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Development of Leaf Structure and Function Learning Application using Augmented Reality Technology: EksplorARDaun

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Abstract

Leaf structure and function is a key topic in the Biology syllabus for Form 5 students in Malaysia and is crucial for the Sijil Pelajaran Malaysia (SPM) examination. This topic includes five subtopics: leaf structure, gaseous exchange, transpiration, photosynthesis and compensation point. These concepts are often challenging to visualize and understand due to their abstract nature and the limitations of traditional learning methods, which rely heavily on static images and text. These limitations make it more difficult for students to imagine and retain the dynamic processes involved in leaf form and function. To address these challenges, the EksplorARDaun mobile learning application was developed using a marker-based augmented reality (AR) approach. The app includes both a learning module and assessment module. Developed using the Multimedia Mobile Content Development (MMCD) methodology, EksplorARDaun was designed for Android platforms and is aligned with Malaysia SPM syllabus. Targeting Form 5 students, beta testing shows a positive result of 75.7% based on the System Usability Scale, confirming the app delivers on its claims and accepted by user.

1. Introduction

In our world, there are countless types of plants, each adapted to different habitats and classified into various species. These plants have unique parts and structures, each of which performs a particular role in the survival and development of the plant [1]. The most significant part among these essential parts is undoubtedly the leaf. Leaves typically grow from the sides of the stems and are usually green, flat and thin, though their shape and size can be vary widely depending on the plant species [2]. A leaf's primary function is to produce nourishment for the plant. Leaves are one of the main organs involved in converting sunlight into food. Sunlight, one of the key components in the process of producing food, is absorbed by the green pigment present in most leaves [3]. Beyond appearance, leaves have separate life cycles and essential to the plant's entire cycle of development and survival of plants.

In modern education, mobile learning application and augmented reality (AR) technology offers engaging ways to bring concepts like leaf structure and function life. AR combines digital information with the real-world environment in real-time, while mobile application provides an accessible platform for students to interact with these virtual elements anytime and anywhere, allowing users to interact with virtual objects that improve understanding [4]. For example, mobile application like PlantSnap [5] and Seek by iNaturalist [6] use AR and image recognition to identify plants and provide information about their structures, making learning more practical and connected to real-world experiences. This technology helps students grasp complex plant biology

concepts more easily by presenting interactive models of leaves and their life cycles, making learning both immersive and relatable.

Understanding the structure and function of leaves is crucial due to their importance in plant survival. However, topics such as photosynthesis, transpiration, and gaseous exchange are often abstract and difficult for students to visualize through traditional methods such as lectures and textbooks. Therefore, this project aims to design a user-friendly EksplorARDaun application that is visually appealing and easy for Form 5 students, to develop EksplorARDaun on Android platform, and to test the usability and user acceptance of the application to the target user. The application is focused for form 5 students to improve their learning experience in biology class through an AR environment. The fully immersive experience is utilized to visualize abstract biological concepts and intricate processes related to leaf structure and function topics. EksplorARDaun application contains three modules which are Learning, Activity, and Practical module which is based on the Biology textbook for Form 5, focusing on Chapter 2, Leaf Structure and Function. The content of this application is delivered in Bahasa Melayu. The Multimedia Mobile Content Development (MMCD) methodology provides a well-organized and structured framework to guide every stage of the development process. The application can be used as a learning tool and additional resources for Form 5 students studying Biology, as well as other students who eagers to learn and teachers to support classroom teaching.

The rest of this paper is arranged as follows: Section 2 covers the domain of study, the technology used, and the result of the comparative analysis. Section 3 describes the chosen methodology to be used in this project which is MMCD methodology, as well as the output of the analysis and design phases of this project. Furthermore, Section 4 discusses the result and discussions, while Section 5 states the conclusion of the current progress.

2. Related Work

This section covers the topic of leaf structure and function for secondary school, the use of AR technology, and a comparative analysis of existing applications such as Plantale, Arloon Plants, and Biology RA against the newly developed application, EksplorARDaun. The section also presents the results of EksplorARDaun in supporting effective Biology education.

2.1 Leaf Structure and Function for Secondary School

Biology is a science course which many students find to be their favorite, but it also contains a number of topics that many other students find challenging [1]. Biology is one of the elective science subjects offered to upper secondary students, alongside with Chemistry and Physics. Leaf structure and function is a key topic in the biology curriculum for Form 5 students. This topic covers the structure of leaves, including their external feature such as lamina and petiole as well as their internal anatomy, like the arrangement of the tissues such as the epidermis, mesophyll, and vascular bundles. In addition, the study of leaf function extends to the main organ for biological processes such as transpiration, photosynthesis and gaseous exchange.

