning enthusiasm, in fact, most students still struggled to apply their knowledge of plant anatomy to solve relevant problems about anatomical structures. This phenomenon was also reflected in students' performances on the PADI-II and the PADI-III when the new teaching strategy was implemented. Division of plant elements during teaching using both conventional and PBL instructional strategies seemed to be a major reason behind the students' difficulty in applying their knowledge. The separation of plant components may hinder students' comprehension of a fundamental principle that a plant is a highly integrated organism. Without an understanding of this core concept, students' interpretations of plant anatomical structures may be inappropriate. The complexity of specimens of plant anatomy can also be another factor causing students' difficulty in interpreting materials in plant anatomy. Sufficient skills in constructing 3D mental models from 2D structures and using a microscope are required to be able to successfully observe and interpret specimens of plant anatomy.

In the next chapter, the answers to each research question addressed in the current study will be summarised. The possibility of further research studies based on the findings of this study are also considered.

# **CHAPTER 7**

## **DISCUSSIONS, CONCLUSIONS, AND IMPLICATIONS**

### **7.1 Overview of the Chapter**

The purpose of Chapter 7 is to tie together and conclude the analysis of the results that have been presented in the previous three chapters (Chapters 4, 5, and 6). Focusing on the major findings, the answers to each research question are discussed as a basis for making conclusions from this thesis. Some of the limitations of this study that need to be taken into account are also outlined. Finally, the recommendations of this research are presented in the later part of this chapter.

### **7.2 Major Findings, Discussions, and Conclusions**

As outlined in Chapter 1, this investigation was driven by three research questions. Now, the major findings of this study are discussed under each research question.

#### **7.2.1 Research Question 1**

Research Question #1 “*What is the extent of undergraduates’ conceptual understanding of plant anatomy concepts?*” aimed to obtain information about the level of students’ comprehension of basic principles in plant anatomy that potentially affected their ability to interpret visual representations in plant anatomy. Relying on students’ responses to tests and interviews, the undergraduates’ conceptualisation of plant anatomy is elaborated in Chapter 4.

Major findings of Chapter 4 are listed below:

- The students’ performances on the three different instruments were low.
- The students hold misconceptions in plant anatomy.
- The students’ knowledge of plant anatomy remained inert.
- The students’ insufficient conceptual understanding of plant anatomy may cause difficulties when the students interpret visual representations in plant anatomy.

As revealed in Chapter 4, most of the three groups of students who studied plant anatomy in the three consecutive semesters experienced difficulties when completing

the three different formats of diagnostic instruments. This finding shows that the majority of the undergraduates who were involved in the current investigation had an insufficient conceptual understanding of the basic principles of plant anatomy. Interestingly, students' lack of understanding of plant anatomy concepts was also reported in the researcher's previous study (Susiyawati et al., 2015) which was conducted in the same university where the current investigation was carried out. Furthermore, the plant anatomy instructor who involved in the current investigation revealed a corresponding phenomenon (see Section 6.4.1). Thus, these facts suggested that the majority of students who studied plant anatomy in the university under investigation had difficulties to learn this subject to the expected level of proficiency.

The students' insufficient conceptual understanding of plant anatomy was also reflected in their misconceptions. Table 4.6 listed 27 misconceptions of plant anatomy that the students hold when completing the three diagnostic instruments. A similar misconception — “Cell wall is the most visible feature of a plant cell” — was reported by Topsakal and Oversby (2012) in a study using drawings and interviews as diagnostic tools. Students' misconceptions that were captured in the current investigation occurred because of surface-level reasoning, inappropriate transfer, narrow understanding, incorrect application of concepts, and superimposing concepts (see Section 4.6).

The five reasons for students' misconceptions in plant anatomy may indicate students' inert knowledge. Although students had studied basic concepts and theories of plant anatomy, they still had difficulties in applying their knowledge to solve relevant problems as presented in the instruments. The available knowledge seemed applicable only for instructional contexts but inaccessible for authentic problem solving (Herrington et al., 2010; Renkl, Mandl, & Gruber, 1996). Furthermore, Renkl et al. (1996) proposed three explanations underlying the phenomena of inapplicable knowledge, namely metaprocess, structure deficit, and situatedness. The findings of this investigation can be best explained using structure deficit explanation instead of either metaprocess which focus on non-cognitive factors (e.g., motivation and interest) or situatedness that emphasises the dynamic relationships between individual and contexts. According to the structure deficit explanation, one of the underlying causes of the inert knowledge is an individual's deficient understanding

of the knowledge itself that results in unavailable relevant components to be applied. This assertion is reflected in the five reasons of the students' misconceptions. The phenomena of inert knowledge resulting from a lack of conceptual understanding have also been observed in several educational studies. For example, Wang (2004) captured a misconnection between concepts of photosynthesis and plant transport in students' response to a diagnostic instrument because of their deficient conceptualisation. Besides, students' misconceptions of topics, such as cell division (Sesli & Kara, 2012), plant growth and development (Lin, 2004) and water transport (Rundgren, Rundgren, & Schönborn, 2010) were identified as a result of their inadequate comprehension of the underlying concepts. The research by Tsui and Treagust (2010) also indicated correlations between students' incorrect scientific reasoning in genetics and their insufficient understanding of the content domain.

The students' lack of correct and adequate conceptualisation significantly impacted on their ability to interpret pictures in plant anatomy because an individual's existing knowledge plays a critical role in the making meaning process of visual representations being observed (Schnotz & Bannert, 2003; Winn, 1994). The linear relationship between students' lack of knowledge and incorrect interpretations of visual representations have also been empirically documented. Cook et al. (2008), for instance, observed that high school students with an inadequate comprehension of content domain tended to interpret diagrams of cellular transport superficially. Although these students gave attention to the salient visual clues, they were unable to retrieve from their memory the relevant concept leading to a surface-level explanation that focuses only on the external features of the representations (e.g., Cheng & Gilbert, 2015; Schönborn & Anderson, 2009). Indeed, Chittleborough and Treagust (2008) identified undergraduates' misinterpretations of chemical diagrams because of the limited background knowledge.

### **7.2.2 Research Question 2**

In order to understand the students' actual ability to interpret visual representations in plant anatomy, Research Question #2 "*How do undergraduates interpret visual representations in plant anatomy?*" was proposed. In this study, the answers to this research question were collected from undergraduates' responses to the interview questions which were supported by the results of the PADI-I, observations, and



document reviews. Detailed descriptions about the students' interpretations of plant anatomy pictures are presented in Chapter 5.

Major findings of Chapter 5 are listed below:

- The students' relied on graphical characteristics to interpret visual representations in plant anatomy.
- The students had difficulties in interpreting visual representations in plant anatomy.
- The students used visual memories to interpret visual representations in plant anatomy.

The results in Chapter 5 revealed that students relied on graphical characteristics, such as colours, distinctive components, dominant parts, sizes, and textures, as clues to recognise and interpret the photographs in plant anatomy. This finding is understandable because the first stage of the process of picture comprehension — perceptual processing — relies on sensory perceptions and depends on graphical features of visual representations (Schnotz & Bannert, 2003; Winn, 1994). A similar phenomenon was also documented in many studies that focused on visual representations (e.g., Cook et al., 2008; Patrick et al., 2005; Plass et al., 2014; Pozzer-Ardenghi & Roth, 2005; Schönborn & Anderson, 2009). For example, Patrick et al. (2005) observed the saliency of colours in middle grades students' explanations and evaluations of two different modes of representations of the DNA. This visual clue (colours) serves to direct students' attention, as apparent in the current investigation, and maintain their motivation to learn (Goldstone & Sakamoto, 2003; Liu et al., 2014; Rourke & O'Connor, 2012). These facts indicates the potential benefit of graphical characteristics as a scaffolding resource for learning from visual representations (Cook et al., 2008; Patrick et al., 2005; Rourke & O'Connor, 2012). However, the design of images also needs to be taken into consideration when using visual representations as a learning tool. As indicated in the current study (see Sections 5.2 and 5.6), inappropriate designs of visual representations have resulted in students' misinterpretation of the information being represented (see Eilam, 2013; Pozzer-Ardenghi & Roth, 2005).

As reported in Chapter 5, the majority of these undergraduates experienced difficulties when interpreting the photographs in plant anatomy. The three prominent

factors contributing to this problem included students' insufficient conceptual understanding, inability to recognise and identify relevant components in the representations, and inability to apply, transfer, and integrate knowledge. These factors were interrelated, meaning that the weakness of one factor could prevent the success of another factor. For example, the lack of conceptual understanding led Student S5 to focus on irrelevant parts of a picture and to bring an incorrect concept resulting in an incorrect interpretation of the picture (see Quotation 4 in Section 5.2). These findings, thus, validate the three factors affecting students' ability to interpret visual representations in the CRM model proposed by Schönborn and Anderson (2009), namely prior knowledge (C), reasoning ability related to the concept of representation (R-C), and reasoning ability related to the mode of representations (R-M). In fact, the three sources of difficulties were also implicitly observed in students' explanations of other biology topics, such human circulatory system (Cheng & Gilbert, 2015), cellular transport (Cook et al., 2008), DNA replication (Patrick et al., 2005) and immunoglobulin (Schönborn et al., 2002).

The current investigation found that some of the undergraduates used visual memories to interpret photographs in plant anatomy (see Sections 5.2 and 5.7). The aspect of visual memory is not included in the CRM model of factors contributing to students' interpretations of visual representations. The difference in the nature between biochemistry and plant anatomy seems to be a possible reason for the exclusion of visual memory from the CRM model. While biochemistry, in which the CRM framework originated, focuses on abstract phenomena, plant anatomy relies heavily on the power of observation and the interpretation of concrete objects. As asserted by Brewer (1974), the ability to memorise visual images and to apply visual memories are critical in learning plant anatomy. Without sufficient understanding, however, students' interpretations of visual representations based on visual memory are quite superficial, as reported in Section 5.2.

### **7.2.3 Research Question 3**

In this study, the instructors' perspectives of the teaching and learning of plant anatomy were also investigated. The information was collected in response to the Research Question #3 *“How do the instructors perceive the teaching of plant anatomy to support undergraduates' ability to interpret visual representations in*

*plant anatomy?*” The detailed answers to this research question were presented in Chapter 6.

Major findings of Chapter 6 are listed below:

- The implemented teaching strategies in plant anatomy courses had contributed to students’ insufficient conceptual understanding of plant anatomy.
- The division of plant organs during teaching hindered students from understanding the relationship among plant components.
- The emphasis of plant anatomy teaching on anatomical structures without connection to the functions of plant components contributed to students’ insufficient conceptual understanding of plant anatomy.

The analysis in Chapter 6 indicates the instructors’ awareness of students’ insufficient conceptual understanding of plant anatomy because of the implemented instructional strategies. This issue would appear to have contributed significantly to the students’ difficulties in interpreting visual representations in plant anatomy. The impact of teaching quality on students’ interpretation ability of visual representations was obvious (Eilam, 2013). McTigue and Flowers (2011), for instance, revealed various misinterpretations of arrows that elementary and middle school students proposed when interpreting water cycle diagrams in their textbooks. This finding was understandable because the majority of elementary teachers do not explicitly teach how to read pictures and simply point to the representations (Coleman et al., 2011). In contrast, Berthold and Renkl (2009) observed that students’ understanding of the concepts represented by multiple representations increased when instructional supports (i.e., highlighting and self-explanation prompt) were provided to students. These facts and the findings of the current study indicate the significant role of teaching for students’ learning from visual representations (Eilam & Gilbert, 2014; McTigue & Flowers, 2011; Pozzer-Ardenghi & Roth, 2005).

The findings of Chapter 6 also reveal that the separation of plant organs during the teaching without any information of the relationships of plant components at the beginning of the instructions hindered students to construct an understanding that plant organs are interconnected. Students’ lack of understanding of such concept prevented students to gain a thorough understanding of plant anatomy (see Section 6.5.2) that would contributed to students’ incorrect interpretations of visual

representations in plant anatomy. Four decades ago, a similar concern was also expressed by Troughton and Donaldson (1972) in the preface of their book. According to the authors, the appreciation that plants are a highly integrated organism in which each components are interrelated is difficult to achieve if teaching focuses on individual component of plants. This assertion, thus, supports the finding of the current study.

As identified in Section 6.4.1, the teaching of plant anatomy emphasises the knowledge of plant anatomical structures with few references to functions. The separation of structures and functions in plants would have restricted students' interpretations of visual representations in plant anatomy. As recorded in Section 5.4, for instance, Student S4 was able to correctly recognise each component in the micrograph but failed to determine the functions of the components that the student correctly identified. This finding is understandable because naturally plant structures and functions are interrelated (Fahn, 1990). The separation of plant structures and functions during teaching restricts students to understand the relationship between plant components (Troughton & Donaldson, 1972) and potentially decreases students' motivation to learn plant anatomy (Cutler et al., 2007).

#### **7.2.4 Conclusions**

In conclusion, it is suggested that most of the biology undergraduates had insufficient ability to interpret visual representations in plant anatomy. The lack of conceptual understanding of plant anatomy together with inadequate skills in scientific reasoning and in object identification significantly influenced the students' difficulties when interpreting micrographs and diagrams in plant anatomy. The contribution of instructional aspects to the students' inability to interpret visual representations in plant anatomy was identified in the current investigation.

Although the findings of this research are empirically supported, transferring these results into other contexts needs to be done with caution because of several limitations. Detailed descriptions of the limitations of this study are outlined in the next section.

### **7.3 Limitations of the Study**

During the investigation, the researcher identified five limitations that may affect the transferability of the findings of this investigation. These limitations include the limited numbers of interview participants, the limited data in Study 3, the limited scope of analysis of qualitative data, the low Cronbach alpha coefficients of the instruments, and the involvement of volunteers. Each of these limitations is addressed in the following paragraphs.

#### **7.3.1 The Limited Numbers of Interview Participants**

As explained in Section 3.3.4.3, interviews with students were only conducted in the Study 1 because the students who were involved in Study 2 declined to participate in the interviews with the reasons that they were overloaded with assignments. In contrast, the researcher struggled to find students to be invited in the interviews in Study 3 because of the semester break. This situation constrained the researcher in obtaining information about the students' actual interpretations of visual representations that were displayed in the PADI-II and the PADI-III. Moreover, only two students were involved in in-depth interviews that were carried out in Study 1. The involvement of more students in interview sessions in each study would have provided more complete information of their interpretations of various representations in plant anatomy.

#### **7.3.2 The Limited Data in Study 3**

In contrast to Studies 1 and 2, the most limited data were obtained in Study 3. Only two types of information were collected in Study 3, namely students' written responses to the PADI-III and an instructor-provided document. The reasons for this limitation includes the same explanations presented in Section 7.3.1 and the researcher's difficulties in organising research schedule because the geographical distance between the sites of doctoral study and investigation. This fact may have decreased the validity and reliability of the third study's findings. However, the results of Study 3 (see Section 4.4.1), in fact, concurred with and supported the findings of the two preceding studies.

### **7.3.3 The Low Cronbach Alpha Coefficient of the Instruments**

Another problem with this investigation was the low internal consistency of the two research instruments. As shown in Section 4.7, the alpha coefficient for the multiple choice questions of the PADI-I and the PADI-III was 0.5. This value indicates the weak correlations among items in the tests. Although the instruments were moderately valid and reliable (Salvucci et al., 1997), the fact that the internal consistency was low restricted the applicability of the first parts of the PADI-I and the PADI-III as a diagnostic tool (Roszkowski & Spreat, 2011).

