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Plant Anatomy: Definition, Classification of Plant Organs and Tissue, and Design of a Visuospatial Transformation Learning Model for Teaching Biology

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ABSTRACT

This research aims to develop a 3-dimensional (3D)-based learning model with Visuospatial Transformation Learning (VTL). We used the Design-Based Research (DBR) research method which was tested on fifth-semester biology students regarding plant anatomy material. The results showed an increase in visual representation abilities in the high category. Students can identify cell shapes in detail based on cell and tissue structures. The VTL model provides a dynamic learning experience. Visualization and transformation of 2D into 3D is easy to understand because students have gone through the learning stages using VTL including (i) independent learning, (ii) making concept maps, (iii) discussing concept maps, (iv) practicum and 2D representation, and (v) representation 3D so students can understand the structure of plant tissues and organs in detail. The VTL model is recommended for learning other abstract material. The impact of using this model is that students can understand abstract material more quickly and help the development of science and its application better.

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1. INTRODUCTION

Plant anatomy as a branch of biological science focuses its study on the structure and function of the inside of plants. The inside of plants, which consists of various forms of cells, has a crucial role in building the plant's system of tissues and organs. The rapid development of technology not only has an impact on other fields but is also relevant for plants as a source of life. Students need to deeply understand plant structures to develop relevant plant sciences in the future. Plant anatomy, whose discussion tends to be microscopic and complex (Okura, 2022; Duncan *et al*., 2022), demands to be imagined in real conditions because they are abstract. Two-dimensional (2D) images are considered less representative because they only show a single perspective. Therefore, to improve students' understanding of analyzing cell types, positions, and morphogenetic processes of plants, the use of more representative 3 dimensional (3D) images is needed (Cerutti *et al*., 2017; Montenegro-Johnson *et al*., 2019).

Modern society today is already dependent on technology. Technology that has developed extraordinarily has an impact on all fields, including education. Learning technology in the form of applications has been widely used. Visual and visuospatial modeling of plant anatomical structures requires technology. 3D modeling of cells, tissues, and organs helps in accurately characterizing plant morphology, allowing anatomical analysis at various scales at the cell, tissue to organ levels (Morales-Navarrete *et al*., 2015; Atkinson & Wells, 2017; Burgess & Majda, 2022).

Visuospatial skills are important in plant anatomy material because these skills are multicomponent processes. This multicomponent process consists of synthesizing parts into a whole, constructing, understanding spatial orientation, and creating models using fine motor movements. Visuospatial construction is the transformation and construction of a model that is presented spatially (Kim & Cameron, 2016).

This study aims to develop a Visuospatial Transformation Learning (VTL) model that involves learning technology to facilitate the understanding of the concept of plant anatomical structures. The 3D technology used in the VTL model is expected to be able to improve students' visual representation skills.

The development of visuospatial (3D)-based learning and its transformation using 3D technology has begun to be carried out. The concept of 3D transformation that is difficult for students to face. The results showed that students lacked spatial reasoning skills to interpret 3D transformation images. A computational model based on the generative manifold model, which can be used to deduce the 3D structure of 2D.

Visuospatial-based research referred to as the Wimba learning model has been carried out by Suprapto *et al*. (2018). In this study, they analyzed spatial intelligence and learning outcomes and how both can support creativity. The results of this study show that spatial intelligence and learning outcomes can support students' creativity in plant anatomy courses. Suprapto *et al*. (2020) also researched the use of 3D software in plant anatomy courses. The results show that the results of 3D assessments made by students still tend to be low, which is caused by a lack of mastery of concepts and a lack of training time in the use of software. Therefore, the novelty of this study is to create a 3D transformation learning model or VTL with learning technology.

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2. LITERATURE REVIEW

2.1. Learning Technology

Learning technology as a means of communication, information, and technology, has a crucial role in improving learning, teaching, and assessment. Digital Learning Technology (DLT) is often used to complement classroom activities with computer-based learning. The use of modern technology in learning integrates communication and information tools to facilitate student interaction. This revolutionized the way knowledge is shared and acquired (Greener, 2017). Modern technology expands the scope of learning from classroom constraints to a more dynamic and flexible learning environment.

Digital Learning Technology (DLT) plays an important role in advancing education and manufacturing various advanced products. Technology in learning is useful for enriching content and improving learning skills. However, the use of DLT can result in dependence on technology. The development of digital skills in students needs to be integrated with balanced technology. Learning technology integrates theory and practice in the design, development, utilization, management, and evaluation of learning processes and resources (Greener, 2017). Learning technology can be used to create products that help students in identification and training to produce products. This is a complete unity to improve the learning outcomes of students in the learning process in the educational unit.

2.2. Development of Visuospatial (3D)-Based Learning Models

3D-based learning is an innovative approach to education that covers various aspects. This learning aims to improve the understanding of geometry and student engagement. The use of 3D objects and deep learning algorithms is integrated in applications such as augmented reality, and robotics (Alaba & Ball, 2023). 3D-based learning can provide an interactive and comprehensive learning experience in various disciplines.

The development of 3D models requires good 2D representations. This ability of visual representation determines the quality of its 3D results. This visual representation ability is facilitated by the Wimba learning model. This model includes four stages, namely: (i) literacy by reading books on plant anatomy, (ii) making concept maps, (iii) class discussion, discussing the results of concept maps that have been made and material presentations, then (iv) practicum and 2D representation. Then create 3D using the 3D playdough app.

Visuospatial skills as a multicomponent process involve several important stages. These stages include (i) the synthesis of parts into a whole, (ii) the ability to build and manipulate visual representations, and (iii) the ability to perceive and understand spatial orientation. In addition, visuospatial skills also involve the ability to make models using fine motor movements. Visuospatial construction essentially involves the transformation and construction of a spatially presented model (Kim & Cameron, 2016). In this context, visuospatial skills have an important role in facilitating a deep understanding of complex objects or phenomena in various fields of science, including in the context of education and scientific research.

2.3. Plant Anatomy

Plants have a very important role in ecosystems and human life. Plants can carry out photosynthesis, producing organic matter and oxygen (Rjosk *et al.*, 2022; Usman *et al.*, 2014). In ecology, plants are the basis of the food chain (Roth-Nebelsick & Krause, 2023) and can produce a variety of natural compounds needed for treatment (Ibrahim *et al.*, 2022). In addition, plants also can adapt to their environment. They can stand upright bearing their

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weight and adjust their posture (Liu *et al*., 2023). Some plants can attach to other plants to carry out their functions. In addition to playing a role in photosynthesis and the food chain, plants also function for water and soil conservation by their sturdy roots and stems being able to withstand soil particles. Plants that have mechanical strength such as woody plants and strong but flexible sclerenchymal tissues are also widely utilized (Słupianek *et al*., 2021). Therefore, the role of plants in ecology, health, and economics cannot be doubted.

The plant body consists of roots, stems, leaves, flowers, and seeds (**Figure 1**) (Usman *et al*., 2014). Each plant organ has a specific function. Roots play a role in supporting the plant's body and are in charge of absorbing water, and minerals as well as storing food reserves. Plant stems serve as transportation channels to transport water, and mineral salts, and distribute the results of photosynthesis throughout the plant body.

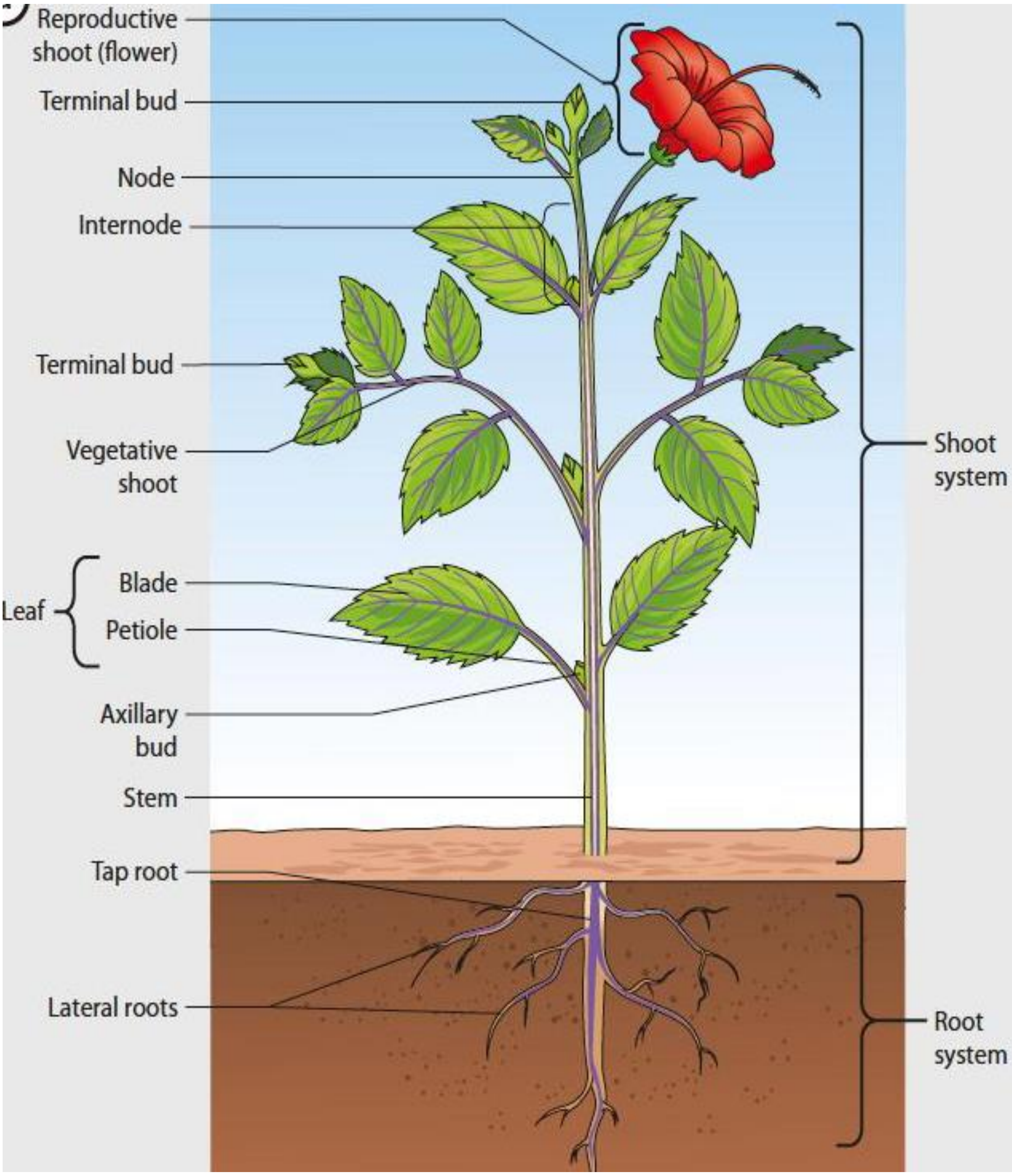

Figure 1. Flowering plant body (Angiosperm) (Crang *et al*., 2018).

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The main function of the leaf is to carry out the process of photosynthesis which forms organic matter as a store of energy and produces oxygen. Leaves also act as a means of respiration and transpiration for plants and can be used as a tool for vegetative reproduction. On the other hand, flowers play a very important role in the life of plants. Flowers are reproductive organs that play a role in the pollination and fertilization process, as well as producing reproductive structures such as pistils and stamens.