Understanding leaf structure and function is important because it helps students connect how plants grow, adapt, and contribute to the ecosystem. However, this topic can be difficult for some because it involves abstract and complex concepts. Research shows that hands-on activities, visuals, and technology can make these concepts easier to understand. Overall, the study of leaf structure and function is an essential part of the Form 5 Biology syllabus. It enhances students' understanding of plant biology, builds their critical thinking abilities, and highlights the vital role of plants in the ecosystem.

2.2 Augmented Reality Technology

Augmented Reality (AR) combines digital information with the real world in real time. Unlike virtual reality (VR), which creates a completely virtual environment, AR lets users see the real world with digital elements added on top [7].

Nowadays, augmented reality has developed rapidly became the new life changing technology from assisting in the decision-making process to entertainment. In education, AR can provide additional information or visually enhance natural environments, making learning more interactive and engaging. For example, apps like Google Expeditions [8] and ARLOOPA [9] use AR to create interactive 3D models of scientific concepts, allowing abstract and complex topics, such as cells and photosynthesis, to be brought to life in the real world through AR technology [3].

2.2.1 Markerless-based AR

Markerless AR technology operates without the need for a physical marker, relying instead on scanning the surrounding environment where the device is being used. Unlike marker-based AR systems, markerless AR offers greater flexibility, accuracy, and professionalism, eliminating the need for object tracking systems [4]. For example, Plantale [10] application use markerless AR to provide interactive 3D visualizations of plant structures

and growth processes, making learning more engaging. However, this may result in tracking problems in settings with low lighting or few surface textures, which could interfere with the educational process.

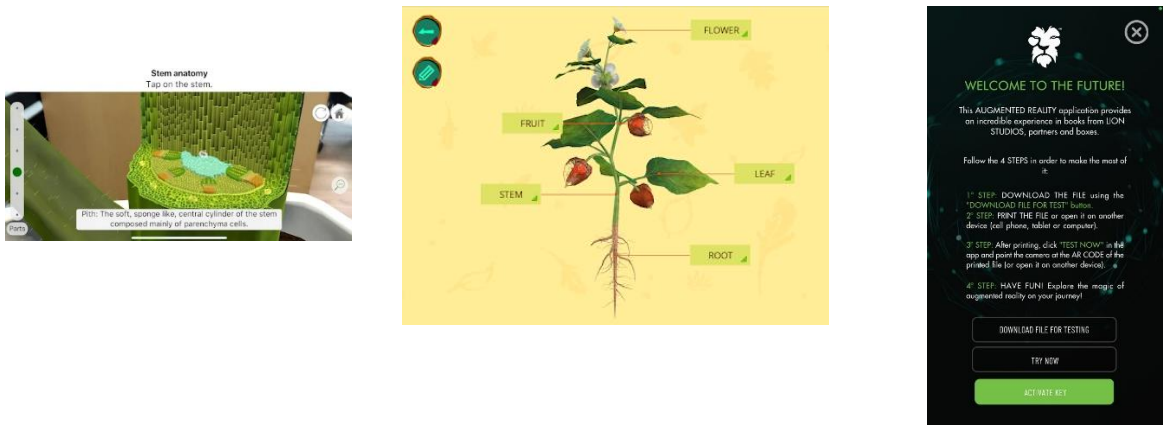
2.2.2 Marker-based AR

Marker-based AR is an interactive experience that is triggered by a particular graphic signal or image such as QR code. This process is referred as tracking and recognition. Markers can be paper-based or real-world physical objects that are visually independent of their surroundings and consist of distinct patterns that cameras can easily identify and process [4]. Identifying a marker using the features that were collected and combining virtual objects in the actual world is the most important step to develop a marker-based AR application.

This technology is particularly suitable for the developed application as it provides a more stable and precise experience for educational purposes, especially for younger users or students who are new to AR. For example, the Biology RA [11] app uses marker-based to support learning by turning textbook images into interactive 3D biological models, helping students better visualize complex concepts.

2.3 Comparative Analysis

Comparative analyses were conducted on three related applications to the developed application. The three applications are Plantale [10], Arloon Plants [12], and Biology RA [11] as shown in Figure 1 (a), (b), and (c) respectively. Table 1 shows the result of the comparative analysis.