### **7.3.4 The involvement of Volunteers**

The recruitment of volunteer students as research participants emerged as another issue in this investigation. As described in 3.5.1, all participants of this study were volunteers who consciously understood that their participation had no impact on their final grade. Despite complying with the research ethics, this situation potentially restricted the students to make maximal efforts when completing the diagnostic instruments. Some of the participants might carelessly respond to the items in the test being administered. Indeed, some students' collusion was detected in this study (see Section 5.6). These uncontrollable situations may have impacted on the validity and reliability of research findings.

## **7.4 Recommendations**

Despite the limitations of this study, the researcher believes that the findings of this research can make significant contributions to plant anatomy teaching and learning, particularly for the course under investigation. The recommendations that are derived from the findings of the current investigation are described in this section.

### **7.4.1 Recommendation for the Instruments Used in Other Studies**

The fact that students experienced difficulties when interpreting visual representations, as reported in the current investigation and in other previous studies, calls for serious attention from instructors who use visual representations as a teaching and learning tool. Teachers cannot simply rely on the assumption that all students could understand the presented visual information in the ways that teachers intended. An evaluation of students' ability to interpret visual representations is necessary for supporting the development of this competency and for addressing the

problems that students encounter when learning from these representations. A diagnostic instrument, such as the PADI-III, can be utilised for this purpose.

As described in Section 3.3.2 step 4, the PADI-III was developed based on the findings of the preceding instruments, the PADI-I and the PADI-II. Although in the current investigation the PADI-I was shown not to be successful in assessing students' comprehension of plant anatomy, the four tiers in each item of Part 1 of the PADI-I cover the essential skills to learn plant anatomy, namely understanding concepts (tier 1), identification (tier 2), labelling (tier 3), and reasoning (tier 4). It is evident that the participants experienced difficulties when completing this instrument because they had insufficient understanding of plant anatomy and had no experiences with a test that required multiple steps. Nevertheless, using the PADI-I, students' ability on specific skills that are examined by the four tiers can be detected. While the PADI-I was developed in the form of multiple choice questions, the PADI-II used questions that required short and extended answers. Although the assessment was time consuming, the PADI-II is potentially beneficial for a study designed to capture students' understanding of plant anatomy based on open response items. As the core instrument in the current study, the PADI-III was administered only to 94 students which might have resulted in the low Cronbach alpha coefficient (see section 4.7) of this instrument. Further research involving a large number of participants is required to support the applicability of this instrument.

#### **7.4.2 Recommendation for Course Design**

The current investigation revealed that the separation between structures and functions during plant anatomy teaching had exacerbated students' conceptual understanding of plant anatomy. This finding implies that one possible solution to address the students' problems with conceptualisation in plant anatomy is integrating plant anatomy and physiology that are taught in different units. This integration does not mean that plant anatomy and physiology instructors guide the lessons separately in one unit, rather they should collaborate to teach about particular plant structures with the corresponding functions and physiological processes. By combining the two units into, for example a "Botany Course", students are potentially capable to construct a holistic and thorough understanding of anatomical structures, the relationship between plant components, and the plant physiological processes.

### **7.4.3 Recommendation for Teaching Plant Anatomy**

This current study recognised the contribution of instructional methods to students' limited conceptual understanding of plant anatomy. This conceptual problem had adverse impact on students' ability to interpret visual representations in plant anatomy. It means that strengthening students' comprehension of underlying plant anatomy concepts will help students to have a better interpretation of visual representations in plant anatomy. To improve students' conceptual understanding, by reflecting on the research findings, the researcher recommends that instructors of plant anatomy establish at the outset that a plant is a highly integrated organism instead of teaching plant organs separately. In addition to conceptual understanding, the difficulties that students experienced when interpreting pictures in plant anatomy resulted from their inadequate skills in identifying plant elements. Some students incorrectly identified a plant part because of the similarity among plant elements. To address this problem, instructors of plant anatomy can use the graphical characteristics that are salient for the students, such as colours and sizes to attract students' attention to the distinctive characteristics of similar plant components. The development of this skill can also be supported through intensive practices of observation and identification of specimens or micrographs. These activities can increase students' visual memories that, as found in this study, were useful for students to recognise the same object or to interpret a new specimen that has similarities with objects they have observed previously.

### **7.4.4 Recommendation for Learning Plant Anatomy**

As observed in this investigation, students experienced difficulties to integrate their knowledge of plant morphology and anatomy. To prevent similar phenomena occurring in future teaching, the researcher recommends that instructors of plant anatomy increase the requirements for enrolling in this unit. For example, only students with grade B in plant morphology course should be eligible to enrol in the plant anatomy unit.

Besides, the instructor revealed that students who studied plant anatomy incorrectly interpreted specimens of anatomical structures because of their inadequate skills in using a microscope. The best solution that the researcher recommends to solve this problem is strengthening students' skills in using a microscope since the student



taking the introductory university biology course. For this purpose, the regular evaluations of the development of students' skills in using microcope is necessary. These evaluations can support the development of students' competency in using microscope that is beneficial for students to learn microscopic objects, such as plant anatomy.

Finally, the findings of this case study research provide instructors of plant anatomy with insights about students' actual ability to interpret visual representations in plant anatomy that they may not have previously considered. The researcher also believes that recommendations that are suggested can give ideas for instructors of plant anatomy to improve teaching and learning.

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## Appendix A

### Propositional Knowledge Statements of Plant Anatomy

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C1	A plant cell consists of two major elements including protoplasm and cell walls.
C2	The protoplasm consists of protoplasmic components, such as cytoplasm, nucleus, and organelles; and non-protoplasmic components involving vacuoles and ergastic materials.
C3	As a secondary metabolite, the ergastic materials can be found in the form of starch grains, aleurons, crystals, and silica bodies.
C4	Characteristics of a plant cell include cell walls, plastids, microbodies, and ergastic materials.
T1	Simple plant tissues contain homogenous cells, whereas complex plant tissues show heterogeneous cells.
T2	The simple plant tissues involve parenchyma, collenchyma, and sclerenchyma, whereas epidermis and vascular bundles are categorised as complex tissues.
T3	The parenchyma is composed of active cells that are covered by thin primary walls with conspicuous intercellular spaces.
T4	Based on the functions, the parenchyma is classified as chlorenchyma, storing parenchyma, aerenchyma, and water-storing parenchyma.
T5	As a characteristic of most aquatic plants, the aerenchyma contains large intercellular spaces to provide buoyancy and to facilitate oxygen transport for avoiding anaerobic condition.
T6	The collenchyma is a plant tissue that is composed of elastic cells covered by unevenly thickened primary walls which are still alive at maturity.
T7	The main function of collenchyma tissue is to provide mechanical support for the growing plant bodies.
T8	The sclerenchyma is composed of rigid cells covered by thickened secondary cell walls which are dead at maturity.
T9	The sclerenchyma provides mechanical support and strength when the primary growth was terminated.
T10	The epidermis is composed of a single or more layers of thin-walled tubular cells that closely attached each other without intercellular spaces and covered by thick or thin cuticle.
T11	Several epidermal cells differentiate into special structures, such as stomata, trichomes, cork cells and silica cells, bulliform cells, lithocysts, and root hairs.
T12	As the outermost layer (dermal tissue), the epidermis functions as a protecting tissue for plant undergoing primary growth.
T13	The vascular system of higher plants consists of xylem and phloem tissues.
T14	The xylem transports water and minerals from the root to the stem and leaves.
T15	The mature xylem is composed of non-living tracheary elements, parenchyma cells, and sclerenchyma cells.
T16	The phloem transports products of photosynthesis from leaves to rest of the plant.
T17	The mature phloem is composed of living sieve elements, parenchyma cells, and sclerenchyma cells.
S1	Stem is an organ functions to support the plant body, to transport water, minerals, nutrients, and photosynthesis products throughout the plant body, to elevate the leaves to be exposed to the light, and to serve as a storage, photosynthetic, or reproductive organ.
S2	In transverse section, the primary stem shows epidermis, cortex, and vascular cylinder (stele) respectively from the outside into the centre of plant.

---

*(Continued)*

## Appendix A (continued)

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S3	The primary stem is surrounded by the epidermis composed of epidermal cells, stomata, and trichomes.
S4	The cortex of stem as a cylindrical region between the epidermis and the vascular cylinder composed of parenchyma and may include collenchyma and sclerenchyma.
S5	The stele of stem is consisted of primary vascular tissues which enclose the pith.
S6	The primary vascular tissues of stem may be arranged in form of closed collateral, open collateral, bicollateral, amphivasal, or amphicribal bundles.
S7	The vascular bundles of stem are endarch means that the vascular bundles develop centrifugally from the central toward the periphery of the organ.
S8	In dicot stem, the vascular bundles are arranged neatly in one ring, whereas the vascular bundles of monocot stem are scattered throughout the parenchymatous tissue.
S9	The pith located in the centre of vascular cylinder is typically composed of parenchyma cells.
S10	Differ from the monocot stem, the cortex and pith of dicot stem can be differentiated clearly.
S11	The secondary growth of stem involves the formation of secondary vascular tissues by cambium and periderm by phellogen.
S12	The secondary vascular tissues of stem consisted of secondary phloem and secondary xylem.
S13	The existence of vascular tissues increases the diameter of stem.
S14	The periderm of stem consists of phellem, phelogen, and pheloderm.
S15	Replacing the function of epidermis, the periderm provides protection to the plant in secondary growth.
S16	The secondary stem commonly retains the pith in the centre of vascular cylinder.
R1	Root is a specialized organ for water and minerals absorbing, and anchoring functions. However, it can also serve as a storage, reproductive, or photosynthetic organ.
R2	Water and minerals flow in the root through apoplast and symplast pathways.
R3	In the apoplast pathway, water and minerals move solely via the cell walls into the xylem of the root.
R4	In the symplast pathway, through plasmodesmata water and minerals travels from cell to cell into the xylem of the root.
R5	In transverse section, the primary root consists of epidermis, cortex, and stele respectively from the outside into the centre of plant.
R6	As an outermost layer, the epidermis of root comprises epidermal cells and root hairs.
R7	The cortex of root located between the epidermis and the stele consists mainly of parenchyma tissue.
R8	In most plants, the single innermost layer of root cortex differentiates into endodermis characterized by impermeable casparian strips on its anticlinal cell walls.
R9	This casparian strips break the continuity of apoplastic route and force water and minerals to cross the endodermis via symplastic route.
R10	As the central portion of root, the stele consists of primary vascular tissues which are surrounded by pericycle.
R11	The vascular bundles of root are typically arranged radially in which the xylem and phloem occur alternately in different rays.
R12	The vascular bundles of root are exarch means that the vascular bundles develop centripetally from the periphery toward the central of the organ.
R13	The centre of vascular cylinder of root can be occupied by primary xylem or pith which is composed of parenchyma.
R14	The secondary growth of root involves the formation of secondary vascular tissues by cambium and periderm by phellogen.
R15	The secondary vascular tissues of root consisted of secondary phloem and secondary xylem.
R16	The existence of vascular tissues increases the diameter of root.
R17	The periderm of root consists of phellem, phelogen, and pheloderm.
R18	As the outermost layer, the periderm protects the secondary root.
R19	The secondary root commonly retains the primary xylem in the centre of vascular cylinder.
L1	Foliage leaves are the major photosynthetic organ.

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*(Continued)*

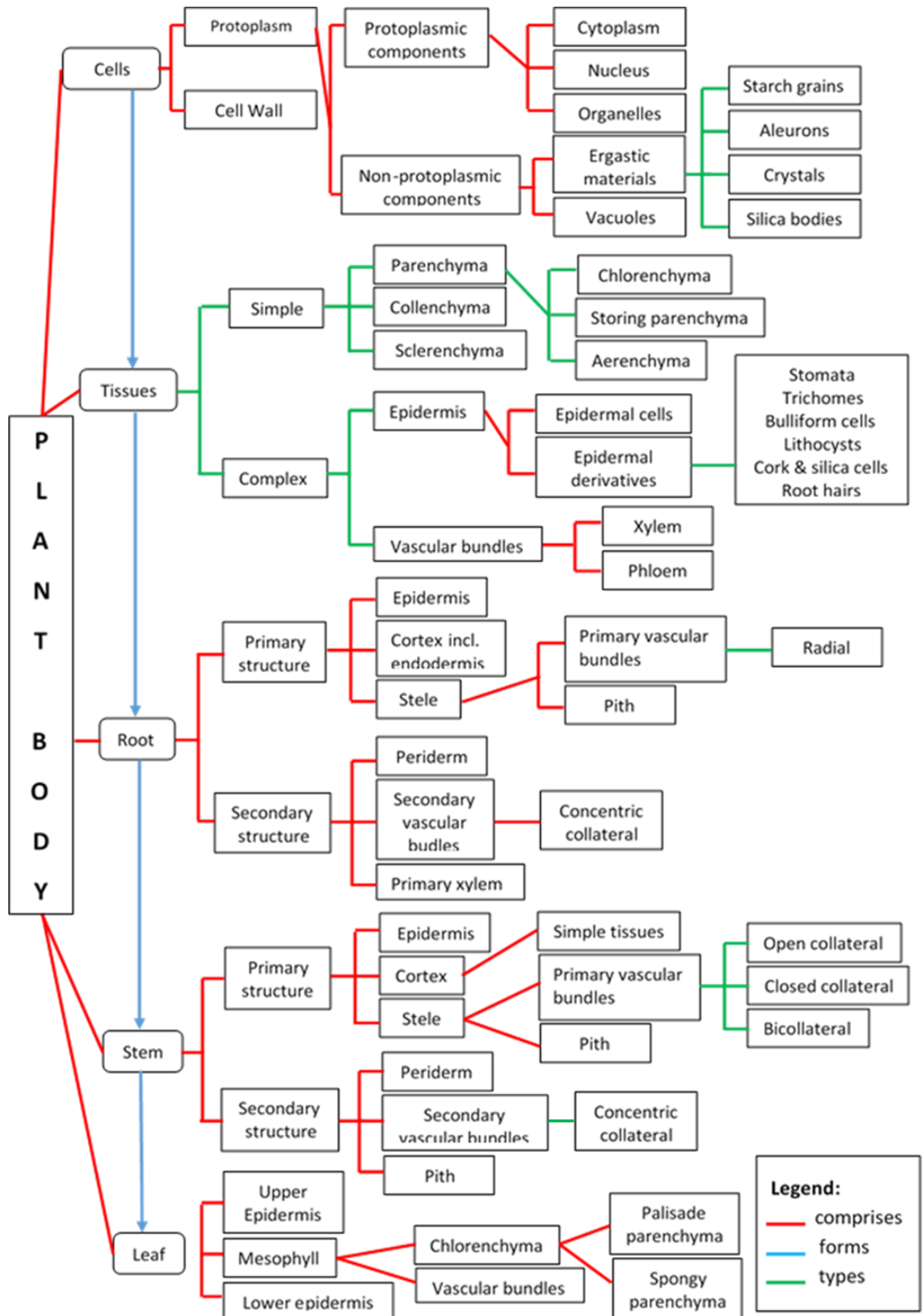
## Appendix A (continued)

- 
- L2 In many plants, the leaf blade can be differentiated into adaxial (upper) and abaxial (lower) surfaces.
- L3 In transverse section, the leaf consists of upper epidermis, mesophyll, and lower epidermis respectively.
- L4 Both the upper and lower epidermis are composed of epidermal cells, stomata, and trichomes, but sometimes special structures, such as, cork cells and silica cells, bulliform cells, and lithocysts can be also found.
- L5 Through open and close its two guard cells, a stoma functions to control gases exchange, to facilitate CO<sub>2</sub> uptake for photosynthesis process, and to regulate the water loss through transpiration process.
- L6 The opening and closing of stoma is influenced by turgor pressure in its guard cells.
- L7 Due to environmental differences, plants develop different stomata which, based on the position of guard cells to the epidermal cells, are classified as phaneropore, cryptopore, and raised types.
- L8 Based on the contents, the trichomes are classified as non-glandular trichomes and glandular trichomes, such as salt glands and hydathode.
- L9 The mesophyll is located between the upper and lower epidermis and composed of chlorenchyma and vascular bundles.
- L10 Differ from mesophyll of monocot leaves which is homogeneous, the mesophyll of dicot leaves differentiates into palisade and spongy parenchyma.
- L11 The palisade parenchyma is composed of elongated, rod-shaped cells which are closely attached to one another and are arranged in rows.
- L12 The spongy parenchyma consists of irregular cells in shape and arrangement with conspicuous intercellular spaces.
- L13 Components and types of the vascular bundles in leaf are similar to those in stem, but both are in different directions. The xylem in leaf is external to the phloem, while it is in opposite position in stem.
- L14 The primary xylem of a leaf is oriented toward the adaxial surface.
- L15 Water in the xylem of leaf is transported into the mesophyll then be released to the atmosphere via stomata in form of water vapour.
- 

**Note:** C, T, S, R, and L indicate propositions for plant anatomy topics that have been taught by lecturers including plant cells, plant tissues, plant stems, plant roots, and plant leaves, respectively.