Plant anatomy is a field of science that studies the structure and function of various parts of plants. Plants consist of cells that are composed of various types of basic tissues, including parenchyma, colony, sclerenchyme, as well as vascular tissue and epidermis. Each type of plant tissue has a specific role in strengthening the structure of plant organs such as roots, stems, leaves, flowers, fruits, and seeds.

The process of forming these tissues supports the vital functions of plants in the process of metabolism, growth, and adaptation to the environment. The study of plant anatomy is not only important for understanding the basic structure but also for revealing the complexity of the interactions between the various components in plant ecosystems, which play a role in maintaining ecological balance and supporting the life of other creatures on earth.

The plant organ consists of several parts, including:

(i) Root organs. Roots have the main function as plant organs that are responsible for absorbing water and minerals needed for growth. In addition, the roots act as a support and support for the plant body as a whole. The root structure consists of several main parts, including the epidermis which is equipped with root hairs (**Figure 2**), cortex, and meristem tissue. The cortex itself is composed of parenchyma tissue and vascular tissue that play a role in the process of transporting important substances through the roots. Inside the cortex are also pericycles, where root branches grow (**Figure 3**). The roots serve as a storage ground for food reserves, as is the case with root tubers (*Ipomoea batatas*).

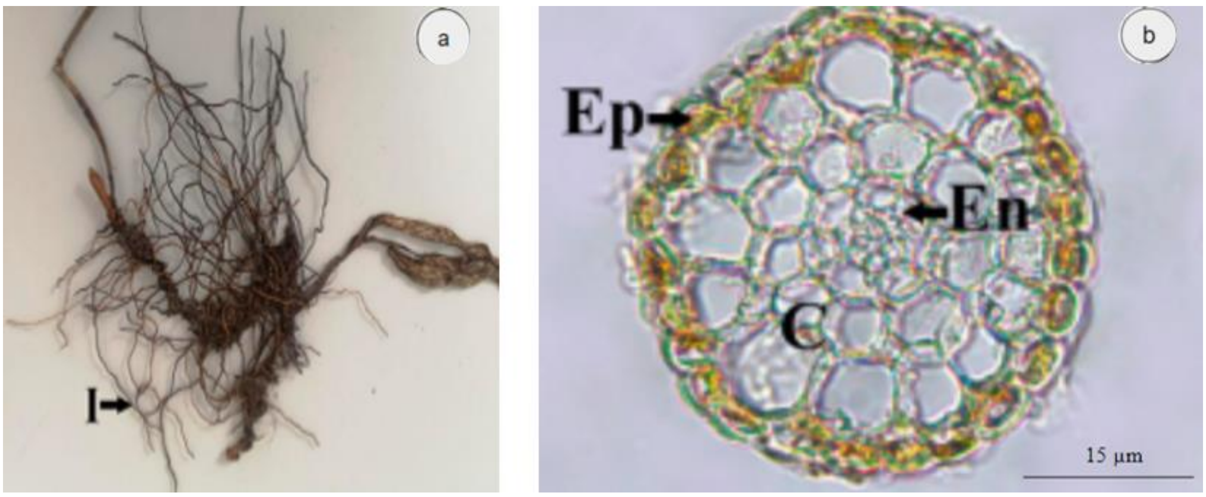

Figure 2. Root section: (a) root organ; (b) microscopic cross-section of young root, Ep: Epidermis, En: Endodermis.

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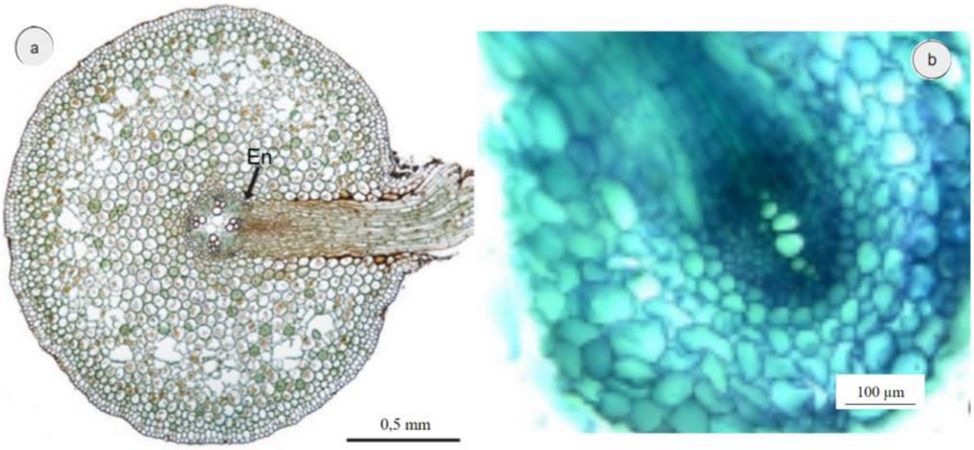

Figure 3. Root Branch section: (a) Cross-section root with tetra acrh; (b) Cross-section of young root (Crang *et al*., 2018).

(ii) Stem organs (**Figure 4**): Plant stems act as supports, a means of transporting water and minerals to the ends of plants through the xylem (Dutra *et al*., 2023). The stem also acts as a means of transporting photosynthetic organic matter that is circulated from the leaves to the rest of the plant body through the phloem (**Figure 4a**). The stem is used as a place for the growth of leaves and flowers. In the secondary growth of the stem, there is a liginification of the xylem wall (**Figure 4b**) which serves as a support and reinforcement of the plant. Secondary growth of the stem can reach a height of 100 meters. The mechanical strength of stems can be harnessed for various human needs and the mechanical design principles of plant stems can be an inspiration for the development of advanced biomimetic materials as well as influence materials science and engineering research (Poppinga *et al*., 2020).

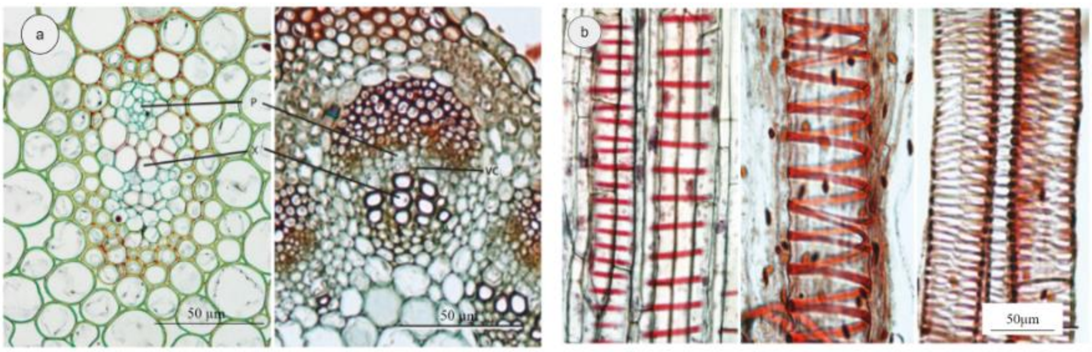

Figure 4. The stem as a reinforcer and the stem containing the transport tissue (Crang *et al*., 2018). Figure (a) is thickening of sclerenchyma and vascular tissue, and Figure (b) is lignification of the xylem wall.

(iii) Leaf organs Leaves play an important role in the photosynthesis process to produce organic matter as the main source of energy for living things (Roth-Nebelsick & Krause, 2023). This process is characterized by the presence of chlorophyll as a green color on the leaves. The color is produced by chlorophyll pigments. In addition to producing organic matter, photosynthesis also produces oxygen which is vital for aerobic living things for respiration through stomata (see **Figures 5** and **6**). The structure of the leaf is made up of several types of tissues, including the epidermis, the mesophyll made up of palisade and spongy mesophyll, as well as sclerenchymal tissue and vascular tissue,

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which work synergistically to support these vital functions in plant life and its ecosystems.

Figure 5. Cross-section of dicot leaves by Morrow in 2023 in book entitled "Photographic Atlas for Botany, College of the Redwoods, Eureka, CA, USA., LibreTexts".

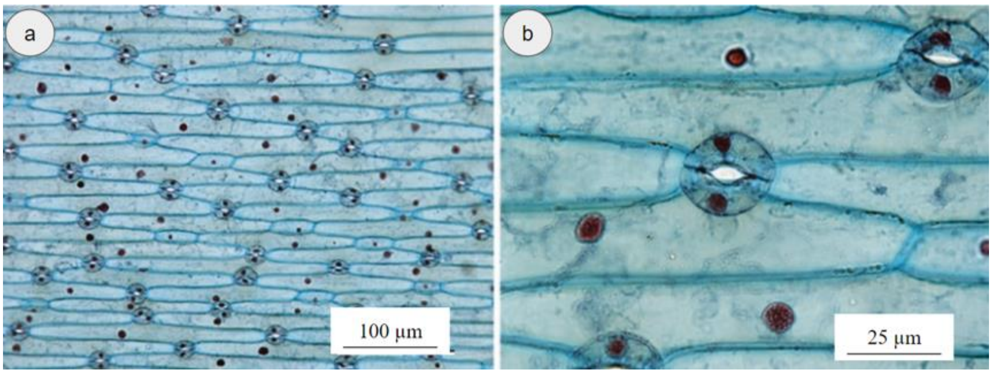

Figure 6. Paradermal section: (a) Epidermis and (b) leaf stomata (Crang *et al*., 2018).

(iv) Reproductive organs plant reproduction can occur in two main ways, namely vegetative and generative. The vegetative reproduction process generally involves plant parts such as roots, stems, and leaves, both in conventional contexts and by using modern methods such as tissue culture. On the other hand, generative reproduction occurs through flowers, which are usually made up of parts such as pistils (carpels) and stamens **(Figure 7)**. The structure of the flower is more detailed consisting of sepals, petals, and peduncles, which are composed of parenchyma tissue and vascular tissue to support the plant's generative reproduction process efficiently and complexly.

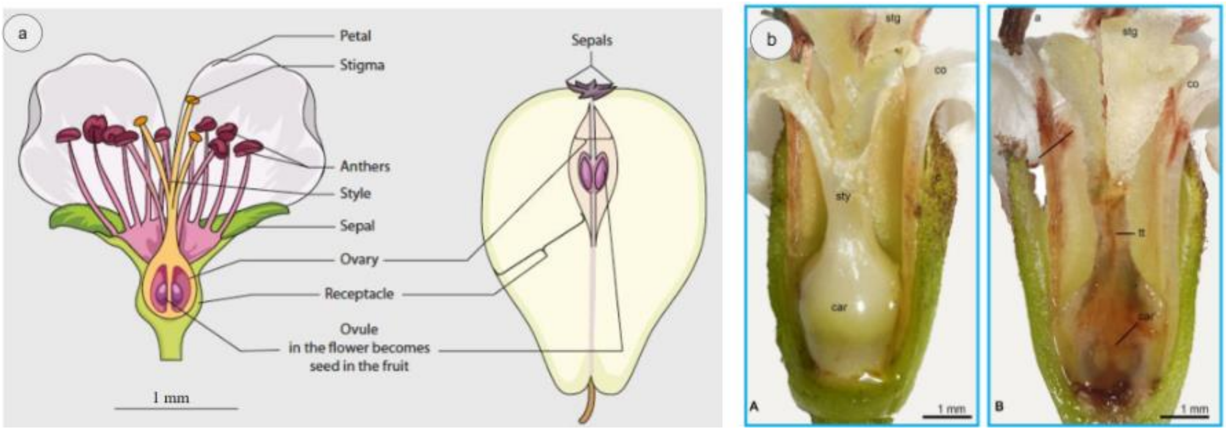

Figure 7. Flower parts (a) (Crang, 2018) and Flower reproduction organ (b) (Pätzold *et al*., 2023). Note: Stg: stigma, a: anther, sty: style, co: corolla, car: carpel. Figure (b) is divided by 2 images: left side (A) is the external view, and right side is slice of the floral organs.