(a) **(b)** **(c)**

Fig. 1 *Screenshot of existing application (a) Plantale apps; (b) Arloon Plants apps; (c) Biology RA apps*

Table 1 *Application Comparison*

Features/ Applications	Plantale	Arloon Plants	Biology RA	EksplorARDaun
Content	Storytelling, interactive exploration.	Structured, 3D models, plant dissection, interactive learning.	3D visualizations. AR of plant anatomy and processes.	3D AR models of leaf structure, and 3D animations of processes like photosynthesis and transpiration.
Technology used	Markerless AR.	AR.	Marker-based AR.	Marker-based AR.
Focus area	Plant life cycle (focused on sunflower), ecology.	Plant anatomy such as leaves, roots, and flowers.	Plant anatomy and biological process.	Detailed study of leaf structure and function, photosynthesis, and transpiration.
Target audience	Young learners, botanist and gardener.	Student of all ages.	Students and educators.	Form 5 students specifically for SPM preparation.

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Table 1: *Application Comparison (cont.)*

Local syllabus relevance	Not specific.	Not specific to local syllabus.	Not specific to local syllabus.	Fully aligned with Malaysian SPM curriculum.
Available platforms	iOS only.	iOS only.	Android and iOS.	Android only.
Modules	One main interactive AR learning module (with multiple sub-components).	Three modules: Grow-a-Plant, Garden Builder + Quiz/Games	One module with 16 AR scenes.	Three modules: Belajar (learning module), Aktiviti (activity module), and Amali (practical module).

Based on Table 1, EksplorARDaun stands out among the compared applications because it is only one full alignment with Malaysian SPM curriculum, specifically designed to support national exam preparation for Form 5 students, unlike the others which are not tied to any local syllabus.

3. Methodology

The EksplorARDaun learning application has been developed using the Multimedia Mobile Content Development (MMCD) as shown in Figure 2. This is because learning application development is the focus of the MMCD methodology [13] and for its comprehensive coverage of the development process. The five phases of this methodology are the application idea creation phase, structure analysis phase, process design phase, main function development phase, and testing phase.

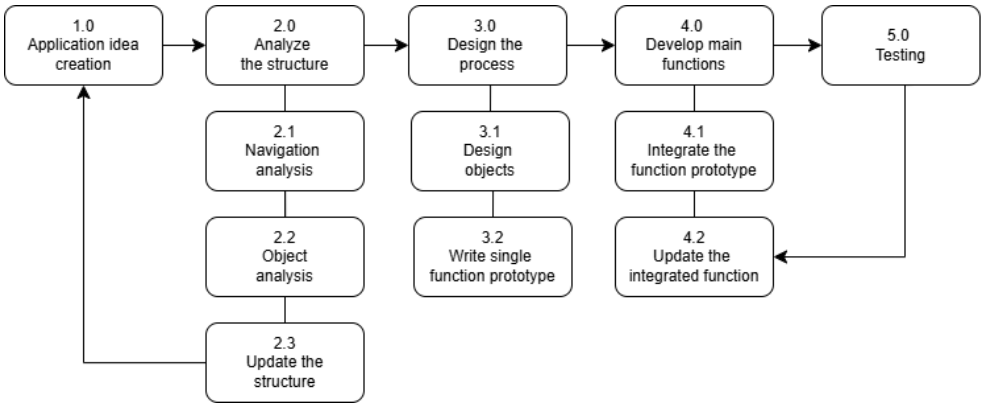

Fig. 2 *MMCD Methodology [13]*

3.1 Application Idea Creation

The first phase of the MMCD methodology is application idea creation. In this phase, the developer engages in individual brainstorming to generate ideas and explore solutions for the project. This process takes place before the design and development phases began. Table 2 showed the checklist of application idea creation stages that describes the mobile learning tool for Form 5 Biology students using Android tablets while Table 3 showed the user requirement analysis for the application, which includes the needs of both teachers and students. This analysis highlights the importance of using simple language, aligning content with the KSSM syllabus, and ensuring easy navigation, all of which help in designing a useful and student-friendly app.

Table 2 *Application idea creation checklist*

Item	Description
Type of application	Mobile learning application
Target device	Android-based tablet
Target users	Form 5 students who studied Biology
Unity	Version: 2022.3.55f1
Images	Background, buttons, information images of the notes
Video	Practical video, 3D animation

Table 2: Application idea creation checklist (cont.)

Augmented Reality (AR)	3D models of complex cell and leaf anatomy
Application synopsis	EksplorARDaun is a learning application specifically for Form 5 students which allows students to learn this specific topic which is Leaf Structure and Function.

Table 3 *User Requirement Analysis*

Stakeholder category	Role in product	Design implication	Action needed
Subject Matter Expert (SME) Puan Siti Nadiyana binti Kardi@Karnadi	Biology teacher	Less use of words, simple sentences	Use simple sentences for users to understand the content easily Deliver content in points or acronyms to improve students' memory
		Content, based on secondary school student syllabus	Follow the KSSM syllabus Amali module should be provided as it is significance for Form 5 Biology Paper 3 SPM
Form 5 students	End-user of the developed application	Easy to use	The application should be developed with easy navigation for users

3.2 Analyze the Structure

Navigation analysis and object analysis are components used in the developed application. Both analyses are included in the structure analysis phase. Table 4 shows a content structure checklist which was created based on the application idea creation phase and conversations between developers, ensuring that all layers, frames, navigation elements, images, and animations required for the application are clearly defined.