# Appendix B

## Concept Map of Plant Anatomy



**Appendix C**  
**Plant Anatomy Diagnostic Instrument I (PADI-I)**

**Appendix C1: The Final Version of the PADI-I..... 169**

**Appendix C2: An Indonesian Version of the PADI-I ..... 174**

**Appendix C3: A Rubric for Assessing Students' Responses to Part 2 of the  
PADI-I ..... 180**

## Appendix C1: The Final Version of the PADI-I

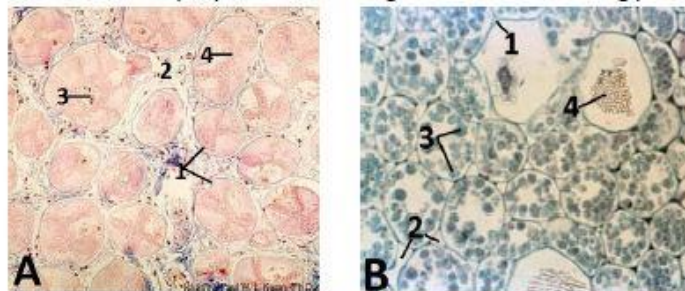
### A PLANT ANATOMY DIAGNOSTIC INSTRUMENT I (PADI-I)

Student Number: \_\_\_\_\_ Class: \_\_\_\_\_

#### Section 1: Multiple Choice Questions

**Direction:** The test consists of 5 (five) sections designed to measure your understanding of plant anatomy concepts. Each section consists of 4 (four) questions with 3-6 multiple choices. Please circle one option for each question. For the last question in each section, you may circle the "I do not know" option in case of not knowing the answer. If you suppose that none of the choices is the correct answer, you may write your own answer on the "Other" space.

1.1 Under a microscope, you see something similar to the following pictures.



Based on the characteristics, which picture shows the plant cells?

- a) A.
  - ★ b) B.
  - c) A and B.
- 1.2 Which parts of the pictures support your answer?
- a) 1 dan 2.
  - b) 2 dan 4.
  - ★ c) 3 dan 4.
  - d) 1 dan 3.
- 1.3 What is the name of the parts?
- ★ a) Starch grains and crystals.
  - b) Intercellular spaces and chromoplasts.
  - c) Cell walls and nucleus.
  - d) Cell walls and intercellular spaces.
- 1.4 The reason is...
- a) both pictures show rigid polyhedral cells with large intercellular spaces for gas exchange in plant.
  - b) the cells contain plastids which bring the colour to the cells.
  - c) the cells contain the major components of plant cells which are clearly seen.
  - ★ d) the cells contain ergastic substances as the products of plant secondary metabolic processes.
  - e) I do not know.
  - f) other (Explanation: \_\_\_\_\_)

*(Continued)*



2.1 A botanist observes a transverse section of an unknown plant organ as shown by picture A. He sees something similar to the picture B under a light microscope. Based on its anatomical structure, he concludes that the organ serves to...

- ★ a) transport water and photosynthesis products.
- b) absorb minerals and water from the soil.
- c) store nutrient.
- d) support the plant body.

2.2 Which part of the picture supports your answer?

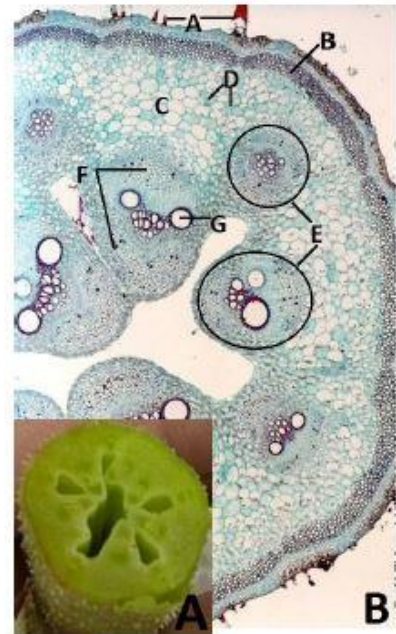
- a) A dan E.
- b) B dan G.
- c) C dan D.
- ★ d) F dan G.

2.3 What is the name of the part?

- a) Sclerenchyma and xylem.
- b) Root hair and vascular bundles.
- ★ c) Phloem and xylem.
- d) Parenchyma and starch grains.

2.4 The reason is...

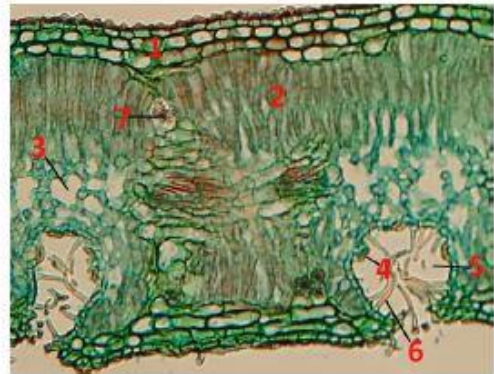
- a) the organ has well-developed vascular bundles in which the xylem and phloem are arranged alternately and develops root hairs at the outermost layer.
- b) the organ has abundant ground tissues which contain starch grains.
- c) the organ is surrounded by supportive tissues which contain lignin.
- ★ d) the organ has well-developed vascular bundles in which the xylem is located in between the outer and inner phloem.
- e) I do not know.
- f) other (Explanation: \_\_\_\_\_)



3.1 A young woman is found killed in a location.

During the investigation, police found a piece of leaf attached to her clothes. Under the microscope, the leaf shows an anatomical structure as shown in the picture. Based on the anatomical structure of the leaf, where do you predict the location of the crime?

- ★ a) Area with high sunlight intensity.
- b) Area with high salinity.
- c) Submerged area.
- d) Shaded area.



3.2 Which parts of the picture support your answer?

- a) 3 dan 4.
- ★ b) 1 dan 5.
- c) 1 dan 2.
- d) 6 dan 7.

(Continued)



3.3 What is the name of the parts?

- a) Intercellular space and stomata.
- b) Multiple epidermis and palisade parenchyma.
- c) Trichomes and salt gland.
- ★d) Multiple epidermis and substomatal chamber.

3.4 The reason is...

- a) the structure facilitates the leaves to capture light as much as possible.
- ★b) the structure prevents the plant from excessive transpiration.
- c) the structure helps the plant excluding salt deposit.
- d) the structure facilitates a faster gas exchange.
- e) I do not know.
- f) other (Explanation: \_\_\_\_\_)

4.1 An agronomist finds a difference of plant productivity in two different areas. Area A produces a greater dry weight than area B. In order to understand the cause of the difference, he observes and compares the anatomical structure of the plant organ collected from the two areas. Under the microscope, he sees something similar to the picture A from the plant in area A and the picture B from the plant in area B. Based on the observation, what should he have been done to improve the plant productivity of area B?

- a) Fertilizing the plant with organic fertilizers.
- b) Watering the plant regularly.
- ★c) Aerating the soil mechanically or biologically.
- d) Reducing the salt level of the soil.

4.2 Which parts of the picture supports your answer?

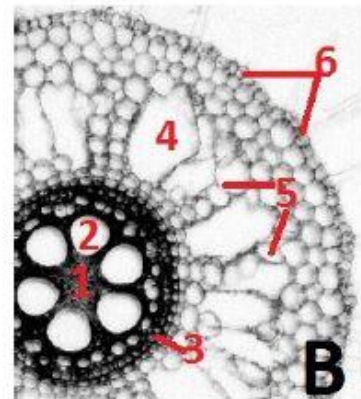
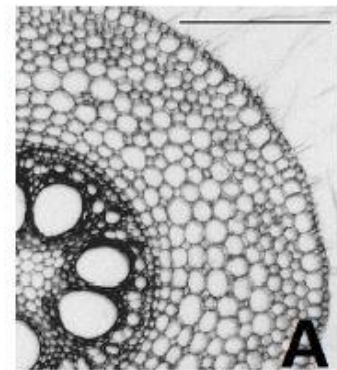
- a) 1 and 2.
- b) 3 and 4.
- ★c) 4 and 5.
- d) 3 and 6.

4.3 What is the name of the parts?

- a) Pith and vessels.
- b) Endodermis and intercellular space.
- ★c) Intercellular space and aerenchyma.
- d) Endodermis and salt glands.

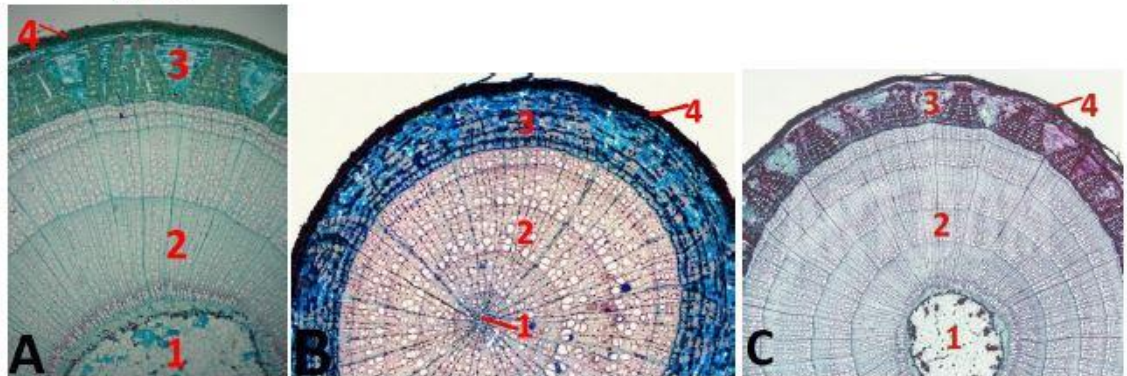
4.4 The reason is...

- ★a) the tissues are formed by the plant to tolerate an oxygen deficiency.
- b) the tissues are formed by the plant to tolerate a nutrient deficiency.
- c) the tissues are formed by the plant to tolerate a water deficit.
- d) the tissues are formed by the plant to tolerate a salt stress.
- e) I do not know.
- f) other (Explanation: \_\_\_\_\_)



(Continued)

5.1 To make a high-quality handicraft, a craftsman has decided to use a 5-year-old trunk of Basswood (*Tilia*). The tree is commonly found in temperate regions and forms a growth ring every year. Based on the description, which picture shows the trunk that the craftsman will choose when buying online?



- a) A.
- b) B.
- ★c) C.

5.2 Which parts of the picture support your answer?

- ★a) 1 and 2.
- b) 2 and 3.
- c) 3 and 4.
- d) 2 and 4.

5.3 What is the name of the parts?

- a) Secondary xylem and secondary phloem.
- ★b) Pith and secondary xylem.
- c) Secondary xylem and periderm.
- d) Primary xylem and secondary xylem.

5.4 The reason is...

- a) the wood shows 5 rings of secondary phloem and an existence of primary xylem as a characteristic of old trunk.
- b) the wood shows 5 rings of secondary xylem and an existence of periderm as a characteristic of old trunk.
- ★c) the wood shows 5 rings of secondary xylem and an existence of pith as a characteristic of old trunk.
- d) the wood shows 5 rings of secondary phloem and an existence of periderm as a characteristic of old trunk.
- e) I do not know.
- f) other (Explanation: \_\_\_\_\_)

Note: star symbol (★) indicates a correct answer.

(Continued)

**Section 2: Drawing test**

**Direction:** Below is a picture of a plant native to Brazil. As a tropical plant, it needs adequate amount of water to grow perfectly. Based on the plant's characteristic shown in the picture, you are asked to draw then provide anatomical descriptions of the plant organs including root, stem, and leaf.

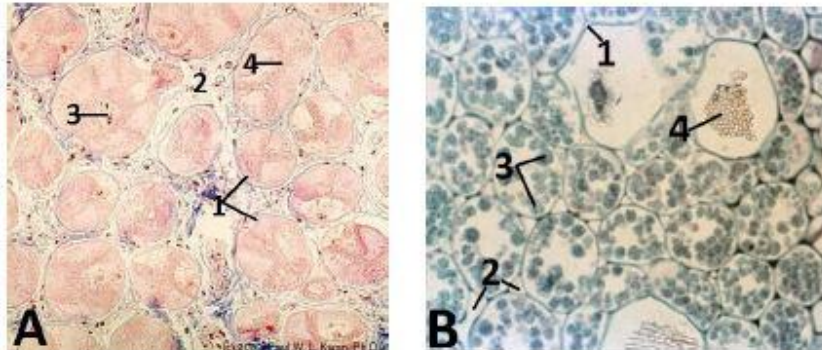




## Appendix C2: An Indonesian Version of the PADI-I

### Bagian 1: Soal Pilihan Ganda

1.1 Di bawah mikroskop, Anda melihat sesuatu yang serupa dengan gambar-gambar berikut ini.



Berdasarkan ciri-cirinya, gambar manakah yang termasuk sel-sel tumbuhan?

- A.
  - B.
  - A dan B
- 1.2 Bagian-bagian manakah dari gambar tersebut yang mendukung jawaban Anda?
- 1 dan 2.
  - 2 dan 4.
  - 3 dan 4.
  - 1 dan 3.
- 1.3 Apa nama bagian-bagian tersebut?
- Amilum dan kristal.
  - Ruang antarsel dan kromoplas.
  - Dinding sel dan intisel.
  - Dinding sel dan ruang antarsel.
- 1.4 Alasannya adalah...
- kedua gambar menunjukkan sel-sel polihedral yang kaku dengan lintasan udara yang cukup besar untuk pertukaran gas pada tumbuhan.
  - gambar tersebut menunjukkan sel-sel yang memiliki butiran-butiran warna di dalamnya.
  - gambar tersebut menunjukkan sel-sel yang mengandung komponen utama sel tumbuhan.
  - gambar tersebut menunjukkan sel-sel yang mengandung zat ergastic sebagai hasil proses metabolisme sekunder pada tumbuhan.
  - saya tidak tahu.
  - Lainnya
- (Penjelasan: \_\_\_\_\_)

*(Continued)*

2.1 Seorang ahli tumbuhan mengamati irisan melintang suatu organ tanaman yang tidak diketahui seperti yang ditunjukkan oleh gambar A. Di bawah mikroskop cahaya, dia melihat sesuatu yang serupa dengan gambar B. Berdasarkan struktur anatominya, dia menyimpulkan bahwa organ tersebut berfungsi untuk...

- mengangkut air dan hasil fotosintesis.
- menyerap mineral dan air dari dalam tanah.
- menyimpan cadangan makanan.
- menopang tumbuhan.