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The organs of plants are composed of many tissues consisting of:

(i) Parenchyma Tissue: Parenchyma tissue is a simple tissue consisting of living cells and is actively metabolized and capable of dividing (Crang *et al*., 2018). Parenchyma tissue can be found in every part of the plant, characterized by a thin cell wall and an isodiametric cell shape, and having intercellular spaces (**Figure 8**). Parenchyma tissue is widespread in all plant organs, including roots, stems, leaves, flowers, fruits, and seeds. Parenchyma tissue has a variety of important functions in plants. Apart from being a place where photosynthesis occurs, parenchyma tissue also plays a role in secretion and respiration, and as a place to store food reserves.

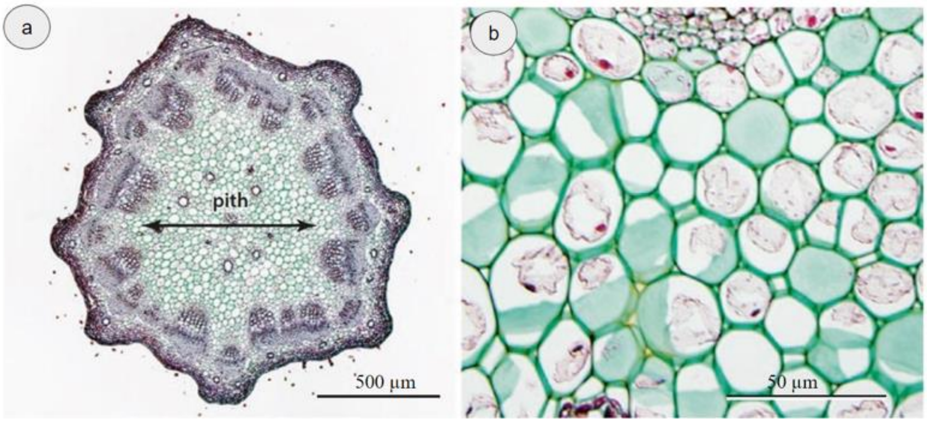

Figure 8. Cross-section parenchyma tissue (Crang *et al*., 2018): (a) Cross section of stem, and (b) Parenchyma tissue.

(ii) Collenchyma Tissue: The collenchyma tissue is a parenchyma tissue that has differentiated into a supporting tissue. The collenchyma tissue consists of living cells that are longer than parenchymal cells with an uneven and elastic thickening of the primary wall (**Figure 9**). The chollenchyma is a very dynamic tissue and is the main supporter of the organ in the growth phase, with walls that can thicken during and after elongation (Leroux, 2012). Collenchyma specifically supports young plant stems, leaves, leaf bones, petioles, as well as root parts, especially on hanging roots (Hawkes, 1997). The role of the colony in providing important mechanical support to plants proves its very important existence in the growth of plant organs.

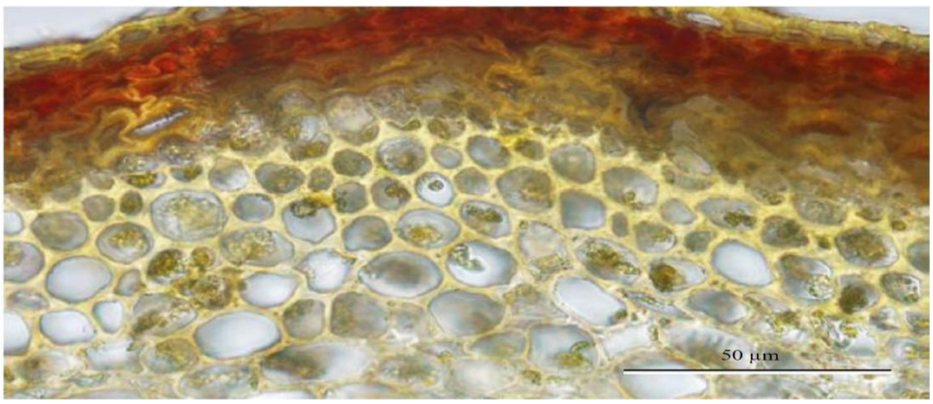

Figure 9. Collenchyma tissue cross-section (Crang *et al*., 2018).

(iii) Sclerenchyma Tissue: Sclerenchyma tissue is found in plants that have undergone secondary growth. These tissues serve as mechanical supports, supporting tissues, and protectors with a thickening of the secondary wall composed of lignin (**Figure 10a**). A

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characteristic feature of sclerenchyma is the form of long fibers **(Figure 10c**), which have a primary wall and undergo secondary thickening. The walls of sclerenchyma cells undergo lignification. Thus, they are rigid and tend to break if bent (**Figures 10a** and **10b**) (Leroux, 2012). Sclerenchymal tissue is widespread in most vascular plants (Leroux, 2012). Sclerenchyma is characterized by a thick, long, narrow fibrous cell wall, and its cells undergo death in adult plants.

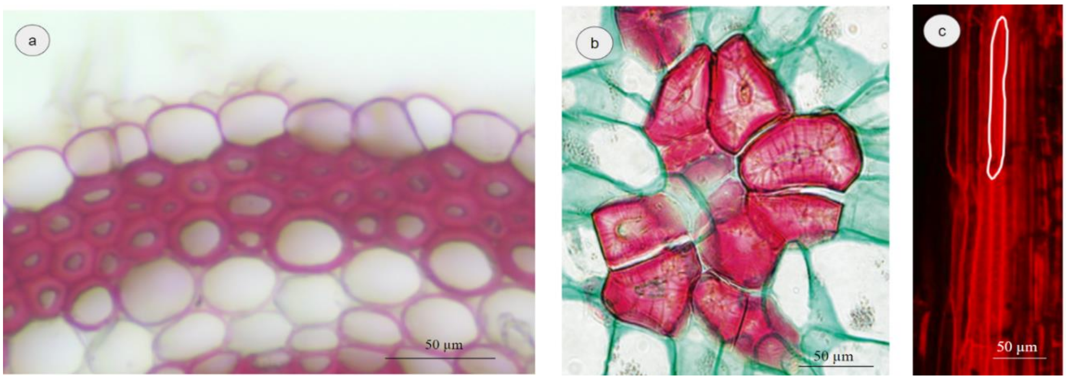

Figure 10. Cross-section sclerenchyma fiber (a), sclereid (b), and Longitudinal-section sclerenchyma (c) (Crang *et al*., 2018; Wang *et al*., 2024).

(iv) Vascular Tissue: Vascular tissue in plants consists of xylem and phloem that function to optimize the transport process of water, photoasimilates, ions, and hormones to all plant organs (Słupianek *et al*., 2021). The xylem and phloem are the two main types of tissue with different functions (**Figure 11a**). Xylem plays a role in transporting water and minerals throughout the plant (He *et al*., 2023), while phloem transports photosynthetic products such as sugars from the leaves to the rest of the plant's body. The xylem is composed of the trachea, tracheid, xylem parenchyma, and xylem fibers, with cell walls undergoing secondary lignification or thickening with spiral type lignification (**Figure 11b**) and scalariform type lignification (**Figure 11c)**. On the other hand, the phloem cell wall consists only of a primary wall without secondary thickening. The phloem consists of filter cells, introduction cells, albumin cells, and phloem parenchyma. The differences in structure and function between the xylem and phloem allow both to play a role in the efficient and effective transport of essential substances that support plant life and growth.

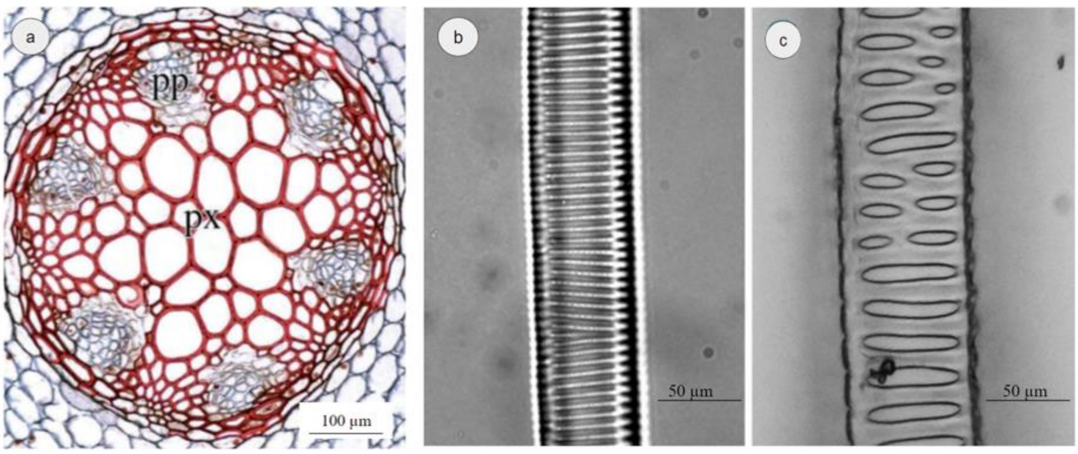

Figure 11. Cross-section vascular tissue: (a) vascular tissue (pp: primary phloem; px: primary xylem); (b) lignification xylem spiral type; and (c) lignification xylem scalariform type.

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(v) Epidermal Tissue: The epidermis is the outermost layer of cells in plant organs. The plant epidermis acts as a protector and directly affects plant interactions with animals or microorganisms (Riglet *et al*., 2021). The epidermis is commonly found in leaves and flowers because these organs do not undergo secondary growth (**Figures 12a** and **12b**). In stems and roots that are still experiencing primary growth, the epidermis is found, while in organs that are experiencing secondary growth, the epidermis will be replaced by the periderm. The epidermal and periderm tissues are also known as protective organs in plants (Campilho *et al*., 2020). Therefore, the arrangement of epidermal cells is very tight, in the absence of intercellular space. This arrangement of cells is a hallmark of the epidermis.