2.2 Bagian manakah dari gambar tersebut yang mendukung jawaban Anda?

- A dan E.
- B dan G.
- C dan D.
- F dan G.

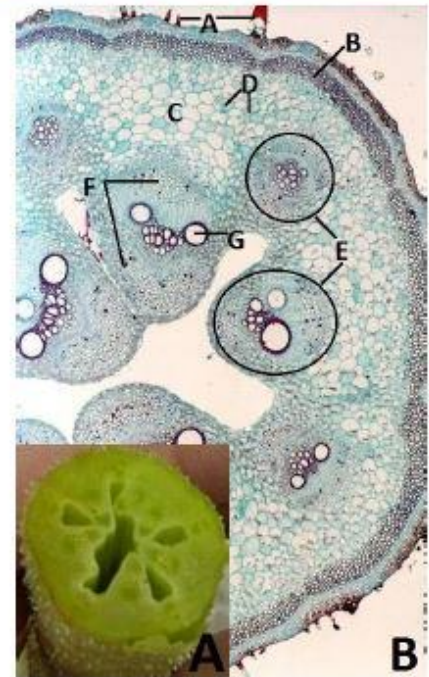
2.3 Apa nama bagian tersebut?

- Sklerenkim dan xilem.
- Rambut akar dan berkas pembuluh.
- Floem dan xilem.
- Parenkim dan butir tepung.

2.4 Alasannya adalah...

- organ tersebut memiliki berkas pembuluh yang tersusun radial dan membentuk rambut akar pada tepinya.
- organ tersebut memiliki jaringan dasar yang melimpah dengan butir-butir amilum di dalamnya.
- organ tersebut memiliki jaringan-jaringan penguat yang mengandung lignin.
- organ tersebut memiliki berkas pembuluh yang berkembang baik dengan jaringan xilem terletak di antara jaringan floem luar dan dalam.
- saya tidak tahu.
- lainnya

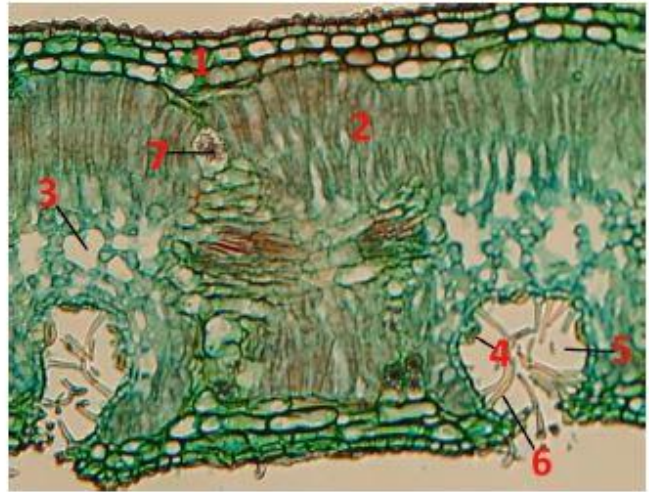
(Penjelasan: \_\_\_\_\_  
\_\_\_\_\_)



(Continued)



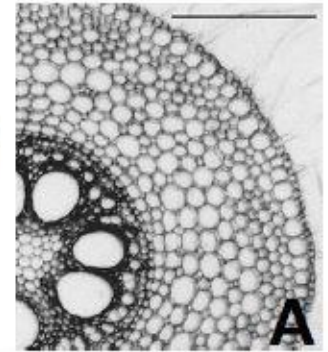
3.1 Seorang wanita muda ditemukan terbunuh di suatu lokasi. Selama penyelidikan, polisi menemukan potongan daun menempel pada bajunya. Di bawah mikroskop, daun tersebut menampilkan struktur anatomi seperti yang ditunjukkan pada gambar. Berdasarkan struktur anatomi daun tersebut, dimanakah lokasi yang Anda prediksi sebagai tempat kejadian perkara?



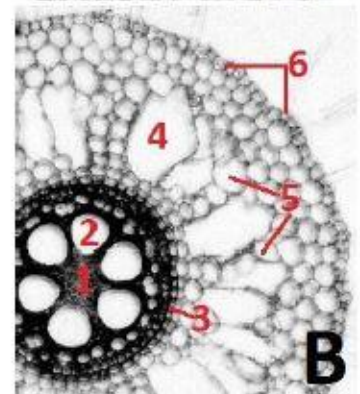
- a) Daerah dengan cahaya matahari terik.
  - b) Daerah berkadar garam tinggi.
  - c) Daerah tergenang.
  - d) Daerah ternaung.
- 3.2 Bagian-bagian manakah dari gambar tersebut yang mendukung jawaban Anda?
- a) 3 dan 4.
  - b) 1 dan 5.
  - c) 1 dan 2.
  - d) 6 dan 7.
- 3.3 Apa nama bagian-bagian tersebut?
- a) Ruang antarsel yang besar dan stomata.
  - b) Epidermis ganda dan parenkim palisade.
  - c) Trikomata dan kelenjar garam.
  - d) Epidermis ganda dan ruang substomata.
- 3.4 Alasannya adalah...
- a) struktur tersebut memfasilitasi tanaman menangkap cahaya matahari sebanyak-banyaknya.
  - b) struktur tersebut mencegah tanaman dari transpirasi berlebihan.
  - c) struktur tersebut membantu tanaman mengeluarkan endapan garam.
  - d) struktur tersebut memfasilitasi pertukaran gas yang terjadi lebih cepat.
  - e) saya tidak tahu.
  - f) lainnya
- (Penjelasan: \_\_\_\_\_  
\_\_\_\_\_ )

(Continued)

4.1 Seorang agronomis menemukan adanya perbedaan produktivitas tanaman pada dua lahan yang berbeda. Lahan A menghasilkan berat kering tanaman jauh lebih banyak dibandingkan lahan B. Untuk memahami penyebab perbedaan tersebut, dia mengamati dan membandingkan struktur anatomi organ tanaman dari kedua lahan tersebut. Di bawah mikroskop, dia melihat sesuatu yang serupa dengan gambar A pada tanaman dari lahan A dan gambar B pada tanaman dari lahan B. Berdasarkan hasil pengamatannya, apa yang seharusnya dia lakukan untuk meningkatkan produktivitas tanaman pada lahan B?



4.2 Bagian-bagian manakah dari gambar tersebut yang mendukung jawaban Anda?



- Memupuk tanaman dengan pupuk organik.
- Menyiram tanaman secara teratur.
- Menggemburkan tanah secara mekanik atau biologi.
- Mengurangi kadar garam tanah.

4.3 Apa nama bagian-bagian tersebut?

- 1 dan 2.
  - 3 dan 4.
  - 4 dan 5.
  - 3 dan 6.
- Empulur dan trakea.
  - Endodermis dan ruang antarsel.
  - Ruang antarsel dan aerenkim.
  - Endodermis dan kelenjar-kelenjar garam.

4.4 Alasannya adalah...

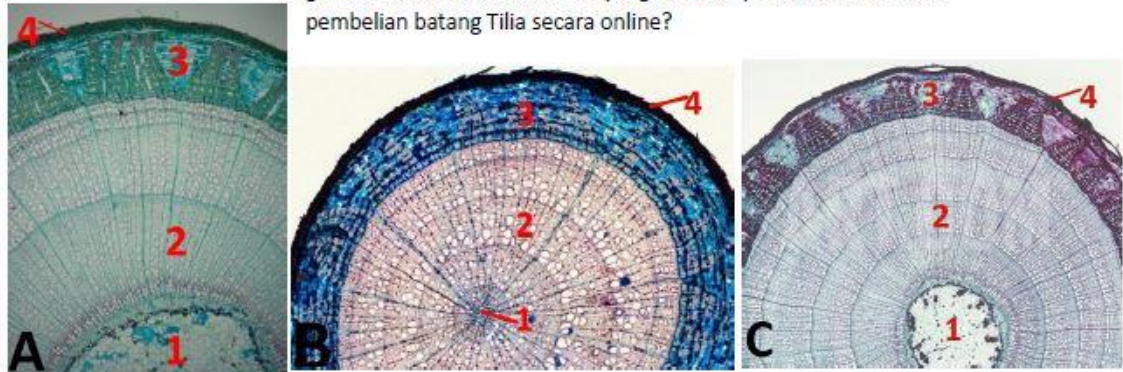
- jaringan tersebut dibentuk oleh tanaman untuk mentoleransi kekurangan oksigen.
- jaringan tersebut dibentuk oleh tanaman untuk mentoleransi kekurangan nutrisi.
- jaringan tersebut dibentuk oleh tanaman untuk mentoleransi kekurangan air.
- jaringan tersebut dibentuk oleh tanaman untuk mentoleransi stres garam.
- saya tidak tahu.
- lainnya

(Penjelasan: \_\_\_\_\_  
\_\_\_\_\_ )

(Continued)



5.1 Untuk menghasilkan kerajinan berkualitas tinggi, seorang pengrajin menggunakan batang pohon *Tilia* berumur 5 tahun. Pohon ini hidup di daerah temperata dan membentuk satu lingkaran pada batang setiap tahun. Berdasarkan deskripsi tersebut, gambar manakah di bawah ini yang akan dia pilih saat melakukan pembelian batang *Tilia* secara online?



- a) A.
- b) B.
- c) C.

5.2 Bagian-bagian manakah dari gambar tersebut yang mendukung jawaban Anda?

- a) 1 dan 2.
- b) 2 dan 3.
- c) 3 dan 4.
- d) 2 dan 4.

5.3 Apa nama bagian-bagian tersebut?

- a) xilem sekunder dan floem sekunder.
- b) empulur dan xilem sekunder.
- c) xilem sekunder dan periderm.
- d) xilem primer dan xilem sekunder.

5.4 Alasannya adalah...

- a) kayu tersebut menunjukkan 5 cincin floem sekunder dan memperlihatkan keberadaan xilem primer sebagai salah satu ciri batang tua.
- b) kayu tersebut menunjukkan 5 cincin xilem sekunder dan memperlihatkan keberadaan periderm sebagai salah satu ciri batang tua.
- c) kayu tersebut menunjukkan 5 cincin xilem sekunder dan memperlihatkan keberadaan empulur sebagai salah satu ciri batang tua.
- d) kayu tersebut menunjukkan 5 cincin floem sekunder dan memperlihatkan keberadaan periderm sebagai salah satu ciri batang tua.
- e) saya tidak tahu.
- f) lainnya

(Penjelasan: \_\_\_\_\_)

\_\_\_\_\_ )

*(Continued)*



**Bagian 2: Tes Menggambar**

Di bawah ini adalah gambar sebuah tanaman asli Negara Brasil. Sebagai tanaman tropis, tanaman tersebut memerlukan air yang cukup untuk tumbuh sempurna. Berdasarkan ciri-ciri tanaman yang ditampilkan pada gambar tersebut, Anda diminta untuk menggambar dan memberi keterangan struktur anatomi organ-organ tanaman tersebut meliputi akar, batang, dan daun serta Anda diminta untuk menunjukkan bagaimana air diserap dan diangkut untuk mendukung kehidupan tanaman tersebut.



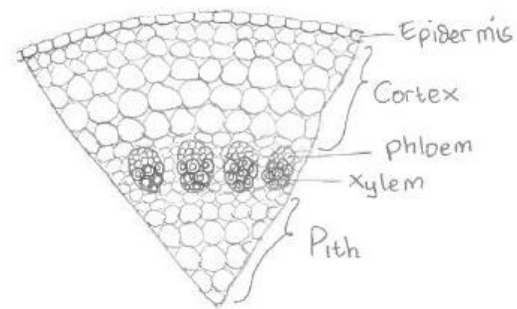
**TERIMA KASIH ATAS PARTISIPASI ANDA**

### Appendix C3: A Rubric for Assessing Students' Responses to Part 2 of the PADI-I

Assessment Aspects	Category	Criteria	Score
Drawing	Comprehensive	The drawing includes all basic parts of the organ as mentioned below with correct structure and position.	4
	Misconception	The drawing includes all parts of the organ as mentioned below, but the structure, shape, and/or position are incorrect; or there are unrelated tissues indicating misconception of the represented organ.	3
	Incomplete	The drawing shows the intended anatomical structure of the organ, but one basic parts as mentioned below is missing.	2
	Incorrect	The drawing does not represent the intended anatomical structure of the organ because of most of the basic parts as mentioned below are missing.	1
	No response	No response is provided in the answer sheet.	0
Labelling	Comprehensive	All parts of the drawing are correctly labelled as shown below.	3
	Partial	Some parts of the drawing are correctly labelled, but others are incorrectly or not labelled.	2
	Incorrect	All parts of the drawing are incorrectly labelled; or some parts of the drawing are incorrectly labelled, but others are not labelled; or only two parts are correctly labelled, but others are incorrectly or not labelled.	1
	No response	All parts of the drawing are not labelled.	0

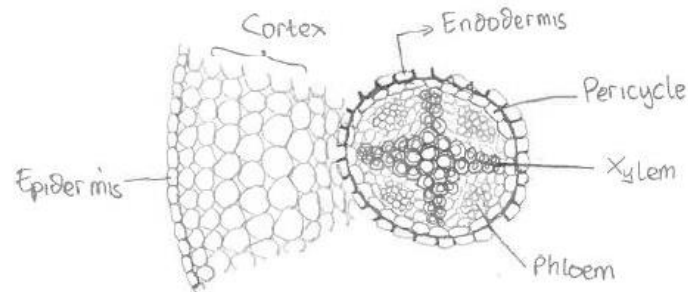
Comprehensive Drawing of Dicot Stem includes:

1. Epidermis
2. Cortex
3. Vascular bundles that are arranged in one ring
4. Pith



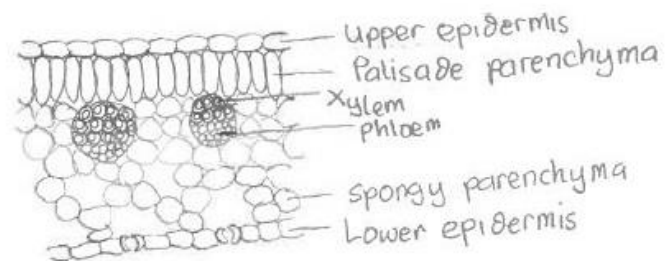
Comprehensive Drawing of Dicot Root includes:

1. Epidermis
2. Cortex
3. Endodermis
4. Pericycle
5. Radial and tetraarches vascular bundles



Comprehensive Drawing of Dicot Leaf includes:

1. Upper epidermis
2. Palisade parenchyma
3. Vascular bundle
4. Spongy parenchyma
5. Lower epidermis



**Appendix D**  
**Plant Anatomy Diagnostic Instrument II (PADI-II)**

**Appendix D1: The Final Version of the PADI-II ..... 188**

**Appendix D2: An Indonesian Version of the PADI-II..... 174**

**Appendix D3: A Rubric for Assessing Students' Responses to Part 1 of the  
PADI-II..... 193**

**Appendix D4: A Rubric for Assessing Students' Responses to Part 2 of the  
PADI-II..... 194**

# Appendix D1: The Final Version of the PADI-II

## A PLANT ANATOMY DIAGNOSTIC INSTRUMENT II (PADI-II)

Student Number: \_\_\_\_\_

Class: \_\_\_\_\_

### Section 1: Closed Questions

Q1. What plant organ is shown in cross section in the picture on the right?

\_\_\_\_\_

Please give reasons for your answer!