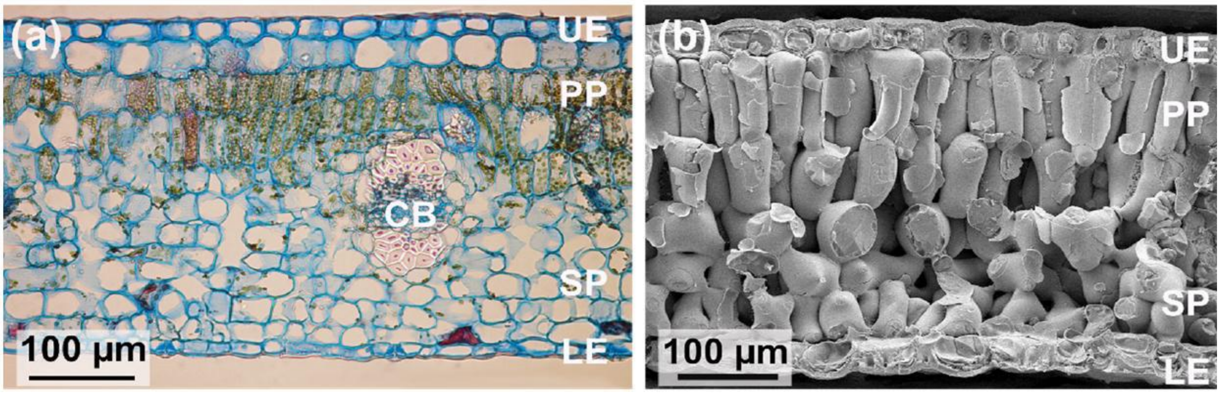

Figure 12. Cross-section of the epidermis on a leaf (Roth-nebelsick & Krause, 2023): (a) Cross section of leaf, and (b) Microscopic cross section of leaf.

3. METHODS

3.1. Context and Participants

The plant anatomy course is abstract. Thus, it is difficult to understand. Several learning models have been tried, but student understanding has not increased significantly. The participants in this research were prospective biology teacher students who took plant anatomy lectures as many as 98 students. Students who take this course are 5th-semester students who are dominated by 85 women while the number is 13 men.

3.2. Research Design

The approach applied in this research is Design-Based Research (DBR). This research adopts DBR to develop a VTL model. This research procedure includes four important stages, namely (i) problem identification and analysis, (ii) designing a 3D-based VTL model, (iii) developing a 3D-based VTL model, and (iv) reflection to obtain an optimal 3D-based VTL model (**Figure 13**).

The problem identification and analysis stages are used to understand in depth the challenges faced in learning plant anatomy. The design of a 3D-based VTL model was carried out to integrate plant anatomy concepts into an interesting and interactive context for students. The development of a 3D-based VTL model is carried out by considering technical and design aspects that support learning objectives. Finally, the reflection stage is important to evaluate the effectiveness and success of the VTL model that has been developed in supporting students' understanding of plant anatomy material.

In the first stage, we carried out an analysis of the existing Wimba learning model. The shortcomings identified in this model are the lack of available information and not utilizing technology optimally. The second stage involved designing a VTL (Visuospatial

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Transformation Learning) model to overcome the shortcomings of the Wimba model. The VTL model was designed to increase students' understanding of studying plant anatomy material. The third stage involves further development of the VTL model, by integrating several supporting applications that can strengthen its effectiveness in the learning process. The final stage, namely the Reflection stage, involves the process of perfecting the VTL model together with the collaboration of a team of experts in the fields of learning and technology, to ensure this model is optimal and in line with modern learning needs.

Figure 13. Research flow.

4. RESULTS AND DISCUSSION

The characteristics of learning plant anatomy generally only rely on visual representations in the form of 2D images, but this approach has proven to be inadequate in understanding the structure and function of plant parts. Taking into account the microscopic size and high complexity of plant structures, it is necessary to use more representative 3D images to improve students' understanding of the analysis of cell types, positions, and morphogenetic processes in plants (Cerutti *et al*., 2017; Montenegro-Johnson *et al*., 2019).

4.1. Results of Problem Identification and Analysis

The Wimba learning model is a 3D-based learning model, consisting of five steps: creating a concept map, conducting discussing of a concept map, providing an introduction to the theory, observing images, and constructing 2D into 3D images. However, several weaknesses was identified in the Wimba learning model (**Table 1)**. Learning outcomes using the Wimba learning model have increased significantly in the low learning outcomes category.

Table 1. Analysis of problems with the Wimba learning model.

No.	Wimba Learning Stage	Emerging Problems
1	Create a concept map	The results of making concept maps tend to be less diverse.
2	Concept map discussion	Students are less active in discussing concept maps.
3	Introduction to theory	Completely delivered by the teaching lecturer.
4	Image observation (2D)	Students find it difficult to recognize the images obtained from practical activities.

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Students making concept maps tend to be less diverse because the references are limited, so the discussion process is less than optimal. It is hoped that discussion regarding concept maps can motivate students to contribute ideas and exchange ideas. However, in reality, only a few students dare to be active in discussion, while most of the others tend to be reluctant to express their opinions. The introductory theory stage was carried out after the discussion regarding the concept map was completed. The theoretical introduction was delivered comprehensively by the teaching lecturer, although the implementation took quite a long time, which ultimately limited the process of further discussion regarding the concept map.

The next stage is practicum in the laboratory, which is an important activity for carrying out visual representations (2D) in studying plant anatomy. This practical activity involves preparing fresh preparations, microscopic observations using a microscope, and students' ability to draw the results of their observations. However, visual observations often cannot be carried out well by students, thus affecting their understanding of the structure and function of cells and tissues in plant anatomy. Some of the reasons include poor quality preparations, a limited number of microscopes, and study groups that are too large. Thus, not all students have sufficient opportunities to carry out practical work and make good visual representations. Efforts are needed to improve conditions and facilities in laboratory practicums. Thus, all students can get the maximum learning experience and can better develop their visual representation skills.Understanding plant anatomy material depends on biology students' visual representation abilities (Susiyawati & Treagust, 2021). In the Wimba model of visuospatial (3D) representation, students still use Play-Doh (**Figures 14a** and **14b**). The results of the visuospatial (3D) representation of parenchymal tissue (**Figure 14a**) show a lack of accurate representation, unable to show typical details of parenchymal cells. Likewise, the 3D representation of dicot stems does not clearly show the thickening of the collenchyma cell walls, which is an important characteristic of collenchyma cells. In the outermost layer, students are trying to describe the shape of sclerenchyma, which has the shape of elongated fibers. The use of play doh makes it difficult for students to depict cell and tissue structures accurately.

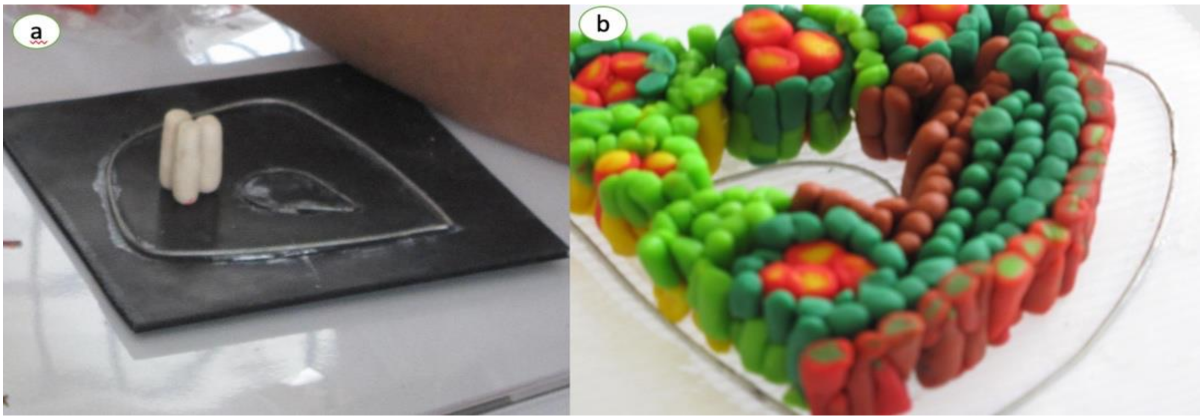

Figure 14. Results of 3D representation of parenchymal tissue (a) and dicot stem (b).

The use of 3D media has a significant influence on learning outcomes and spatial abilities in learning plant anatomy. A comparison between the use of Play-Doh and 3DsMax media shows that student learning outcomes in plant anatomy material are much better when using 3DsMax media. Furthermore, the research results of Chaidir and Suprapto (2021) found that using the 3D Blender application resulted in better spatial abilities compared to using the 3DsMax application in the Wimba learning context. These findings show that the right choice

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of 3D media can positively influence learning outcomes, both in terms of learning outcomes and students' spatial abilities in understanding the anatomical structure of plants.

Based on the results of the evaluation carried out by a team of experts, the most difficult difficulty in learning plant anatomy is understanding the concepts and visuospatial imagination of plant anatomy. Understanding the concept of plant anatomy can be a challenge for students, as shown by various research findings. Suprapto (2019) research results show that the results of learning plant anatomy using the Wimba model can improve learning outcomes in the medium category. This shows that some students are still unable to understand plant anatomy material. Visual literacy plays an important role in understanding plant anatomy, especially in the interpretation of visual images. Difficulties that often arise are due to cell shapes that appear similar but have different functions. Examples include the difficulty of distinguishing parenchyma cells from collenchyma cells, as well as distinguishing between sclerenchyma cells and xylem cells. Research has revealed that students strive to describe and understand the structure of tissues in plant organs (Ermayanti, 2023).

Understanding the internal structure of plants requires visual representation (2D) and visuospatial representation (3D) abilities. Students generally have tried to use these two abilities through practical activities, but still face difficulties in verbally describing plant cells, tissues, and organs. This indicates that their ability to understand the complexity of plant anatomical structures still needs to be improved. The lack of visual literacy among biology students also hinders the interpretation and creation of (2D) photo visualizations. This shows deficiencies in understanding and applying the knowledge they have.

The development of effective instructional strategies is critical in overcoming these challenges. Efforts to improve students' visuospatial representation skills through innovative instructional strategies can be significant in improving their understanding of plant anatomy. Research results support that students who have good visuospatial skills will be better able to imagine the anatomical structure of plants, such as the structure of cells and tissues in the plant body (Azalia *et al*., 2018).

The results of analysis, observations, and interviews show that students show significant interest in using technology to complete their academic assignments. The involvement of technology in the learning context is essential for developing students' visual and visuospatial representation skills, which helps them understand plant structures better. Various educational technology applications are available to support this learning process. The use of technology in education not only facilitates more effective delivery of material but also enriches students' overall learning experience.

Although the use of technology in education provides many benefits, such as efficiency in completing assignments and a more interactive learning experience, some risks need to be considered. However, it is important to recognize that technology has a crucial role in improving the quality and relevance of education in this modern era. Therefore, developing wise strategies in the use of technology for education is very important to maximize the potential for better and more sustainable education for students.

4.2. Design of VTL Model

Plant anatomy deals with very complex topics. Understanding the concept and good visuospatial skills are very necessary to understand it. The aim of learning plant anatomy is for students to be able to analyze the structure of cells, tissues, and organs in 3D and relate them to the physiological processes that occur. Determining the right learning model is an important part of achieving these learning goals (Wantu *et al*., 2023). The importance of this learning model is reflected in efforts to create meaningful and enjoyable learning experiences

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(Mawikere, 2022). One learning model that is considered appropriate to the learning objectives in plant anatomy material is the VTL model.

Visuospatial transformation learning can provide new skills through visual perception. The information obtained by students in the visuospatial learning process can improve long-term memory. Visuospatial abilities influence spatial memory throughout adulthood (Muffato *et al*., 2020). Visuospatial thinking plays an important role in students' predictions of molecular geometry, with some students demonstrating higher accuracy using 3D diagrammatic representations than analytical reasoning (Kiernan *et al*., 2021). Spatial displays facilitate non-verbal learning (Darling *et al*., 2020). Visuospatial training in elementary schools can improve spatial reasoning and mathematics performance through a 10-week intervention program that focuses on spatial visualization, mental rotation, and spatial orientation skills (Lowrie *et al*., 2017). The spatial work process involves transforming shapes from 2D to 3D (Iwanowska & Voyer, 2013). Samples with high spatial abilities had higher anatomical drawing scores. Participants who studied artistic 3D models had higher post-test scores (Koh *et al*., 2023).

The development of the VTL learning model in this research was based on the results of students' cognitive evaluations as well as improvements to the Wimba learning model which had previously been applied in the learning process. The syntax of this VTL model is explained as depicted in **Figure 15**.

Figure 15 shows the learning stages using the VTL model. The first stage is to explain the lecture activities in class. During one semester, learning materials are stored in the Trello application. This application includes a lecture timeline, reference books, practical instructions, lecture material videos, video tutorials for making concept maps, and video tutorials for using the 3D Blender application. All information in the Trello application can be accessed by students taking plant anatomy courses that semester, allowing them to carry out independent study at home. The application of Trello has been proven to be effective and has received a positive response from students in Trello-based blended learning. Thus, it can be developed into Trello-based learning (Connie & Risdianto, 2022). The use of Trello also shows a significant impact on student learning outcomes and perceptions. Trello's advantage lies in its effectiveness as a project-based virtual learning environment that can facilitate independent learning.

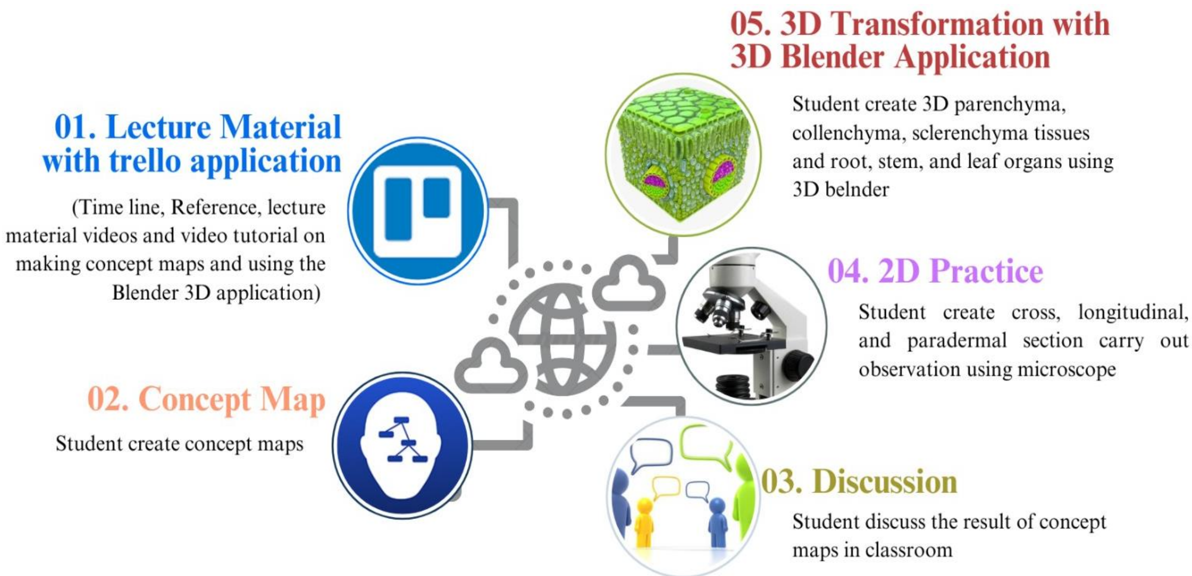

Figure 15. VTL model.

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The second stage in the learning process is for students to create concept maps using the C-map Tools application based on their understanding obtained from Trello and other teaching sources. Before entering class, students are advised to prepare a concept map which will be discussed and verified in class. Concept maps have a very important role in facilitating the learning process because they function as a tool to visually represent students' understanding through concept images (Torre *et al*., 2023). Using the C-map Tools application provides easy visualization of ideas, preparation of concepts, and recording. Thus, it can be an indicator of student learning progress.

In the third stage, students hold discussion in class and participate in the verification of the results of the concept map that has been made by the course lecturer. This discussion process allows students to exchange information and strengthen each other's arguments regarding the concepts they have understood. Discussion has a significant role in improving students' cognitive abilities, strengthening interactions between students, building knowledge, and increasing motivation to participate in online discussion which lead to a deeper understanding of concepts (Alwafi, 2022). Discussion is also very important in the context of a learning community to reconstruct knowledge collaboratively (Hasani *et al*., 2022; Eryilmaz *et al*., 2023; Krecko *et al*., 2023).

The fourth stage involves a practical process to produce 2D images from observations using a microscope. This practicum is carried out in small groups by carrying out two types of incisions, namely cross and longitudinal section for parenchyma, collenchyma, sclerenchyma, root organs, and stem organs. Apart from that, cross and paradermal section were also made on the epidermis tissue and leaf organs. Observations were made at 100x and 400x magnification. The results of these observations were then recorded in the form of sketches using a pencil. This practicum plays an important role in developing visuospatial abilities which ultimately has an impact on improving cognitive abilities (Owens, 2020).

The application of the 3D Blender application in learning plant anatomy involves structured stages. The fifth stage of this practicum requires students to create 3D structures based on the results of practicum observations using the 3D Blender application. The main purpose of using this application is to produce a more representative structure of the observed tissues and organs. Practical guidance on using this application can be obtained from the Trello application. The resulting 3D models have significant benefits in the context of anatomy education by enabling more detailed visualization of complex cellular structures (Roth *et al*., 2015). In addition, the application of 3D models and fusion technology can also improve independent learning capabilities through interactive visualization of tissue and organ structures (Yuan *et al*., 2021). Using the 3D Blender application has also been proven to improve academic performance and provide satisfaction with the results that have been produced in an educational context.

4.3. Results of VTL Model Development

The results of developing the VTL model are divided into five stages (**Table 2**): (i) independent learning, (ii) making concept maps, (iii) discussing concept maps, (iv) practicum and 2D representation, and (v) 3D representation. **Figure 16** shows the flowchart for creating 3D tissues and organs. The process begins with the first step: the 3D modeling process of tissues and organs. The second step involves preparing a fresh specimen with cross and longitudinal-section using a microscope to produce 2D and 3D images of the product. The third step is to confirm the results of the incision with the course lecturer to ensure the correctness of the resulting preparation; If errors are found, the preparation is repeated. The fourth step is to create a 2D model of the tissue by drawing and coloring the confirmed

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preparation results. The fifth step involves creating tissues such as Parenchyma Tissues, Collenchyma Tissues, and Sclerenchyma Tissues in the same way. The sixth step is to confirm the 2D tissues model with the course lecturer; if there are errors, the 2D model creation is repeated. The seventh step is to create a 2D model of the organ similarly, drawing and coloring the confirmed preparation results. The eighth step is to create organs such as roots, leaves, and stems. The ninth step is to confirm the 2D organ model with the course lecturer; if there are errors, modeling is repeated. The tenth step is to create a 3D model of the organ using the 3D Blender application from the 2D modeling results. In the eleventh step, if the 3D product represents the anatomy of the plant well, the modeling process ends.

4.4. Reflection Results

4.4.1. Visuospatial transformasi learning

Learning using VTL is an approach that integrates visuospatial transformation in the learning process, different from conventional models such as Wimba. Significant improvements occur with the use of more advanced technology in VTL. **Table 3** shows the differences between the Wimba and VTL models. In the Wimba model, learning tends to be conventional. However, in VTL there is the addition of the Trello application (**Table 3**) which provides various information about plant anatomy, such as a timeline, eight reference books, PowerPoint presentations regarding Plant Anatomy lecture material, as well as videos that support understanding of plant anatomy, complete with assignments. assignments that must be completed by students. This technology integration aims to increase interactivity and learning effectiveness in understanding abstract material such as Plant Anatomy.

Making concept maps is usually done using a computer or by hand, but VTL uses C-maps. Concept maps are created and adapted to learning materials based on the timeline listed in Trello. C-maps is an application that provides various element features such as flat shapes, arrows, and other components to create a hierarchy for creating concept maps. Therefore, C-maps make it easy for students to create concept maps. In practical activities, students sometimes face difficulties in making preparations properly and correctly. As an alternative, students can search for additional information through sources such as Google. The theoretical introduction in VTL was omitted to provide more time for concept map discussion, with the hope that the results of the discussion can provide sufficient material information for lectures.

Activities to construct 3D images based on visual observations using the 3D Blender application are also carried out to enrich students' visual understanding. The VTL model is 3D learning through the process of creating digital representations from 2D image objects into 3D images through special software called 3D modeling software, namely 3D Blender.

The 3D representation process is as follows:

(i) Preparation of replacement software. Software is a set of instructions or programs that instruct a computer or other electronic device to perform a specific task. The software used is 3D Blender.

(ii) 2D visual modelling. The 2D modeling process is carried out to create a model that is close to realism, concrete, and easy to understand. This process is the first step in visualizing the detailed anatomical structure of plants. Next, the 3D modeling process in plant anatomy begins with making plant tissue preparations which will be observed through a microscope with magnifications of (10x10) and (10x40). The best observation results will be photographed to represent an accurate picture of the actual tissue structure. By using these photos, it is hoped that students will be able to recognize the shape and characteristics of the cells in the plant tissue they are

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observing. Thus, they can produce more detailed and informative image representations.

Visuospatial modeling (3D). The visuospatial (3D) modeling process involves transforming 2D images into 3D images, which can be represented through two forms of incision, namely cross and longitudinal-section. The steps and techniques for creating 3D representations of objects in digital space involve the use of special software. This software allows users to create, edit, and manage 3D models with high detail and precision, thereby facilitating more accurate and in-depth visualization of the objects being studied.

Table 2. Development of the VTL learning model.

No.	VTL Model Stage	Description
1	Independent Learning	At the start of the lecture, the lecturer in charge of the Plant Anatomy course introduced the Trello application as a means to support students' independent learning. The Trello application is used as a container that contains a timeline for one semester, containing various important information such as material in the form of PowerPoint presentations and learning videos regarding the concepts of cells, tissues, and plant organs. Apart from that, this application also provides various additional references that support students' independent learning process. Trello not only functions as a material store but also as a tool to facilitate students in creating concept maps and developing skills in making 3D models using the 3D Blender application and the tutorials available in it. Thus, using the Trello application provides comprehensive support for students in carrying out an effective and efficient independent learning process.
2	Making Concept Maps	At the first meeting, the lecturer instructed that the next meeting would include a concept map presentation activity according to the timeline available in Trello using the C-maps Tools application. Each student is required to create a concept map based on the references provided in Trello.
3	Concept Map Discussion	After the creation of the concept map is complete, a presentation of the results is carried out and the concept verification is carried out by the lecturer in charge of the plant anatomy course.
4	Practicum and 2D representation	The next stage in this experiment is conducting practicum. The practical process is carried out to observe cells directly in 2D form based on the results of cross and longitudinal-section. Next, the results of the cell observations are recorded and drawn in sketch form as visual documentation that describes the structure and characteristics of the cells observed.
5	3D Representation	The next stage in this research is to transform 3D images using photos of cross and longitudinal-section using the 3D Blender application. This process aims to produce a more detailed and accurate visual representation of the internal structure of plants. These transformations allow to gain a deeper picture of cell types, tissue distribution, and cellular organization in plants. This method utilizes advanced technology in the field of 3D modeling to present more complex and useful information in the context of plant anatomy. Thus, the use of the 3D blender application is key in expanding our understanding of the microscopic structure and function of plants.