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

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\_\_\_\_\_

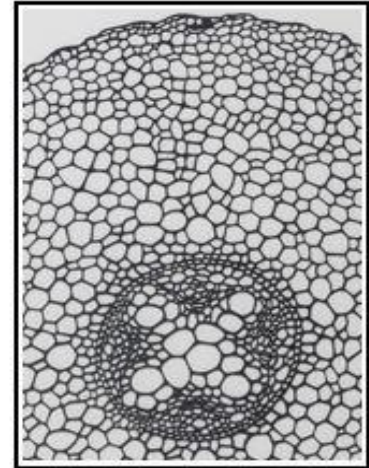
What are the functions of this organ?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



Q2. Which part of the plant picture on the right side prevents the outward leakage of fluids?

\_\_\_\_\_

What is the name of this part?

\_\_\_\_\_

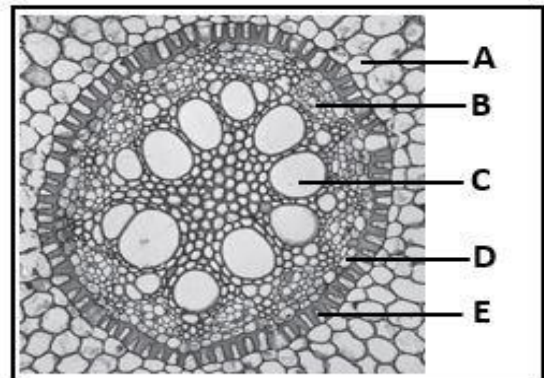
How does this part function?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



*(Continued)*

Q3. A On the right side, there is a picture of a vascular bundle. Based on the anatomical structure, what is the type of this vascular bundle?

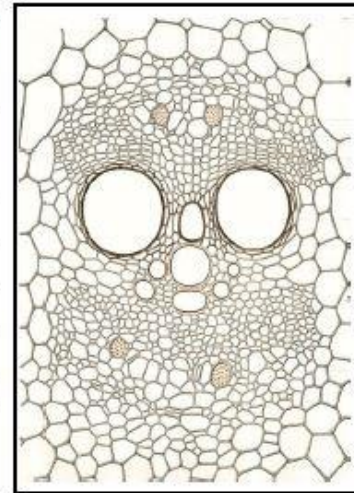
\_\_\_\_\_

B Please give reasons for your answer!

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

C In which organ can you find this vascular bundle?

\_\_\_\_\_



Q4. A The picture on the right is showing a cross section of a leaf blade. Please determine in which side is the adaxial surface located! (Side A/Side B)

\_\_\_\_\_

B Please give reasons for your answer!

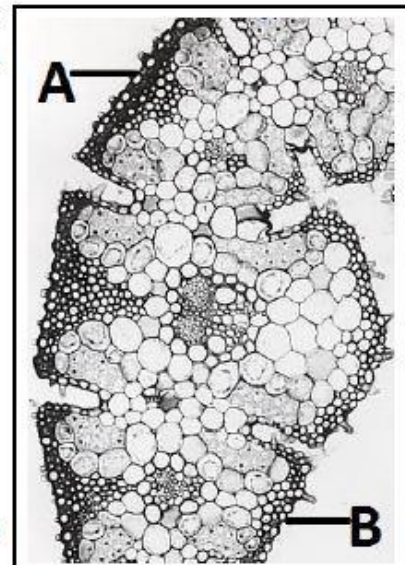
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\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

C Based on the anatomical structure, in which plant can we find this leaf? (Monocotyledon/Dicotyledon plant).

\_\_\_\_\_

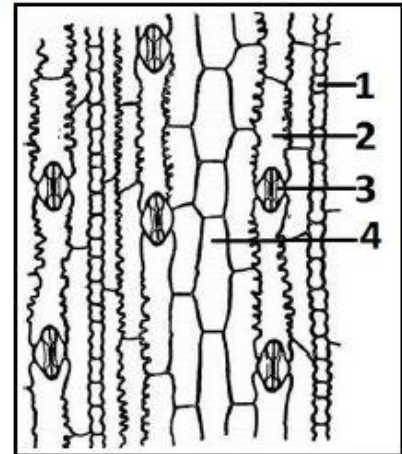
D Please give reasons for your answer!

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



*(Continued)*

Q5. A The picture on the right is showing a diagram of leaf blade in surface view. In which number is a stoma pointed?



B What are the functions of stomata?

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C How does a stoma work?

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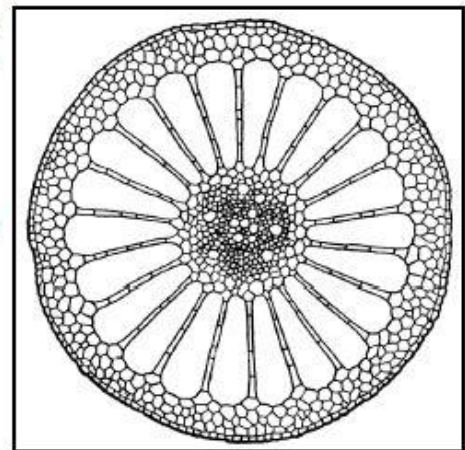


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Q6. A Based on the anatomical structure of an organ showing by the picture on the right, it can be predicted that the plant's habitat is



B The reason is that this organ has a special tissue called

---

C The functions of this tissue include

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(Continued)



Q7. A Inside a cell, there is a component as showing by the picture on the right. What is the name of this component?

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B Please give reasons for your answer!

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C What are the functions of this component?

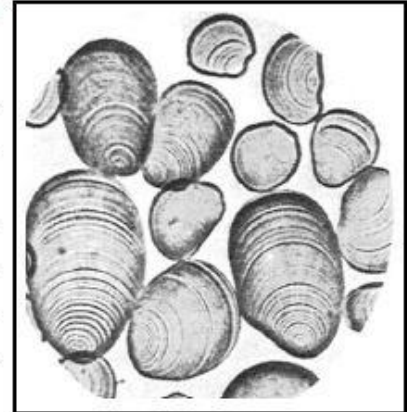
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Q8. A The picture on the right is showing a cross section of an organ in secondary growth. Based on the anatomical structure, this organ is (stem/root/leaf)

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B Please give reasons for your answer!

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C What are the functions of this organ?

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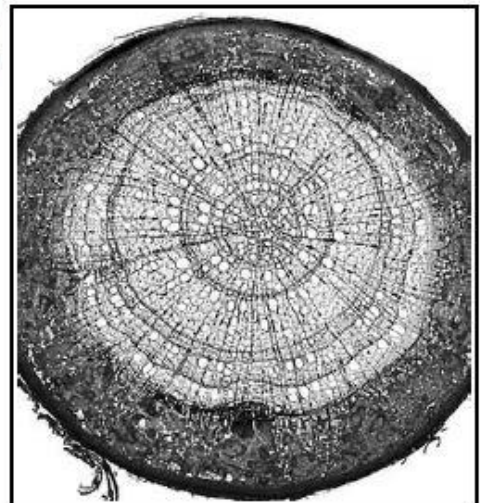
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*(Continued)*



Q9. In which plant can we find the organ as showing by the picture on right? (Monocotyledon/Dicotyledon plant)

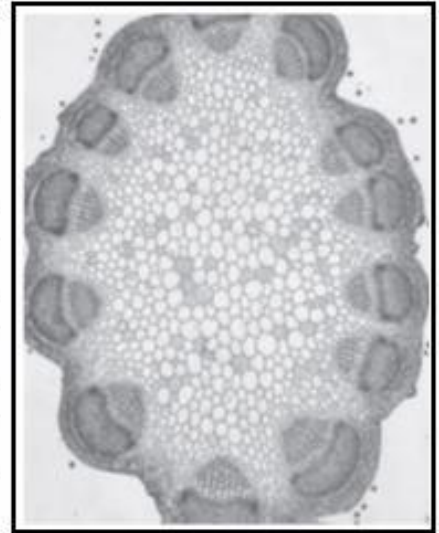
\_\_\_\_\_

Please give reasons for your answer!

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

What are the functions of this organ?

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



**Section 2: Drawing Test**

Please draw the anatomy of a cross section of a dicot leaf and label each part of the organ!

**THANK YOU FOR YOUR PARTICIPATION**

## Appendix D2: An Indonesian Version of the PADI-II



### TES ANATOMI TUMBUHAN

NIM: \_\_\_\_\_

Kelas: \_\_\_\_\_

**Q1.** Organ apakah yang ditunjukkan oleh gambar irisan melintang di sebelah kanan?

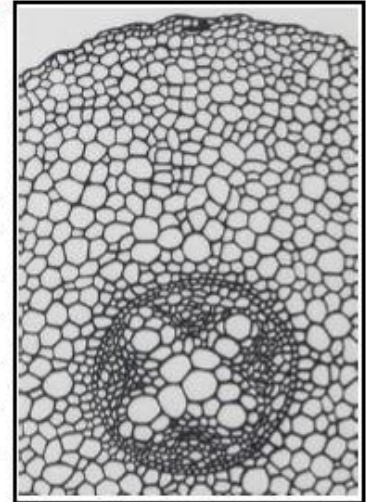
\_\_\_\_\_

Berikan alasan-alasan untuk jawaban Anda!

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Sebutkan fungsi-fungsi organ tersebut!

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



**Q2.** Bagian manakah dari gambar organ tanaman di sebelah kanan yang dapat mencegah aliran balik cairan keluar dari organ?

\_\_\_\_\_

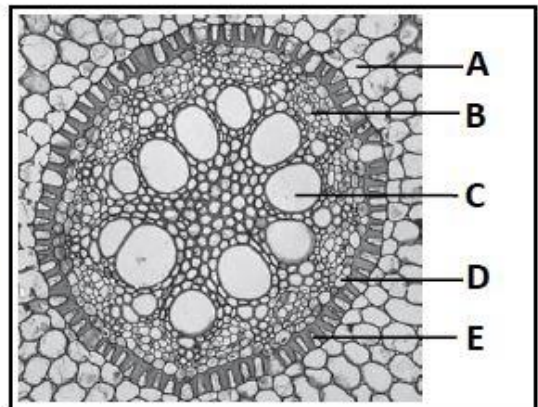
Apa nama bagian tersebut?

\_\_\_\_\_

Bagaimana bagian tersebut mencegah aliran balik cairan keluar dari organ?

\_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_



*(Continued)*

**Q3.** Di sebelah kanan terdapat gambar sebuah berkas pengangkut. Berdasarkan struktur anatominya, tentukan tipe berkas pengangkut tersebut!

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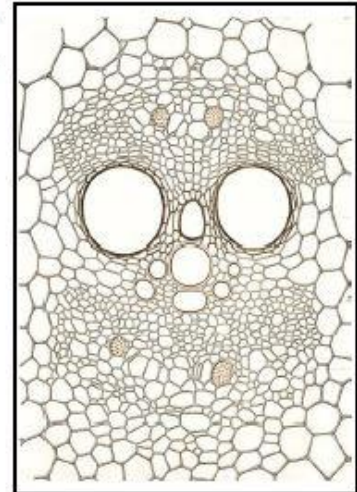
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Pada organ apakah berkas pengangkut tersebut dapat ditemukan?

---



**Q4.** Gambar di sebelah kanan menunjukkan irisan melintang sebuah helaian daun. Tentukan pada bagian manakah sisi adaksial daun tersebut! (Sisi A/Sisi B)

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Berdasarkan struktur anatominya, pada tumbuhan apakah daun tersebut dapat ditemukan? (Tumbuhan Monokotil/Dikotil).

Berikan alasan-alasan untuk jawaban Anda!

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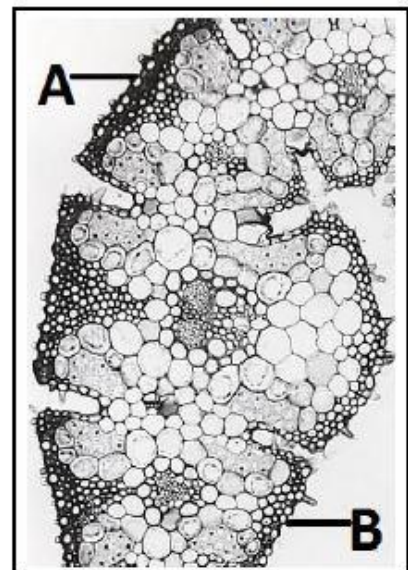
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*(Continued)*

Q5. Gambar di sebelah kanan menunjukkan sebuah diagram helaian daun dilihat dari sisi permukaan. Ditunjuk pada nomer berapakah sebuah stoma?

\_\_\_\_\_

Sebutkan fungsi-fungsi stomata!

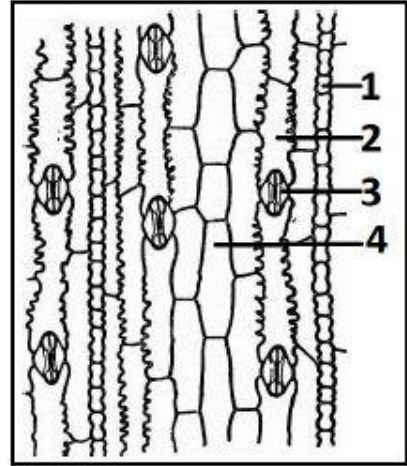
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\_\_\_\_\_



Bagaimana sebuah stoma bekerja?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Q6. Berdasarkan struktur anatomi organ yang ditunjukkan pada gambar di sebelah kanan, dapat diprediksikan bahwa habitat tanaman tersebut adalah di

\_\_\_\_\_

\_\_\_\_\_

Alasannya adalah organ tersebut memiliki jaringan khusus yang disebut

\_\_\_\_\_

Adapun fungsi-fungsi jaringan tersebut meliputi

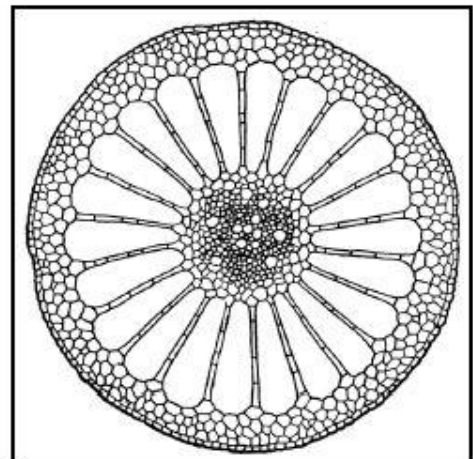
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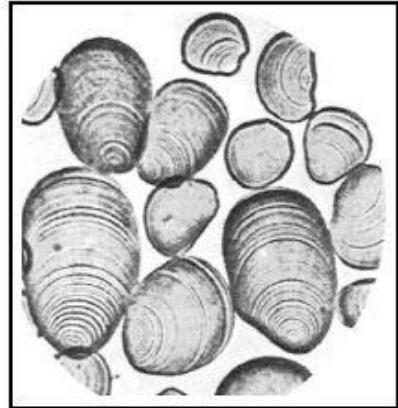
\_\_\_\_\_

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*(Continued)*

**Q7.** Di dalam sebuah sel, terdapat komponen seperti yang ditunjukkan oleh gambar di sebelah kanan. Apa nama komponen tersebut?



\_\_\_\_\_

Berikan alasan-alasan untuk jawaban Anda!

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Sebutkan fungsi-fungsi komponen tersebut bagi tumbuhan?

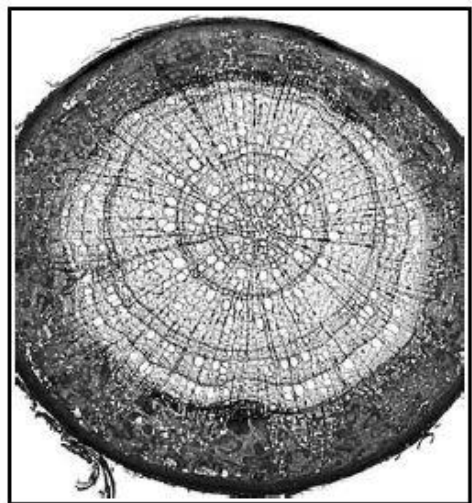
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**Q8.** Gambar di sebelah kanan menunjukkan irisan melintang sebuah organ pada pertumbuhan sekunder. Berdasarkan struktur anatominya, organ tersebut ialah (batang/akar/daun)



\_\_\_\_\_

Berikan alasan-alasan untuk jawaban Anda!