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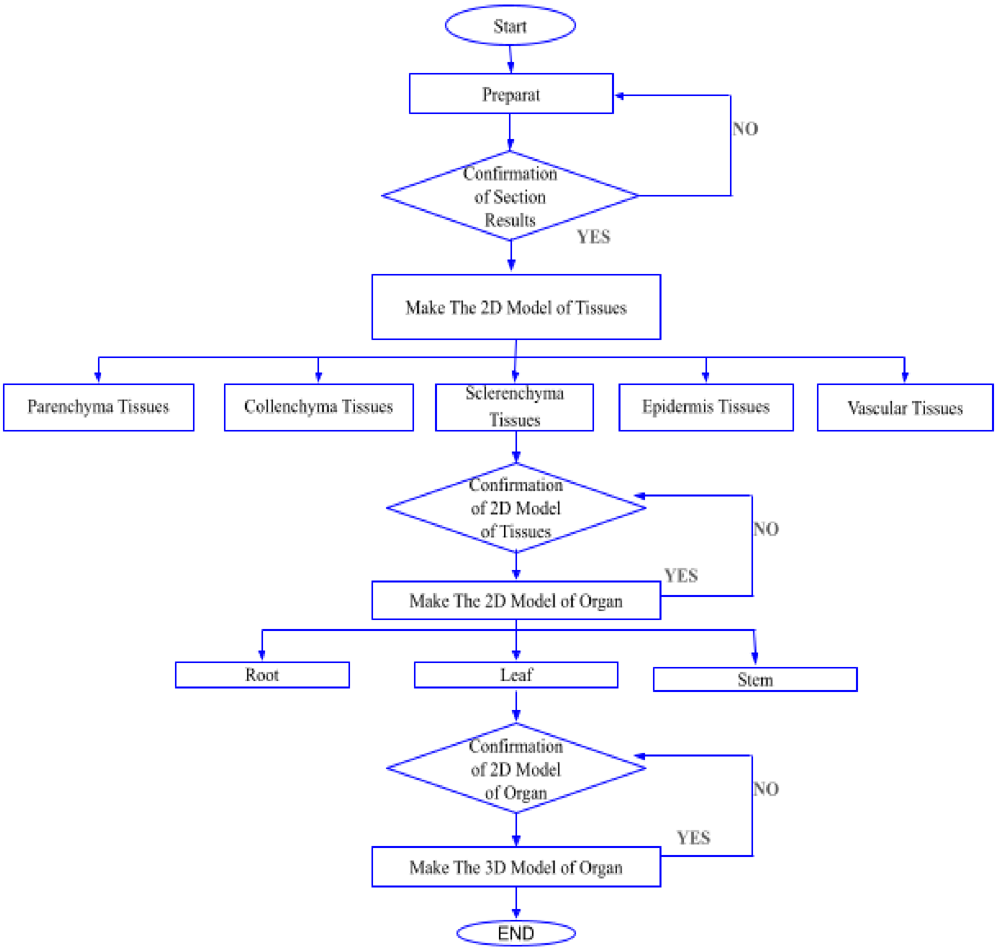

Figure 16. 3D development flowchart.

Table 3. Difference between Wimba Learning and VTL.

No.	Learning Steps	Wimba Learning	VTL
1.	Reference	Limited	There are quite a lot available in the Trello application
2	Concept map	Conventional	C-map
3	Concept map discussion	Students are less active	Active student
4	Introduction to theory	Available	Not available
5	Image observation (2D)	The picture is not clear, it is recommended to look at the picture in the book	Does not limit references, but it is not recommended to take information sources from Google
6	Constructing 2D into 3D	Using playdoh	Using 3D Blender

4.4.2. Results of visual representation of plant anatomy learning using VTL

VTL implementation trials were carried out by measuring visual representation abilities. The research results show that the use of VTL can significantly improve students' visual representation abilities, with an NGain value of 0.72 which is in the high category (Meltzer, 2002). Statistical analysis shows that the average pre-test score for students' visual abilities related to plant cells and tissues is 13.19 ± 2.309, while the average post-test score is 20.13 ± 4.163 (**Table 4**). Detailed information on how to calculate using the statistic analysis is

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explained elsewhere (Afifah *et al*., 2022; Fiandini *et al.,* 2024). The correlation score is 0.649 which indicates the large correlation coefficient between paired data. The results of the analysis show that the P-value (0.000) is <0.05, illustrating that the correlation between the pretest and post-test is significant. The results of this research hypothesis test show a significance level of 0.000, which is lower than the value α = 0.05, indicating that the null hypothesis (Ho) is rejected and the alternative hypothesis (Ha) is accepted. These findings indicate that there is a significant difference or significant influence on the measured pretest and post-test assessment results.

Table 4. Pretest and posttest of visual representation abilities with VTL.

Paired Samples Statistics			
Mean	**N**	**Std. Deviation**	**Std. Error Mean**
13.19	98	4.163	0.421
20.13	98	2.309	0.233

4.4.3. Results of learning media development in the form of 3D plant tissues and organs

The transformation of 3D representations of plant anatomy, as depicted in **Table 5**, shows that students have very good visuospatial abilities. Students can identify the shape of cells and tissues in detail, for example, the shape of parenchyma cells which have thin walls and spaces between cells. Apart from that, they were also able to classify plant organs which consist of several types of tissue that are connected to carry out their functions. This shows a high level of creativity in creating accurate digital representations of real objects and those created in the imagination. In this context, 3D transformation technology has an important role in the development of science.

The image shown in **Table 5** number 1 is a depiction of parenchyma tissue, a type of basic tissue found in all parts of the plant body. The parenchymal tissue observed in **Table 5** is the result of observing cross and longitudinal-section. A cross section of the specimen shows the characteristics of parenchymal tissue from a top perspective, including large lumens, thin cell walls, and intercellular spaces. On the other hand, a longitudinal-section depicts the characteristics of parenchyma tissue from the side, shaped like a tube with cell ends that are not tapered like sclerenchyma cells. This microscope observation is the basis for creating a 2D sketch that highlights the anatomical structure of the parenchymal tissue. Next, 3D images were created using the 3D Blender application to integrate the results of cross and longitudinal-section to produce a more complete representation of the tissue. This process requires good visuospatial skills to ensure an accurate representation of the characteristics of the observed parenchymal tissue.

The image shown in **Table 5** number 2 depicts collenchyma tissue. This sketch is based on the results of cross-section and longitudinal-section observations to obtain an accurate picture. The typical structure of collenchyma tissue is reflected in the 2D sketch. One of the main characteristics of collenchyma tissue is uneven thickening, which are obtained from the results of a cross-section. There are three types of collenchyma thickening, namely lamellar, angular, and lacunar collenchyma. Lamellar collenchyma has even thickening on one side of some cells. Lacunar collenchyma is characterized by thickenings that form spaces between the cells, while angular collenchyma is formed from at least three corner cells.

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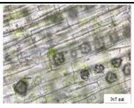
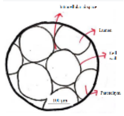
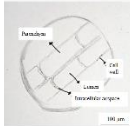
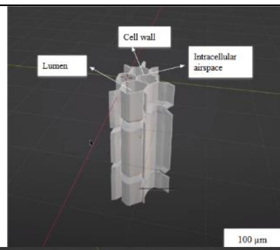
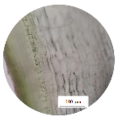
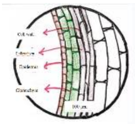
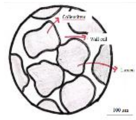
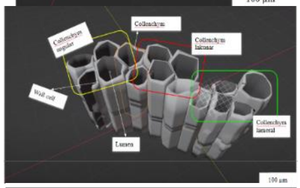
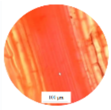
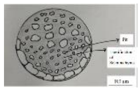
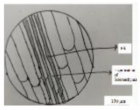
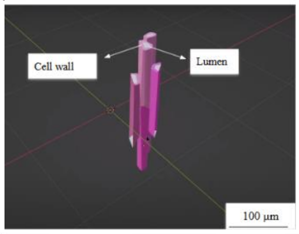
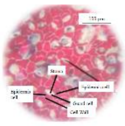
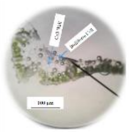
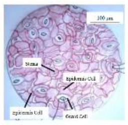
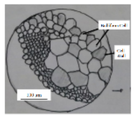
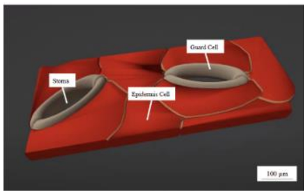
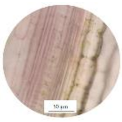
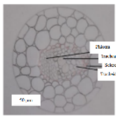
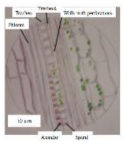
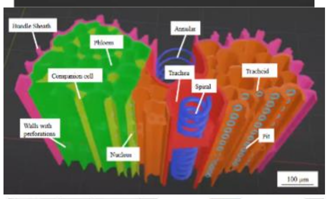
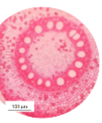
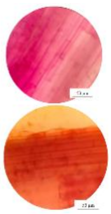
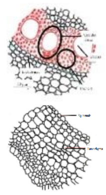
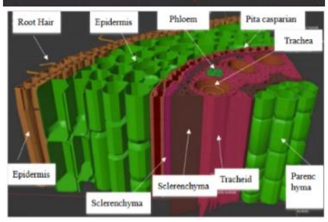
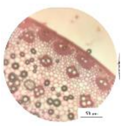
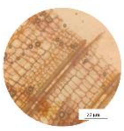
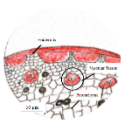
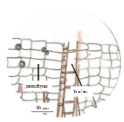
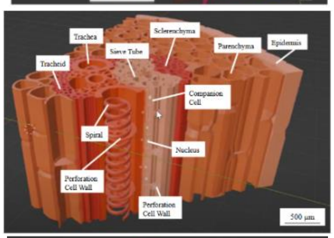
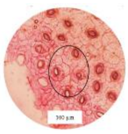
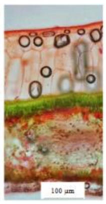
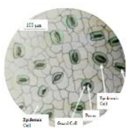
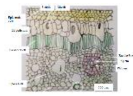
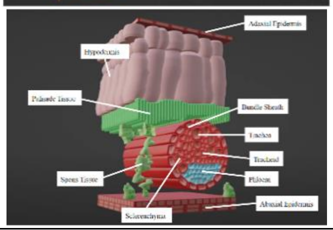
Table 5. Results of learning media development.

No	Parts of Plant	Original		2D Representation		3D Representation
		Cs	Ls	Cs	Ls	
1	Parenchyma Tissues					
2	Collenchyma Tissues					
3	Sclerenchyma Tissues					
4	Epidermis Tissues					
5	Vascular Tissues					
6	Root					
7	Stem					
8	Leaf					

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The main function of collenchyma is as a supporting structure in plants. From the results of longitudinal-section observations, collenchyma cells are characterized by being longer than parenchyma, but shorter than sclerenchyma. In addition, their diameter is also smaller compared to parenchyma cells, indicating structural adaptations that are appropriate to their function as supporting elements in plants.