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Sebutkan fungsi-fungsi organ tersebut?

\_\_\_\_\_

\_\_\_\_\_

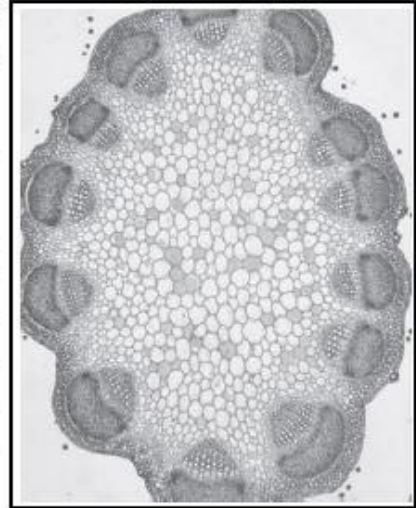
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*(Continued)*



**Q9.** Pada tumbuhan apakah dapat kita jumpai organ seperti yang ditunjukkan oleh gambar di sebelah kanan? (Tumbuhan Monokotil /Dikotil)



\_\_\_\_\_

Berikan alasan-alasan untuk jawaban Anda!

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Sebutkan fungsi-fungsi organ tersebut!

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Q10.** Gambarlah sebuah diagram irisan melintang daun dikotil dan berilah keterangan setiap bagian-bagiannya!

**TERIMA KASIH ATAS PARTISIPASI ANDA**

### **Appendix D3: A Rubric for Assessing Students' Responses to Part 1 of the PADI-II**

Categories	Criteria	Codes
Comprehensive	Overall, each answer responds each question in one item correctly and contained one or more key terms. The explanations are complete, clear, and understandable.	5
Incomplete	Overall, each answer is related to each question in one item and contained one or more key terms. Each explanation seems to be correct but incomplete or unclear.	4
Lack understanding	Overall, one answer is correct, the rest responses in the same item are incorrect, unrelated one another, and inherently incorrect; or two answers are correct but no response to one question.	3
Misconception	Overall, each answer responds each question in one item incorrectly. However, each answer is related one another and inherently correct; or one answer is correct but no response to one question.	2
Incorrect	Overall, each answer responds each question in one item incorrectly; or one answer missing but other responses are incorrect. Each answer is unrelated one another and inherently incorrect.	1
No Response	No responses are provided in two or more questions in one item.	0

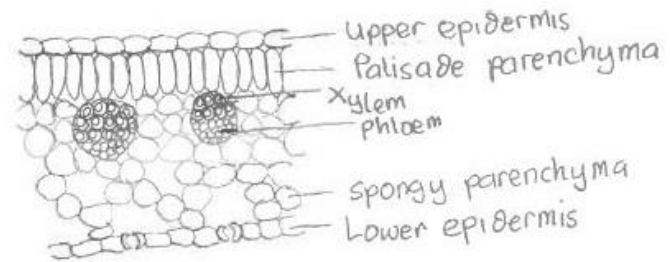
### Appendix D4: A Rubric for Assessing Students' Responses to Part 2 of the PADI-II

Assessment Aspects	Category	Criteria	Score
Drawing	Comprehensive	The drawing includes all basic parts of the organ as mentioned below with correct structure and position.	4
	Misconception	The drawing includes all parts of the organ as mentioned below, but the structure, shape, and/or position are incorrect; or there are unrelated tissues indicating misconception of the represented organ.	3
	Incomplete	The drawing shows the intended anatomical structure of the organ, but one basic parts as mentioned below is missing.	2
	Incorrect	The drawing does not represent the intended anatomical structure of the organ because of most of the basic parts as mentioned below are missing.	1
	No response	No response is provided in the answer sheet.	0
Labelling	Comprehensive	All parts of the drawing are correctly labelled as shown below.	3
	Partial	Some parts of the drawing are correctly labelled, but others are incorrectly or not labelled.	2
	Incorrect	All parts of the drawing are incorrectly labelled; or some parts of the drawing are incorrectly labelled, but others are not labelled; or only two parts are correctly labelled, but others are incorrectly or not labelled.	1
	No response	All parts of the drawing are not labelled.	0



Comprehensive Drawing of Dicot Leaf includes:

1. Upper epidermis
2. Palisade parenchyma
3. Vascular bundle
4. Spongy parenchyma
5. Lower epidermis



**Appendix E**  
**Plant Anatomy Diagnostic Instrument III (PADI-III)**

<b>Appendix E1: The Final Version of the PADI-III.....</b>	<b>196</b>
<b>Appendix E2: An Indonesian Version of the PADI-III .....</b>	<b>201</b>
<b>Appendix E3: A Rubric for Assessing Students' Responses to Part 2 of the PADI-III .....</b>	<b>206</b>

## Appendix E1: The Final Version of the PADI-III

### A PLANT ANATOMY DIAGNOSTIC INSTRUMENT III (PADI-III)

**Direction:** This test consists of two sections designed to examine your understanding of plant anatomy concepts. The first section contains 9 pairs of multiple choice questions. Choose the correct option for each question based on your knowledge. Place the letter in the answer box and the number in the reason box on the answer sheet. If you suppose that none of the options is the correct answer, you may write your own answer on the blank space. However, you need to indicate this by putting number 7 in the reason box. The second section is a drawing test which requires you to draw the anatomical structure of a plant organ. Please write down your answers on the provided answer sheet. Do not forget to record your details on the answer sheet.

#### Section 1: Multiple Choice Questions

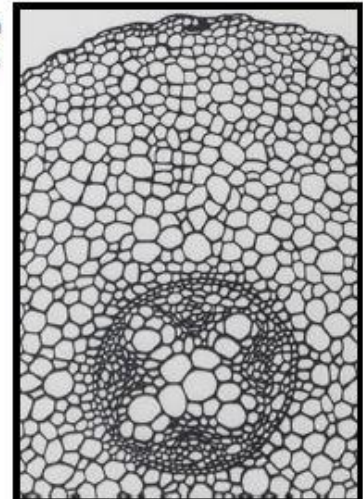
##### Item 1

Under a microscope, a student sees the anatomical structure of an organ similar to the picture on the right. Based on the anatomy, what is the plant organ that the student is observing?

- (A) Stem
- ★ (B) Root
- (C) Leaf

The reason is:

- (1) The xylem is polyarch.
- (2) The type of the vascular bundles is collateral.
- (3) There is a wide cortex.
- ★ (4) The type of the vascular bundles is radial.
- (5) There is an exodermis.
- (6) The xylem is located in the adaxial surface.
- (7) I have my own answer.



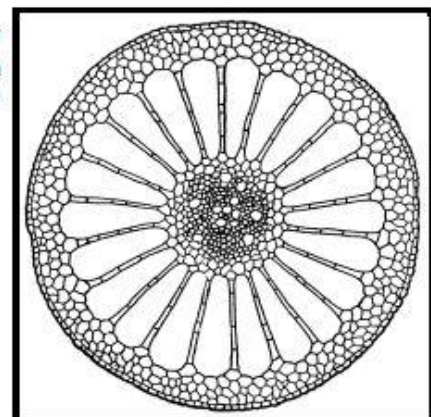
##### Item 2

An agronomist decides to grow a plant in which the anatomy in a cross section shown by the picture on the right. Based on its anatomy, what is the best planting medium for the plant?

- (A) Soil
- (B) Sand
- ★ (C) Water

The reason is:

- (1) The plant has a structure for water storage.
- ★ (2) The plant has a structure for gas exchange.
- (3) The plant has a structure for water flow.
- (4) The plant has a structure for gas storage.
- (5) The plant has a structure to prevent absorption of excess water.
- (6) The plant has a structure for minimise transpiration.
- (7) I have my own answer.



*(Continued)*

## Section 1: Multiple Choice Questions

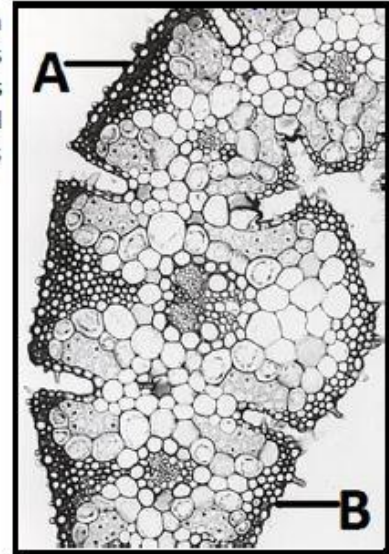
## Item 3

The literature mentions that an adaxial epidermis contains a huge amount of tannin. To test this, a scientist makes a cross section of a leaf then observes it under a microscope. The leaf's anatomy is similar to the picture on the right. To find the adaxial epidermis, which side of the picture should be the focus of his observation?

- (A) Side A
- ★ (B) Side B

The reason is:

- (1) On this side, the cells are thick and compact.
- (2) On this side, there are a small number of stomata.
- (3) On this side, there are a small number of trichomes.
- (4) The phloem is oriented toward this side.
- ★ (5) The xylem is oriented toward this side.
- (6) The chlorenchyme is oriented toward this side.
- (7) I have my own answer.



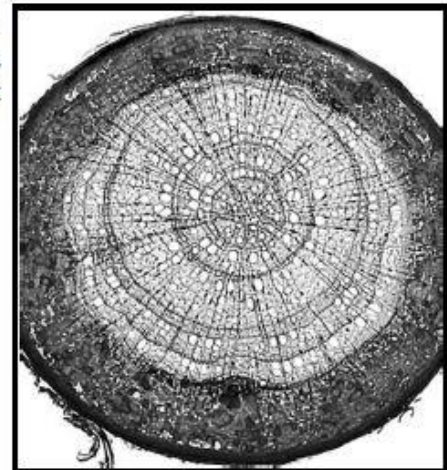
## Item 4

The picture on the right is a cross section of a plant organ. The organ functions to anchor the plant into the substrate, provide a physical support for the plant, and transport water. What is the organ?

- (A) A young stem
- (B) A young root
- (C) An old stem
- ★ (D) An old root

The reason is:

- (1) The vascular bundles are radial.
- (2) The vascular bundles are collateral.
- ★ (3) The primary xylem is retained.
- (4) There are several annual rings.
- (5) The pith is retained in the centre.
- (6) The epidermis is replaced by the periderm.
- (7) I have my own answer.



(Continued)



Section 1: Multiple Choice Questions

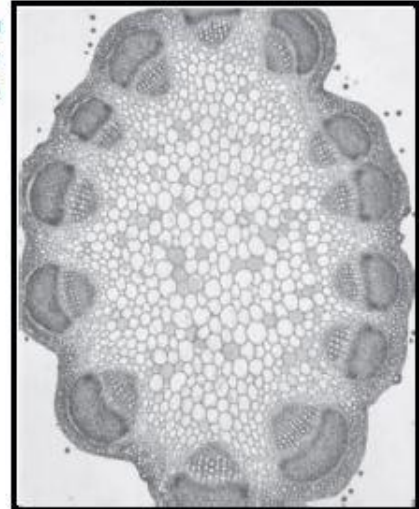
Item 5

A florist asks for your help to find a plant in which the stem anatomy is similar to the picture on the right. As a biology student, what is the plant group you recommend to help the florist?

- ★ (A) Dicotyledon
- (B) Monocotyledon

The reason is:

- (1) The vascular bundles are collateral.
- (2) The vascular bundles are radial.
- (3) The vascular bundles are scattered at the periphery.
- ★ (4) The vascular bundles are arranged in one ring.
- (5) The pith is wide.
- (6) The cortex is narrow.
- (7) I have my own answer.



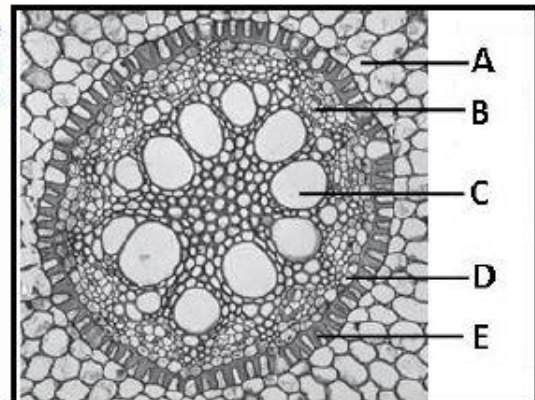
Item 6

A botanist is investigating how a plant prevents the outward leakage of fluids. For this purpose, which part of an organ as shown on the right will be the focus of the investigation?

- (A) Part A
- (B) Part B
- (C) Part C
- (D) Part D
- ★ (E) Part E

The reason is:

- (1) The cells are thick and strong.
- (2) The cells have U-like shapes.
- (3) The cells have thin and permeable cell walls.
- (4) The cells have large cavities in the centre.
- (5) The cells are small and compact.
- ★ (6) The cells have an impermeable strip on their walls.
- (7) I have my own answer.



*(Continued)*

## Section 1: Multiple Choice Questions

## Item 7

To produce a high quality noodle, a chef observes the characteristics of a plant cell component as shown on the right picture. What is the cell component he observes?

- (A) Ergastic substances
- ★ (B) Starch grains
- (C) Crystals
- (D) Sclereids

The reason is:

- (1) The component has an ovate shape and grey colour.
- (2) The component has secondary thickened walls.
- (3) The component contains amyllum.
- (4) The component is transparent and clear like glasses.
- (5) The component has circular strips as an age indicator.
- ★ (6) The component has a hilum and successive lamellae.
- (7) I have my own answer.



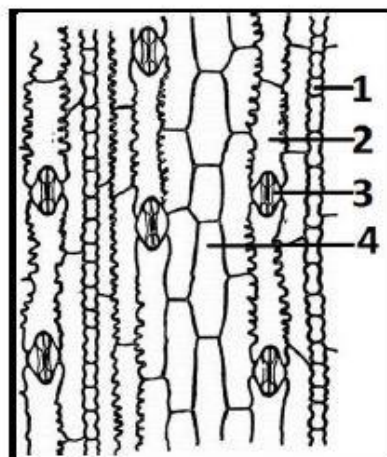
## Item 8

A scientist conducts an experiment to investigate the effect of  $K^+$  concentration in the epidermis on the rate of photosynthesis. To obtain a significant result, which part of the epidermis shown by the picture on the right should be the focus of the scientist's experiment?

- (A) Part 1
- (B) Part 2
- ★ (C) Part 3
- (D) Part 4

The reason is:

- (1) The part functions to facilitate water uptake.
- ★ (2) The part functions to facilitate  $CO_2$  uptake.
- (3) The part functions to facilitate  $O_2$  uptake.
- (4) The part functions to catch sunlight
- (5) The part functions to synthesis carbohydrate.
- (6) The part functions to regulate transpiration rate.
- (7) I have my own answer.



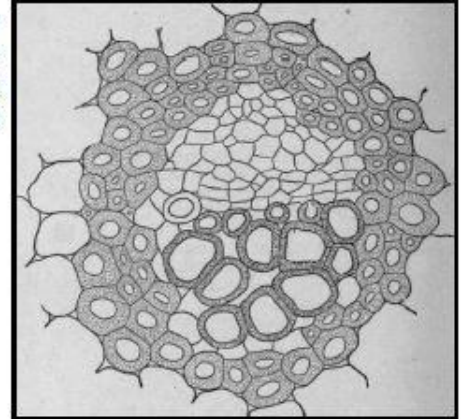
(Continued)



## Section 1: Multiple Choice Questions

## Item 9

Under a microscope, a biology student sees a vascular bundle in a cross section of a stem. The structure of the vascular bundle is similar to the picture on the right. Based on the structure, what is the type of vascular bundle that the student found?



- ★ (A) Collateral
- (B) Bicollateral
- (C) Radial
- (D) Concentric

The reason is:

- (1) The xylem is surrounded by the phloem.
- (2) The phloem is surrounded by the xylem.
- (3) The xylem is located in between the external and internal phloem.
- ★ (4) The xylem is inside the phloem.
- (5) The phloem is inside the xylem.
- (6) The xylem and phloem are located alternately.
- (7) I have my own answer.

Note: The star symbols indicate the correct answers.

## Section 2: Drawing Test

The picture on the right shows leaves of a terrestrial monocotyledonous plant. This C<sub>4</sub>-plant lives in area with high sunlight intensity. To support the C<sub>4</sub> photosynthetic pathway, the leaves develop Kranz anatomy. Besides, during the hot of the day, the leaves are rolled to minimise transpiration. Because of vertical orientation, the stomata can be found in both sides of the leaves. Based on the provided information and the morphological structure of the plant, please draw the anatomy of a cross section of the leaf and label each part of the organ that you think it should be! Please use a pencil so that you can more easily make corrections to your drawing.



## Appendix E2: An Indonesian Version of the PADI-III

Tes Diagnostik Anatomi Tumbuhan



### Bagian 1: Soal Pilihan Ganda

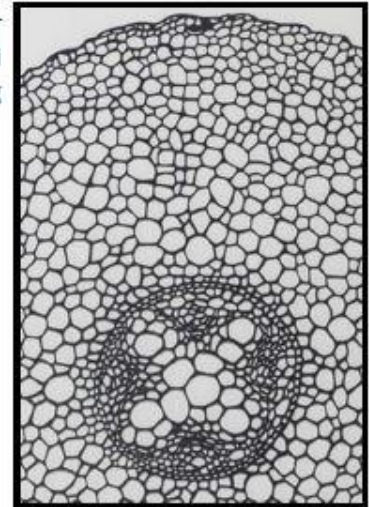
#### Butir 1

Di bawah sebuah mikroskop, seorang mahasiswa melihat struktur anatomi sebuah organ tanaman yang serupa dengan gambar di sebelah kanan. Berdasarkan anatominya, organ apa yang sedang diamati mahasiswa tersebut?

- (A) Batang
- (B) Akar
- (C) Daun

Alasannya ialah:

- (1) Tipe berkas xilemnya poliarch.
- (2) Tipe berkas pengangkutnya kolateral.
- (3) Terdapat korteks yang lebar.
- (4) Tipe berkas pengangkutnya radial.
- (5) Terdapat eksodermis pada bagian tepi.
- (6) Berkas xilem terletak pada permukaan adaksial.
- (7) Saya memiliki jawaban sendiri.



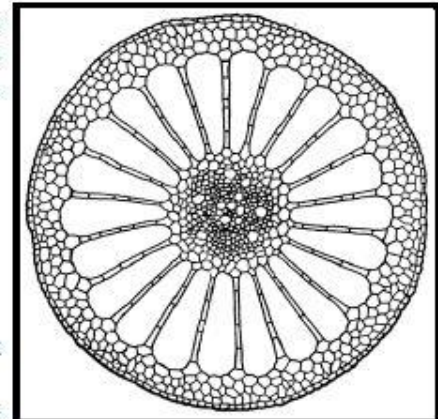
#### Butir 2

Seorang agronomis memutuskan untuk menanam tanaman yang anatominya pada irisan melintang ditunjukkan oleh gambar di sebelah kanan. Berdasarkan anatominya, media tanam apakah yang terbaik untuk tanaman tersebut?

- (A) Tanah
- (B) Pasir
- (C) Air

Alasannya ialah:

- (1) Tanaman tersebut memiliki struktur untuk menyimpan air.
- (2) Tanaman tersebut memiliki struktur untuk pertukaran gas.
- (3) Tanaman tersebut memiliki struktur untuk aliran air.
- (4) Tanaman tersebut memiliki struktur untuk menyimpan gas.
- (5) Tanaman tersebut memiliki struktur untuk mencegah penyerapan air yang berlebih.
- (6) Tanaman tersebut memiliki struktur untuk mengurangi transpirasi.
- (7) Saya memiliki jawaban sendiri.



*(Continued)*



## Bagian 1: Soal Pilihan Ganda

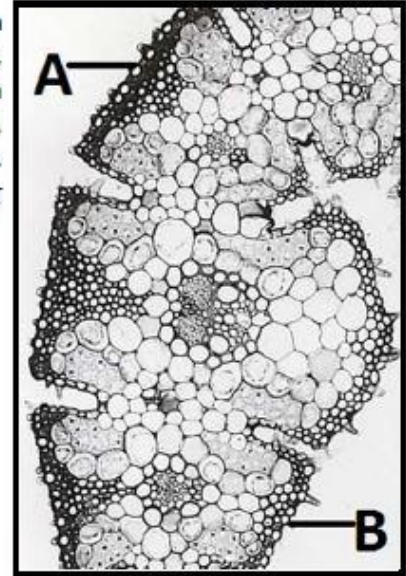
## Butir 3

Sebuah literatur menyebutkan bahwa epidermis adaksial daun mengandung sejumlah besar tanin. Untuk menguji hal tersebut, seorang ilmuwan membuat irisan melintang sebuah daun kemudian mengamati irisan tersebut di bawah mikroskop. Anatomi daun tersebut serupa dengan gambar di sebelah kanan. Untuk menemukan epidermis adaksial, sisi manakah dari gambar yang seharusnya menjadi fokus pengamatan ilmuwan tersebut?

- (A) Sisi A
- (B) Sisi B

Alasannya ialah:

- (1) Pada sisi ini, sel-selnya tebal dan rapat.
- (2) Pada sisi ini, terdapat sejumlah kecil stomata.
- (3) Pada sisi ini, terdapat sejumlah kecil trikomata.
- (4) Berkas floem mengarah pada sisi ini.
- (5) Berkas xilem mengarah pada sisi ini.
- (6) Klorenkim mengarah pada sisi ini.
- (7) Saya memiliki jawaban sendiri.



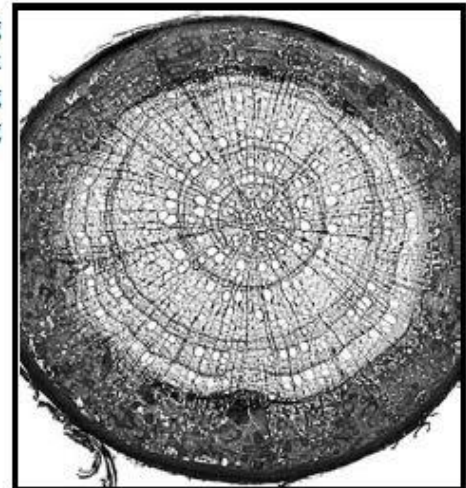
## Butir 4

Gambar di sebelah kanan merupakan irisan melintang sebuah organ tanaman. Organ tersebut berfungsi untuk menancapkan tanaman pada substrat, menyokong tanaman, dan menghantarkan air. Organ apa yang dimaksud?

- (A) Batang muda
- (B) Akar muda
- (C) Batang tua
- (D) Akar tua

Alasannya ialah:

- (1) Berkas pengangkutnya radial.
- (2) Berkas pengangkutnya kolateral.
- (3) Xilem primer dipertahankan di pusat organ.
- (4) Terdapat beberapa lingkaran tahun.
- (5) Empulur tetap dipertahankan di pusat organ.
- (6) Lapisan epidermis telah digantikan oleh lapisan periderm.
- (7) Saya memiliki jawaban sendiri.



(Continued)

## Bagian 1: Soal Pilihan Ganda

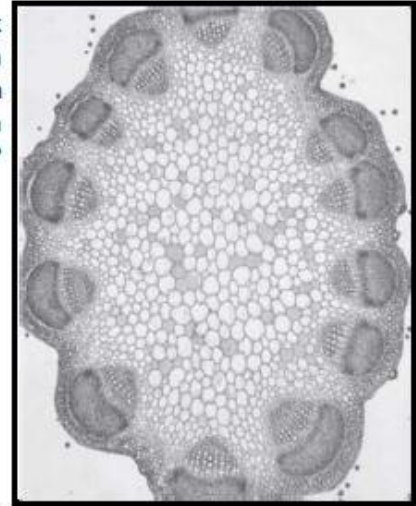
## Butir 5

Seorang penjual tanaman meminta bantuan Anda untuk menemukan sebuah tanaman yang anatomi batangnya serupa dengan gambar di sebelah kanan. Sebagai seorang mahasiswa biologi, kelompok tanaman apa yang akan Anda rekomendasikan untuk membantu penjual tanaman tersebut?

- (A) Dikotiledon
- (B) Monokotiledon

Alasannya ialah:

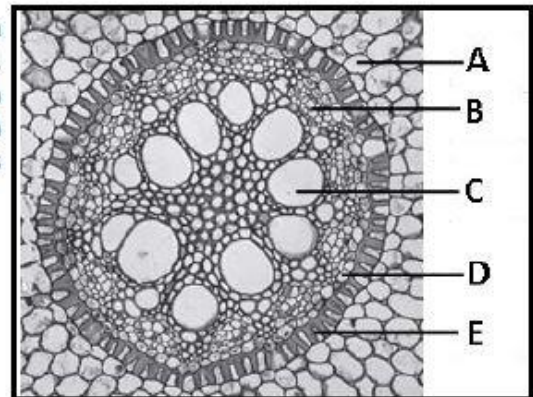
- (1) Berkas pembuluhnya kolateral.
- (2) Berkas pembuluhnya radial.
- (3) Berkas pembuluhnya tersebar di bagian tepi.
- (4) Berkas pembuluhnya tersusun dalam satu lingkaran.
- (5) Empulurnya lebar.
- (6) Korteksnya sempit.
- (7) Saya memiliki jawaban sendiri.



## Butir 6

Seorang botanis sedang menyelidiki bagaimana sebuah tanaman mencegah kebocoran cairan. Untuk tujuan tersebut, bagian manakah dari organ tanaman yang ditunjukkan oleh gambar di sebelah kanan yang akan menjadi fokus penelitian botanis tersebut?

- (A) Bagian A
- (B) Bagian B
- (C) Bagian C
- (D) Bagian D
- (E) Bagian E



Alasannya ialah:

- (1) Sel-selnya tebal dan rapat.
- (2) Sel-selnya memiliki bentuk seperti huruf U.
- (3) Sel-selnya memiliki dinding sel yang tipis dan tembus air.
- (4) Sel-selnya memiliki rongga-rongga besar di bagian pusatnya.
- (5) Sel-selnya kecil dan rapat.
- (6) Sel-selnya memiliki pita tidak tembus air pada dindingnya.
- (7) Saya memiliki jawaban sendiri.

(Continued)



## Bagian 1: Soal Pilihan Ganda

## Butir 7

Untuk menghasilkan mie berkualitas tinggi, seorang juru masak mengamati ciri-ciri sebuah komponen sel tanaman yang ditunjukkan oleh gambar di sebelah kanan. Komponen sel apakah yang sedang diamati oleh juru masak tersebut?



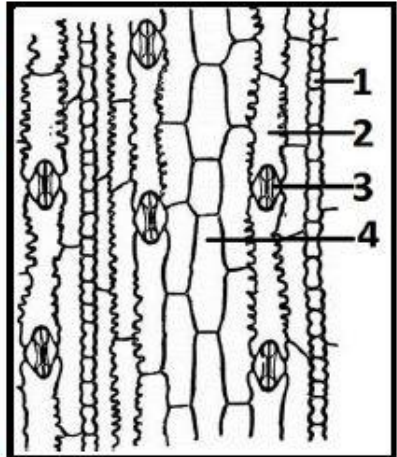
- (A) Zat ergastik
- (B) Butir tepung
- (C) Kristal
- (D) Sklereid

Alasannya ialah:

- (1) Komponen tersebut berbentuk telur dan berwarna abu-abu.
- (2) Komponen tersebut memiliki penebalan dinding sel sekunder.
- (3) Komponen tersebut mengandung amilum.
- (4) Komponen tersebut tembus pandang dan berkilau seperti gelas.
- (5) Komponen tersebut memiliki benang-benang melingkar sebagai penanda umur.
- (6) Komponen tersebut memiliki hilum dan lamella.
- (7) Saya memiliki jawaban sendiri.

## Butir 8

Seorang ilmuwan melakukan sebuah penelitian untuk menyelidiki pengaruh konsentrasi  $K^+$  pada epidermis terhadap kecepatan fotosintesis. Untuk memperoleh hasil yang signifikan, bagian epidermis manakah yang ditunjukkan oleh gambar di sebelah kanan yang seharusnya menjadi fokus penelitian ilmuwan tersebut?



- (A) Bagian 1
- (B) Bagian 2
- (C) Bagian 3
- (D) Bagian 4

Alasannya ialah:

- (1) Bagian tersebut berfungsi untuk mempermudah penyerapan air.
- (2) Bagian tersebut berfungsi untuk mempermudah penyerapan  $CO_2$ .
- (3) Bagian tersebut berfungsi untuk mempermudah penyerapan  $O_2$ .
- (4) Bagian tersebut berfungsi untuk menangkap cahaya.
- (5) Bagian tersebut berfungsi untuk mensintesis karbohidrat.
- (6) Bagian tersebut berfungsi untuk mengatur kecepatan transpirasi.
- (7) Saya memiliki jawaban sendiri.

(Continued)

## Bagian 1: Soal Pilihan Ganda

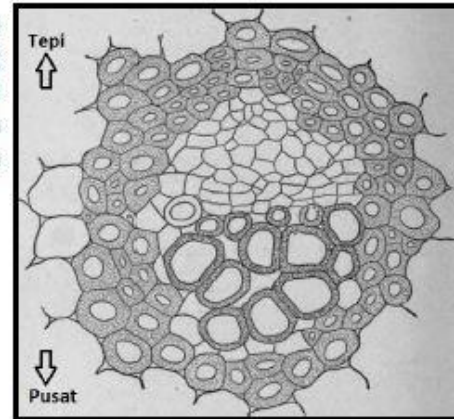
## Butir 9

Di bawah sebuah mikroskop, seorang mahasiswa biologi melihat sebuah berkas pembuluh pada irisan melintang sebuah batang. Struktur berkas pembuluh tersebut serupa dengan gambar di sebelah kanan. Berdasarkan strukturnya, berkas pengangkut tipe apa yang ditemukan oleh mahasiswa tersebut?

- (A) Kolateral
- (B) Bikolateral
- (C) Radial
- (D) Konsentrik

Alasannya ialah:

- (1) Berkas xilem dikelilingi oleh berkas floem.
- (2) Berkas floem dikelilingi oleh berkas xilem.
- (3) Berkas xilem terletak di antara floem eksternal dan internal.
- (4) Berkas xilem terletak di sebelah dalam berkas floem.
- (5) Berkas floem terletak di sebelah dalam berkas xilem.
- (6) Berkas xilem dan floem terletak berselang-seling.
- (7) Saya memiliki jawaban sendiri.