The basic sclerenchyma tissue in **Table 5** number 3 is shown from the stem of a dicot plant. This tissue was observed through practical work involving incisions and observations with a 10x10 microscope, as well as making 2D and 3D images. 2D images are created manually using drawing and coloring techniques based on the results of microscopic observations. Meanwhile, 3D images were created using the 3D Blender application. Column Cs displays the results of a cross-section which shows the tissue structure from above. On the other hand, the Ls column shows the results of a longitudinal-section with a microscope magnification of 10x10. The results of these observations indicate that sclerenchyma tissue has nodal channels and cell walls that are thicker than parenchyma and collenchyma tissue. This makes the sclerenchyma tissue function as a support or strengthening tissue, consisting of mature cells with thick secondary walls, and containing lignin and cellulose. Its main function is structural support for plant parts that are no longer growing, such as in mature monocot and dicot plants.

Epidermal tissue (**Table 5** number 4) is the outermost layer of primary plants that have stomata. These stomata are found on both leaf surfaces, both adaxial (top) and abaxial (bottom), so they are called amphistomatic. Based on the description of the 3D model using a peridermal section as a reference, it can be observed that the number of stomata on the abaxial leaf surface is greater or denser than on the adaxial leaf surface. The characteristics of these stomata indicate that they are of the diacytic type, where the stomatal pore is formed by two guard cells of equal length, with one small guard cell in between. In addition, the structure of the stomata shows the presence of two guard cells of the same length, which are surrounded by two shorter guard cells forming diagonal lines.

The main function of this epidermal tissue is as a protective layer, which plays a role in regulating the exchange of gases such as oxygen and carbon dioxide. Epidermal cells are generally flat and arranged tightly to each other. Apart from that, the stomata in the epidermal tissue function to open and close to regulate the process of evaporation of water from the leaves. In hot environmental conditions, the stomata tend to close to reduce evaporation, while in humid environmental conditions, the stomata will open to increase the rate of evaporation.

Vascular tissue, listed in **Table 5** number 5, plays an important role in plant structure. Vascular tissue consists of two main types, namely xylem and phloem tissue. Xylem tissue is characterized by the presence of trachea and tracheids, which are known for their thick walls which tend to be red in preparations due to the lignin content which reacts with the red dye in the reagent used. Meanwhile, phloem has thin cell walls and is not red. In analysis via 3D transformation, the characteristics of cells and vascular tissue can be more clearly seen. Wall thickening in xylem cells can be observed in cross-section, indicating the deep structural complexity of plant vascular tissue.

Table 5 number 6 describes the structure of the root organ which consists of epidermis tissue, parenchyma, and vascular tissue consisting of xylem and phloem along with pith, which is shown in the original image.The details of this structure are further clarified using a cross section (cs). The image of the root shows the characteristic location of the vascular tissue which has the polyarch type, which is a characteristic characteristic of roots in monocot plants. The results of the 2D representation show that students can identify the original

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image, and then transform it into a 3D model from the root. The 3D representation of the root shows the presence of an epidermis equipped with root hairs, parenchyma in the cortex, endodermis with Caspary bands, and vascular tissue consisting of trachea, tracheids, and phloem.

Table 5 number 7 shows the stem organs in the original image, clearly consisting of the epidermis, vascular bundles, and parenchyma. The vascular bundles appear spread out, showing a special characteristic of monocot stems. The results of the 2D representation emphasize the characteristics of the observed cells and tissues. The transformation results show that students have recognized the typical characteristics of cells and tissues found in monocot stems.

The last images in **Table 5** number 8 shows the leaf organs. The original incision consists of a paradermal section and a cross-section of the leaf. The results of the 2D representation show the presence of the epidermis and stomata, while in cross-section the upper surface epidermis, hypodermis, palisade, spongy tissue, vascular tissue, and lower epidermis tissue are visible. The characteristics of the location of the tissue in the image indicate that the image is a picture of a dicot leaf.

Based on the results of interviews regarding the use of the Trello application as a source of information for learning plant anatomy, it is said to be quite complete and interesting and can help lectures on plant anatomy. The following interview results with "SB" believe that Trello, which contains lecture information, is very helpful because it is easier to see and understand the material through learning videos made by lecturers and teachers. Esau's E-Book reference is rarely used because it uses English. And video tutorials also help in making 3D blender projects." Students are assigned to read the scheduled material by making a concept map. Through concept maps, teachers know students' preparations for taking part in learning. The results of concept maps discussed in class help solve problems that students do not yet understand and easily remember the material discussed. The results of an interview with "FB" regarding concept maps said that "Concept maps, students read a lot of literature and study a lot of theory but it doesn't become a debate because there are references, with concept maps we can easily remember the material, with crosslinks it helps us unite one concept with another. other".

Practical activities should be carried out by drawing by hand (hands-on), this activity can make it easier to remember and construct 3D shapes as said by respondent "SN", who stated that "practicum needs to be done because it makes it easier to understand the details of cell characteristics because If you just look at it, it's easy to forget, even though you can still recognize it, the memory period is shorter. Thus, in practice, the results of the microscopic representation need to be redrawn. Creating 2D and 3D sketches is used as a basis for creating 3D Blender products." Practicum in the laboratory and carry out all practicum activities to obtain the best possible information. Thus, to be able to build better visual representation skills in this learning. Through active learning overall students feel satisfied and students feel more confident after completing the activity.

Agree with the interview results above regarding the importance of understanding visual images (2D) as a basis for creating 3D images, and requiring comparison images from the references provided or from Google. It is not recommended to take images from Google. "SB" also believes that there is still not enough practicum time, because the results of making preparations are still not good. Following the results of the interview, "SB" believes that "Making 2D and 3D images helps to understand the details of the characteristics of cells, tissues, and organs. Without making 2D and 3D sketches, you can still recognize the types of cells, tissues, and organs, but you need to additionally understand the detailed structure

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through 2D and 3D images because the incision results are sometimes less supportive (blurry and incisions that are too thick). 2D and 3D sketches must remain intact. carried out and the duration of the practicum must be extended" Interviews were also conducted with "RS", that "Using 3D blender still needs practice and requires sufficient equipment. Some student teachers do not have good computer facilities."

The results of the visual representation test show that VTL can improve students' visual abilities. The results of this test show an increase in NGain of 0.72, which is included in the high category. This increase shows that VTL is effective in increasing students' visual literacy regarding the structure of plant tissues. Therefore, the VTL model is recommended for use in learning Plant Anatomy.

The learning technology used is the Trello application, which helps students in their lectures. The Trello application contains plant anatomy learning information which includes timelines, lecture plans, learning videos, and lecture texts in the form of PowerPoint. This application is also equipped with a tutorial on using Cmaps to create concept maps and a 3D Blender tutorial to help students construct 3D models. However, several weaknesses are still found in its implementation. The available practical time is still insufficient, and the quality of the microscope or preparations made sometimes requires more time. Apart from that, students' skills in using the 3D Blender application and notebook devices that do not support 3D assignments are also an obstacle. These weaknesses must be anticipated during learning to provide maximum results. Finally, this study adds new information, ideas, and suggestions regarding teaching and learning, especially relating to biology to students, as reported elsewhere (Glorifica, 2021; Olumorin *et al*., 2021; Babalola, 2022; Olumorin *et al*., 2022; Hofifah & Sumiati, 2023; Alhassan *et al*., 2024; Tipmontiane & Williams, 2022; Abdussemiu, 2022; Babalola *et al*., 2023; Ala *et al*., 2022).

5. CONCLUSION

A 3D-based learning model called VTL is a development of the Wimba learning model. VTL involves innovative learning technology implemented in plant anatomy material. The learning technology used in the VTL model is the Trello, Cmaps, and 3D Blender applications. The use of learning technology in the VTL model makes it easier to understand the concept of plant anatomical structure. The measurement results show an increase in visual representation abilities in the high category. The results of visuospatial representation with VTL show that students can identify cell shapes in detail and classify plant organs based on cell and tissue structure. The VTL model provides a dynamic learning experience. Visualization and transformation from 2D to 3D using 3D technology makes abstract concepts more concrete and easier to understand. The VTL model is recommended for use in learning other abstract materials. The impact of using this model is that students can understand abstract material more quickly and help the development of science and its applications better.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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p- ISSN 2528-1410 e- ISSN 2527-8045

8. REFERENCES

Abdussemiu, A. (2022). Problems of teaching practical biology in senior secondary schools. *ASEAN Journal of Science and Engineering Education*, *2*(3), 199-206.

Afifah, S., Mudzakir, A., and Nandiyanto, A.B.D. (2022). How to calculate paired sample t-test using SPSS software: From step-by-step processing for users to the practical examples in the analysis of the effect of application anti-fire bamboo teaching materials on student learning outcomes. *Indonesian Journal of Teaching in Science*, *2*(1), 81-92.

Ala, N.A., Onojah, A.O., Ishyaku, A.M., and Adamu, S.B. (2022). Development of an animation package in biology for teaching vertebrate, anatomy, and physiology. *ASEAN Journal for Science Education*, *1*(2), 117-130.

Alaba, S. Y., and Ball, J. E. (2023). Deep learning-based image 3-d object detection for autonomous driving. *IEEE Sensors Journal*, *23*(4), 3378-3394.

Alhassan, N., Alhassan, A., and Chioma, A.F. (2024). Examining the role of biology teachers' beliefs, motivations, and self-reported practices in constructing curves for biology class. *Indonesian Journal of Teaching in Science*, *4*(1), 11-26.

Alwafi, E. M. (2022). Designing an online discussion strategy with learning analytics feedback on the level of cognitive presence and student interaction in an online learning community. *Online Learning*, *26*(1), 80-92.

Atkinson, J. A., and Wells, D. M. (2017). An updated protocol for high throughput plant tissue sectioning. *Frontiers in Plant Science*, *8*, 1721.

Azalia, H., Rahmat, A., and Nuraeni, E. (2018). Students’ visual-spatial ability in representing single cell epidermis of rhoeo discolor leaf. *International Conference on Mathematics and Science Education of Universitas Pendidikan Indonesia, 3*, 44-49.

Babalola, E.O. (2022). Design and Development of 3-Dimensional Model of Human Circulatory System to Teach a Concept of Biology in Senior Secondary Schools. *Indonesian Journal of Teaching in Science*, *2*(1), 17-28.

Babalola, E.O., Ayoola, D.A., and Omolafe, E.V. (2023). Analysis of experts' opinion on the human excretory system model for teaching biology in Nigeria. *ASEAN Journal of Science and Engineering Education*, *3*(1), 19-26.

Burgess, A. J., and Majda, M. (2022). A future in 3D: Analyzing morphology in all dimensions. *Plant Physiology*, *189*(3), 1175–1176.

Campilho, A., Nieminen, K., and Ragni, L. (2020). The development of the periderm: the final frontier between a plant and its environment. *Current Opinion in Plant Biology*, *53*, 10-14.

Cerutti, G., Ali, O., and Godin, C. (2017). DRACO-STEM: an automatic tool to generate high-quality 3d meshes of shoot apical meristem tissue at cell resolution. *Frontiers in Plant Science*, *8*, 353.

Chaidir, D. M., and Suprapto, P. K. (2021). Implementation of 3D software towards representation microscopic and spatial intelligence of prospective biology teachers. *BIOTIK: Jurnal Ilmiah Biologi Teknologi dan Kependidikan*, *9*(1), 15-23.