## Bagian 2: Tes Menggambar

Gambar di sebelah kanan menunjukkan daun-daun sebuah tanaman darat monokotil. Tanaman C-4 ini hidup di area dengan intensitas cahaya matahari tinggi. Untuk memfasilitasi jalur fotosintesis C4, daun-daun tersebut memiliki Kranz anatomi. Selain itu, ketika panas terik, daun-daun tersebut menggulung untuk mengurangi transpirasi. Karena orientasinya yang vertikal, stomata dapat ditemukan pada kedua sisi daun. Berdasarkan informasi tersebut dan struktur morfologi tanaman yang ditunjukkan oleh gambar di sebelah kanan, gambarlah anatomi irisan melintang daun tersebut dan berilah label setiap bagian organ tersebut! Gunakan pensil untuk menggambar sehingga Anda mudah melakukan perbaikan.



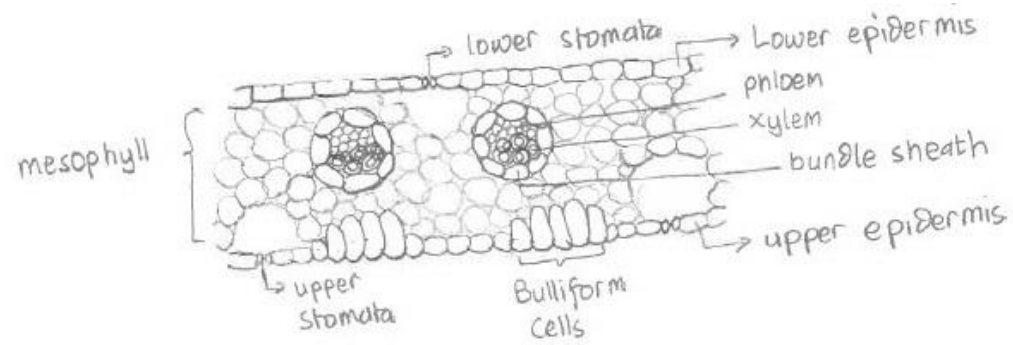
**TERIMA KASIH ATAS PARTISIPASI ANDA**

### Appendix E3: A Rubric for Assessing Students' Responses to Part 2 of the PADI-III

Assessment Aspects	Category	Criteria	Score
Drawing	Comprehensive	The drawing includes all basic parts of the organ as mentioned below with correct structure and position.	4
	Misconception	The drawing includes all parts of the organ as mentioned below, but the structure, shape, and/or position are incorrect; or there are unrelated tissues indicating misconception of the represented organ.	3
	Incomplete	The drawing shows the intended anatomical structure of the organ, but one basic parts as mentioned below is missing.	2
	Incorrect	The drawing does not represent the intended anatomical structure of the organ because of most of the basic parts as mentioned below are missing.	1
	No response	No response is provided in the answer sheet.	0
Labelling	Comprehensive	All parts of the drawing are correctly labelled as shown below.	3
	Partial	Some parts of the drawing are correctly labelled, but others are incorrectly or not labelled.	2
	Incorrect	All parts of the drawing are incorrectly labelled; or some parts of the drawing are incorrectly labelled, but others are not labelled; or only two parts are correctly labelled, but others are incorrectly or not labelled.	1
	No response	All parts of the drawing are not labelled.	0

Comprehensive Drawing of Monocot Leaf includes:

1. Upper epidermis
2. Bulliform cells
3. Upper stomata
4. Mesophyll
5. Bundle sheath
6. Vascular bundle
7. Lower epidermis
8. Lower stomata



## **Appendix F**

### **Interview Protocol with Students**

**Research:** Students' interpretations of plant anatomy representations.

**Time of Interview:**

**Date:**

**Place:**

**Interviewer:**

**Interviewee:**

**Introduction:**

- ✓ Interviewer introduces herself.
- ✓ Explaining student information sheet.
- ✓ Explaining consent form and have the interviewee to sign it.
- ✓ Giving the diagnostic tests that have been completed by the interviewee.
- ✓ Turning on an audiotape.

**Questions:**

1. What do you think about the test?
2. Can you recognize a picture of these test items? (How do you identify the picture?)
3. Have you seen the pictures in these test items before? (Where?)
4. Would you explain to me how you answer these test items?
5. How did you identify the cells or the tissues? (Based on the colour, the shape, or the position).
6. Which was the most difficult test item? Why?
7. Which was the easiest test item? Why?
8. Did you compare the pictures in the test item number 1 and 5? Why? (How did you compare them?)
9. Overall, do the second and third questions help you answer the first and fourth questions for each test item?
10. For the drawing test, what did you do first to draw these pictures?
11. What did you remember to draw these pictures?
12. Would you explain to me what you drew?
13. Why did you draw these pictures?
14. Why did you think that the plant's organs have anatomical structures like you drew?

(Thank the interviewee for their cooperation and participation in this interview).

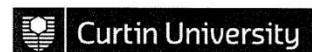
## **Appendix G**

### **Informed Consent**

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<b>Appendix G2: Dean Information Sheet.....</b>	<b>211</b>
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<b>Appendix G4: Lecturer Information Sheet .....</b>	<b>213</b>
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<b>Appendix G6: Student's Consent Form.....</b>	<b>215</b>



## Appendix G1: Ethics Approval



### Memorandum

<b>To</b>	Enny Susiyawati, SMEC
<b>From</b>	Mun Yin Cheong, Form C Ethics Co-ordinator Faculty of Science and Engineering
<b>Subject</b>	Protocol Approval <b>SMEC-28-14</b>
<b>Date</b>	26 May 2014
<b>Copy</b>	David Treagust, SMEC

Office of Research and Development  
Human Research Ethics Committee  
Telephone 9266 2784  
Facsimile 9266 3793  
Email hrec@curtin.edu.au

Thank you for your "Form C Application for Approval of Research with Low Risk (Ethical Requirements)" for the project titled "*Student interpretations of texts and pictures and student-generated drawings of plant anatomy*". On behalf of the Human Research Ethics Committee, I am authorised to inform you that the project is approved.

Approval of this project is for a period of 4 years **17<sup>th</sup> May 2014 to 16<sup>th</sup> May 2018**.

Your approval has the following conditions:

- (i) Annual progress reports on the project must be submitted to the Ethics Office.
- (ii) **It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.**

The approval number for your project is **SMEC-28-14**. Please quote this number in any future correspondence. If at any time during the approval term changes/amendments occur, or if a serious or unexpected adverse event occurs, please advise me immediately.

Regards,

*Mun Yin*

MUN YIN CHEONG  
Form C Ethics Co-ordinator  
Faculty of Science and Engineering

---

Please Note: The following standard statement must be included in the information sheet to participants:  
*This study has been approved under Curtin University's process for lower-risk Studies (Approval Number xxxx). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21). For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.*

CRICOS Provider Code 00301J

## Appendix G2: Dean Information Sheet



Curtin University

Science and Mathematics  
Education Centre

GPO Box U1987  
Perth Western Australia 6845

### Dean Information Sheet

Faculty of Mathematics and Natural Sciences  
The State University of Surabaya  
Prof. Dr. Suyono, M.Pd.  
Jl. Ketintang, Surabaya 60231  
East Java, Indonesia

Dear Mr. Prof. Dr. Suyono, M.Pd.,

My name is Enny Susiyawati. I am currently completing a piece of research for my Doctoral Degree of Science and Mathematics Education at Curtin University, Western Australia.

#### **Purpose of Research**

I am investigating students' interpretation of texts and pictures and their-generated drawings of plant anatomy.

#### **Your Role**

I am seeking your permission to conduct research by asking for biology and education students of Biology Department to take part in short diagnostic tests on plant anatomy. The results of the tests will be given back to the students after the completion of the test.

I may also ask for the students' participation in a short interview (individual) about their interpretations of texts and pictures and their-generated drawings of plant anatomy. The semi-structured interview process will take approximately 30 minutes.

#### **Consent to Participate**

The students and your faculty's involvement in the research are entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form, I will assume that you have agreed to give me permission to conduct research and allow me to use students' data in this research.

#### **Confidentiality**

The information provided will be kept separate from students' personal details, and only myself and my supervisor will have access to this. The interview transcript will not have student names or any other identifying information on it and, in adherence to university policy, the interview tapes and transcribed information will be kept by me in electronic form on an external hard drive with password protection for at least seven years after which they will be destroyed.

#### **Further Information**

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number **SMEC-28-14**). If you would like further information about the study, please feel free to contact me. If you would like further information about the research, please feel free to contact me on +62 85730518325 or +61 424787351 or by email [enny.susiyawati@posgrad.curtin.edu.au](mailto:enny.susiyawati@posgrad.curtin.edu.au) or [susiyawatienny@gmail.com](mailto:susiyawatienny@gmail.com). Alternatively, you can contact my supervisor Prof. David F. Treagust on +61 8 9266 7924 or email [d.treagust@curtin.edu.au](mailto:d.treagust@curtin.edu.au).

**Thank you very much for your involvement in this research.**

**Your participation is greatly appreciated.**

1 of 2

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CRICOS Provider Code 00301J (WA), 02637B (NSW)

## Appendix G3: Head of Department Information Sheet



Curtin University

Science and Mathematics  
Education Centre

GPO Box U1987  
Perth Western Australia 6845

### Head of Department Information Sheet

Biology Department  
Faculty of Mathematics and Natural Sciences  
The State University of Surabaya  
Dr. Raharjo, M.Si.  
Jl. Ketintang, Surabaya 60231  
East Java, Indonesia

Dear Mr. Dr. Raharjo, M.Si.,

My name is Enny Susiyawati. I am currently completing a piece of research for my Doctoral Degree of Science and Mathematics Education at Curtin University, Western Australia.

#### Purpose of Research

I am investigating students' interpretation of texts and pictures and their-generated drawings of plant anatomy.

#### Your Role

I am seeking your permission to conduct research by asking for biology and education students of Biology Department to take part in short diagnostic tests on plant anatomy. The results of the tests will be given back to the students after the completion of the test.

I may also ask for the students' participation in a short interview (individual) about their interpretations of texts and pictures and their-generated drawings of plant anatomy. The semi-structured interview process will take approximately 30 minutes.

#### Consent to Participate

The students and your department's involvement in the research are entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form, I will assume that you have agreed to give me permission to conduct research and allow me to use students' data in this research.

#### Confidentiality

The information provided will be kept separate from students' personal details, and only myself and my supervisor will have access to this. The interview transcript will not have student names or any other identifying information on it and, in adherence to university policy, the interview tapes and transcribed information will be kept by me in electronic form on an external hard drive with password protection for at least seven years after which they will be destroyed.

#### Further Information

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number **SMEC-28-14**). If you would like further information about the study, please feel free to contact me. If you would like further information about the research, please feel free to contact me on +62 85730518325 or +61 424787351 or by email [enny.susisyawati@posgrad.curtin.edu.au](mailto:enny.susisyawati@posgrad.curtin.edu.au) or [susiyawatienny@gmail.com](mailto:susiyawatienny@gmail.com). Alternatively, you can contact my supervisor Prof. David F. Treagust on +61 8 9266 7924 or email [d.treagust@curtin.edu.au](mailto:d.treagust@curtin.edu.au).

1 of 2

**Thank you very much for your involvement in this research.  
Your participation is greatly appreciated.**

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## Appendix G4: Lecturer Information Sheet



Curtin University

Science and Mathematics  
Education Centre

GPO Box U1987  
Perth Western Australia 6845

### Lecturer Information Sheet

Dear Lecturer,

My name is Enny Susiyawati. I am currently completing a piece of research for my Doctoral Degree of Science and Mathematics Education at Curtin University, Western Australia.

#### **Purpose of Research**

I am investigating students' interpretation of texts and pictures and their-generated drawings of plant anatomy.

#### **Your Role**

I am seeking your permission to conduct research by asking for your biology and education students to take part in short diagnostic tests on plant anatomy. The results of the tests will be given back to the students after the completion of the test.

I may also ask for the students' participation in a short interview (individual) about their interpretations of texts and pictures and their-generated drawings of plant anatomy. The semi-structured interview process will take approximately 30 minutes.

#### **Consent to Participate**

Your students and classes' involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form, I will assume that you have agreed to participate and allow me to use your data in this research.

#### **Confidentiality**

The information you provide will be kept separate from your personal details, and only myself and my supervisor will have access to this. The interview transcript will not have your name or any other identifying information on it and, in adherence to university policy, the interview tapes and transcribed information will be kept by me in electronic form on an external hard drive with password protection for at least seven years after which they will be destroyed.

#### **Further Information**

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number **SMEC-28-14**). If you would like further information about the study, please feel free to contact me. If you would like further information about the research, please feel free to contact me on +62 85730518325 or +61 424787351 or by email [enny.susiyawati@posgrad.curtin.edu.au](mailto:enny.susiyawati@posgrad.curtin.edu.au) or [susiyawatienny@gmail.com](mailto:susiyawatienny@gmail.com). Alternatively, you can contact my supervisor Prof. David F. Treagust on +61 8 9266 7924 or email [d.treagust@curtin.edu.au](mailto:d.treagust@curtin.edu.au).

**Thank you very much for your involvement in this research.  
Your participation is greatly appreciated.**



## Appendix G5: Student Information Sheet



Curtin University

Science and Mathematics  
Education Centre

GPO Box U1987  
Perth Western Australia 6845

### Student Information Sheet

Dear Student,

My name is Enny Susiyawati. I am currently completing a piece of research for my Doctoral Degree of Science and Mathematics Education at Curtin University, Western Australia. I would like to invite you to participate in the research that focuses on multiple representations.

#### **Purpose of Research**

I am investigating students' interpretation of texts and pictures and their-generated drawings of plant anatomy.

#### **Your Role**

I am interested in finding out how you interpret texts and pictures and generate drawing of plant anatomy by administering two types of diagnostic tests. The tests will take approximately 30 minutes to be responded.

#### **Consent to Participate**

Your involvement in the research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or my responsibilities. When you have signed the consent form, I will assume that you have agreed to participate and allow me to use your data in this research.

#### **Confidentiality**

The information you provide will be kept separate from your personal details, and only myself and my supervisor will have access to this. In adherence to university policy, the information will be kept by me in electronic form on an external hard drive with password protection for at least seven years after which they will be destroyed, whereas the original data in form of papers will be destroyed at the conclusion of this research.

#### **Further Information**

This research has been reviewed and given approval by Curtin University Human Research Ethics Committee (Approval Number **SMEC-28-14**). If you would like further information about the study, please feel free to contact me. If you would like further information about the research, please feel free to contact me on +62 85730518325 or +61 424787351 or by email [enny.susiyawati@posgrad.curtin.edu.au](mailto:enny.susiyawati@posgrad.curtin.edu.au) or [susiyawatienny@gmail.com](mailto:susiyawatienny@gmail.com). Alternatively, you can contact my supervisor Prof. David F. Treagust on +61 8 9266 7924 or email [d.treagust@curtin.edu.au](mailto:d.treagust@curtin.edu.au).

**Thank you very much for your involvement in this research.  
Your participation is greatly appreciated.**

## Appendix G6: Student's Consent Form



Curtin University

Science and Mathematics  
Education Centre

GPO Box U1987  
Perth Western Australia 6845

### STUDENT'S CONSENT FORM

- 
- I understand the purpose and procedures of the study.
  - I have been provided with the participation information sheet.
  - I understand that the procedure itself may not benefit me.
  - I understand that my involvement is voluntary and I can withdraw at any time without problem.
  - I understand that no personal identifying information like my name, address or school will be used in any published materials.
  - I understand that all information will be securely stored for at least 7 (seven) years before a decision is made as to whether it should be destroyed.
  - I understand that updates of the progress of the research will be provided to me.
  - I have been given the opportunity to ask questions about this research.
  - I agree to participate in the study outlined to me.
- 

Name: \_\_\_\_\_

Signature: \_\_\_\_\_

Date: \_\_\_\_\_