Connie, C., and Risdianto, E. (2022). MOOCs and trello based blended learning to increase student involvement. *Al-Islah: Jurnal Pendidikan*, *14*(1), 1001-1008.

Crang, R., Lyons-Sobaski, S., and Wise, R. (2018). Plant anatomy: A concept-based approach to the structure of seed plants. *Springer*, *2018*.

Darling, S., Havelka, J., Allen, R. J., Bunyan, E., and Flornes, L. (2020). Visuospatial bootstrapping: Spatialized displays enhance digit and nonword sequence learning. *Annals of the New York Academy of Sciences*, *1477*(1), 100-112.

Duncan, K. E., Czymmek, K. J., Jiang, N., Thies, A. C., and Topp, C. N. (2022). X-ray microscopy enables multiscale high-resolution 3D imaging of plant cells, tissues, and organs. *Plant Physiology*, *188*(2), 831-845.

Dutra, R., Nogueira, A., Rossi, S., Chacon Dória, L., Buttò, V., and Marcati, C. R. (2023). The role of organ and leaf habit on the secondary xylem anatomy variation across 15 species from Brazilian Cerrado. *Forests*, *14*(2), 269.

Ermayanti, E., Susanti, R., Santoso, L. M., Huzaifah, S., and Deluciana, C. N. (2023). Student extraneous load analysis in online-based plant tissue structure learning. *Jurnal Penelitian Pendidikan IPA*, *9*(5), 2541-2547.

Eryilmaz, E., Thoms, B., Ahmed, Z., and Lee, H. (2023). Formation and action of a learning community with collaborative learning software. *Journal of Management Information Systems*, *40*(1), 38-55.

Fiandini, M., Nandiyanto, A.B.D., Al Husaeni, D.F., Al Husaeni, D.N., and Mushiban, M. (2024). How to calculate statistics for significant difference test using SPSS: Understanding students comprehension on the concept of steam engines as power plant. *Indonesian Journal of Science and Technology*, *9*(1), 45-108.

Glorifica, I. (2021). Media analysis of biology teaching book grade xii: A study based on science literation category. *Indonesian Journal of Educational Research and Technology, 1*(2), 17-22.

Greener, S. (2017). Apa yang ditambahkan teknologi pada pembelajaran?. *Lingkungan Pembelajaran Interaktif*, *25* (6), 683-684.

Hasani, L. M., Santoso, H. B., and Junus, K. (2022). Designing asynchronous online discussion forum interface and interaction based on the community of inquiry framework. *The International Review of Research in Open and Distributed Learning*, *23*(2), 191-213.

Hawkes, R. (1977). Matriks fibrilar tangkai karchesium sebagai jaringan polimer yang terisi penuh. *Jurnal Fisiologi Seluler*, *90*(1), 31-40.

He, L., Fu, Y., Liu, Z., and Wei, P. (2023). Structural variation patterns in xylem vessels and parenchyma cells and their association with tree evolution. *Forests*, *14*(5), 950.

Hofifah, S.N., and Sumiati, S. (2023). The effectiveness of the practicum video guide on distance learning in improving biology learning outcomes in enzyme content. *Indonesian Journal of Teaching in Science*, *3*(2), 201-212.

Ibrahim, S. R., Bagalagel, A. A., Diri, R. M., Noor, A. O., Bakhsh, H. T., and Mohamed, G. A. (2022). Phytoconstituents and pharmacological activities of Indian Camphorweed

(Pluchea Indica): A multi-potential medicinal plant of nutritional and ethnomedicinal importance. *Molecules*, *27*(8), 2383.

Iwanowska, K., and Voyer, D. (2013). Dimensional transformation in tests of spatial and environmental cognition. *Memory and Cognition*, *41*(8), 1122-1131.

Kiernan, N. A., Manches, A., and Seery, M. K. (2021). The role of visuospatial thinking in students' predictions of molecular geometry. *Chemistry Education Research and Practice*, *22*(3), 626-639.

Kim, H., and Cameron, C. E. (2016). Implications of visuospatial skills and executive functions for learning mathematics: Evidence from children with autism and Williams syndrome. *AERA Open*, *2*(4), 2332858416675124.

Koh, M. Y., Tan, G. J. S., and Mogali, S. R. (2023). Spatial ability and 3D model colour-coding affect anatomy performance: a cross-sectional and randomized trial. *Scientific Reports*, *13*(1), 7879.

Krecko, L. K., Stalter, L. N., Pavuluri Quamme, S. R., Steege, L. M., Zelenski, A. B., Greenberg, C. C., and Jung, S. (2023). Discussion-based Interprofessional education: A positive step toward promoting shared understanding between surgical residents and nurses. *Journal of Interprofessional Care*, *37*(6), 974-989.

Leroux, O. (2012). Collenchyma: A versatile mechanical tissue with dynamic cell walls. *Annals of Botany*, *110*(6), 1083-1098.

Liu, L., Luan, Y., Fang, C., Hu, J., Chang, S., and Fei, B. (2023). Structural characteristics of reaction tissue in plants. *Plants*, *12*(8), 1705.

Lowrie, T., Logan, T., and Ramful, A. (2017). Visuospatial training improves elementary students' mathematics performance. *British Journal of Educational Psychology*, *87*(2), 170-186.

Mawikere, M. C. S. (2022). Model-model pembelajaran. *EDULEAD: Journal of Christian Education and Leadership*, *3*(1), 133-139.

Meltzer, D. E. (2002). The relationship between mathematics preparation and conceptual learning gains in physics: A possible "hidden variable" in diagnostic pretest scores. *American Journal of Physics*, *70*(12), 1259-1268.

Montenegro-Johnson, T., Strauss, S., Jackson, M. D., Walker, L., Smith, R. S., and Bassel, G. W. (2019). 3D cell atlas meristem: A tool for the global cellular annotation of shoot apical meristems. *Plant methods*, *15*, 1-9.

Morales-Navarrete, H., Segovia-Miranda, F., Klukowski, P., Meyer, K., Nonaka, H., Marsico, G., and Kalaidzidis, Y. (2015). A versatile pipeline for the multi-scale digital reconstruction and quantitative analysis of 3D tissue architecture. *Elife*, *4*, e11214.

Muffato, V., Meneghetti, C., and De Beni, R. (2020). The role of visuo-spatial abilities in environment learning from maps and navigation over the adult lifespan. *British Journal of Psychology*, *111*(1), 70-91.

Okura, F. (2022). 3D modelling and reconstruction of plants and trees: A cross-cutting review across computer graphics, vision, and plant phenotyping. *Breeding Science*, 72(1), 31-47.

DOI: https://doi.org/10.17509/ijost.v9i2.72105
p- ISSN 2528-1410 e- ISSN 2527-8045

Olumorin, C.O., Babalola, E.O., Aladesusi, G.A., Issa, A.I., and Omolafe, E.V. (2021). Experts' validation of the developed 3-dimensional automated model of the human heart to teach a biology concept in Ilorin, Nigeria. *Indonesian Journal of Multidiciplinary Research, 1*(2), 299-308.

Olumorin, C.O., Babalola, E.O., and Ayoola, D.A. (2022). Design and development of human excretory system model to teach a biology concept in Ilorin, Nigeria. *Indonesian Journal of Teaching in Science*, *2*(2), 107-116.

Owens, K. (2020). Transforming the established perceptions of visuospatial reasoning: Integrating an ecocultural perspective. *Mathematics Education Research Journal*, *32*(2), 257-283.

Pätzold, J., Feyrer, B., Saumweber, J., Hilger, H. H., and Gottschling, M. (2023). Observations on flower and fruit anatomy in dioecious species of Cordia (Cordiaceae, Boraginales) with evolutionary interpretations. *Organisms Diversity and Evolution*, *23*(1), 77-90.

Poppinga, S., Correa, D., Bruchmann, B., Menges, A., and Speck, T. (2020). Plant movements as concept generators for the development of biomimetic compliant mechanisms. *Integrative and Comparative Biology*, *60*(4), 886-895.

Riglet, L., Gatti, S., and Moyroud, E. (2021). Sculpting the surface: Structural patterning of plant epidermis. *Iscience*, *24*(11), 103346.

Rjosk, A., Neinhuis, C., and Lautenschläger, T. (2022). Anatomy and biomechanics of peltate Begonia leaves—Comparative case studies. *Plants*, *11*(23), 3297.

Roth, J. A., Wilson, T. D., and Sandig, M. (2015). The development of a virtual 3D model of the renal corpuscle from serial histological sections for E-learning environments. *Anatomical Sciences Education*, *8*(6), 574-583.

Roth-Nebelsick, A., and Krause, M. (2023). The plant leaf: A biomimetic resource for multifunctional and economic design. *Biomimetics*, *8*(2), 145.

Słupianek, A., Dolzblasz, A., and Sokołowska, K. (2021). Xylem parenchyma—role and relevance in wood functioning in trees. *Plants*, *10*(6), 1247.

Suprapto, P. K. (2019). The influence of concept maps and visuospatial representations to students achievement and creativity on plant anatomy courses. *Journal of Physics: Conference Series*, *1360*(1), 012031.

Suprapto, P. K., Bin Ahmad, M. Z., Chaidir, D. M., Ardiansyah, R., and Diella, D. (2018). Spatial intelligence and students--™ achievement to support creativity on visuospatial-based learning. *Jurnal Pendidikan IPA Indonesia*, *7*(2), 224-231.

Suprapto, P. K., Chaidir, D. M., and Ardiansyah, R. (2020). The use of 3D software on plant anatomy courses for prospective biology teachers. *Journal of physics: Conference series*, *1440*(1), 012065.

Susiyawati, E., and Treagust, D. F. (2021). Students' visual literacy: a study from plant anatomy learning. *Journal of Physics: Conference Series*, *1747*(1), 012021.

Tipmontiane, K., and Williams, P.J. (2022). The integration of the engineering design process in biology-related STEM activity: A review of Thai secondary education. *ASEAN Journal of Science and Engineering Education, 2*(1), 1-10.

DOI: https://doi.org/10.17509/ijost.v9i2.72105
p- ISSN 2528-1410 e- ISSN 2527-8045

Torre, D., German, D., Daley, B., and Taylor, D. (2023). Concept mapping: An aid to teaching and learning: AMEE Guide No. 157. *Medical Teacher*, *45*(5), 455-463.

Usman, A. B., Abubakar, S., Alaku, C., and Nnadi, O. (2014). Plant: a necessity of life. *International Letters of Natural Sciences*, *20,* 151-159.

Wang, Q., Guo, Q., Shi, Q., Yang, H., Liu, M., Niu, Y., and Li, G. (2024). Histological and single-nucleus transcriptome analyses reveal the specialized functions of ligular sclerenchyma cells and key regulators of leaf angle in maize. *Molecular Plant*, *17*(6), 920-934.

Wantu, H. M., Djafri, N., Lamatenggo, N., and Umar, M. K. (2023). Learning models: A literature review. *International Journal of Social Science and Human Research*, *6*(5), 2763-2767.

Yuan, Q., Chen, X., Zhai, J., Chen, Y., Liu, Q., Tan, Z., and Shao, X. (2021). Application of 3D modelling and fusion technology of medical image data in image teaching. *BMC Medical Education*, *21*, 1-10.