Table 4 *Content structure checklist*

Item	Description
Layers Design	• Layer 3: C# Script • Layer 2: Content • Layer 1: Background
Frame Design	• Scene 1: Launching interface • Scene 2: Homepage interface (to choose module) • Scene 3: Belajar module • Scene 4: Aktiviti module • Scene 5: Amali module • Scene 6: Submodule interface • Scene 7: AR module
Menu and Navigation	• Start button • Back button • Belajar module button • Aktiviti module button • Amali module button • Home button • AR button
Number of main GUI	• Application logo
Images	• Background images • Button icons
Video	• 3D animation of transpiration process • 3D animation of photosynthesis • 3D animation of closing and opening of stoma mechanism

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System design is the process of specifying components of a system such as architecture, modules, interface, and data according to the requirements. To meet the specific requirements, systems must be defined, developed and designed through the process. The navigation structure created for the developed application is shown in Figure 3.

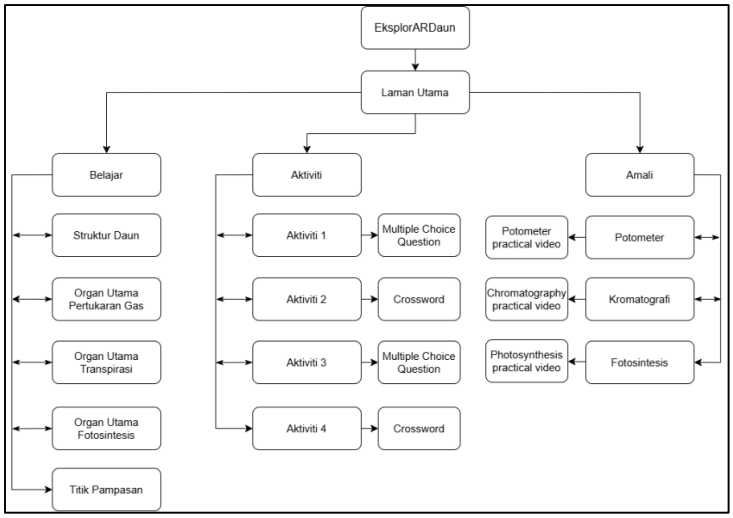


Fig. 3 *Navigation Structure of the application*

This phase also covers the functional requirement as shown in Table 5 and non-functional requirements which are indicated in Table 6.

Table 5 *Functional requirements*

Functional Requirements	Module/Scene	Description
User interaction	Welcome interface	The application should allow users to click on Mula button to go to the home page.
	Homepage interface	The application should allow users to select the Belajar Module, Activity Module, and Amali Module.
	Belajar Module	The application should allow users to select five different submodules based on subtopics in Biology Chapter 2.
	Aktiviti Module	The application should allow users to input the answer to the question.
	Amali Module	The application should allow users to select 3 practical experiments they want.
Learning/practice content	Submodule interface	The application should allow users to learn five subtopics in Biology Chapter 2
	Aktiviti Module	The application should allow users to answer interactive questions based on what they have learn.
	Amali Module	The application should allow users to learn practical

Table 6 *Non-functional requirements*

Non-Functional Requirements	Description
Performance	• The application should be able to perform and load all the modules and pages
Availability	• The application and its data should be able accessed without the internet
Ease of Use	• The developer shall provide an application that is easy to navigate • The developer shall provide tutorials in the application
Cultural	• The application should be built in English

3.3 Design the Process

The design the process phase's purpose is to prepare all the components in the second phase of MMCD model. This stage explained the design of applications that concerning the user's interactions. The overall effectiveness of an application is depended on the user's need. Hence, the development of the developed application should achieve several principles such as the allure of multimedia elements used in designing interfaces. The process design stage has two sub-stages which are designing the objects and writing single-function prototypes. In this project, specific design software such as Adobe Illustrator was used for graphical designs, and Unity was used to compile and integrate all the assets needed along with the scripting process.

In addition, the 2D user interface, interaction button, 3D image object, and button icons produced by using the sample software mentioned above. Interaction buttons were connected between the main page and the other relevant pages in this application. The prototype is created with consideration for the object and graphic designs that define the AR framework of the suggested application. Later on in this process, the first scripting were written to create the module and ensure that all of its key features are operating as intended. Table 7 and Table 8 shows the designs of the buttons and some interfaces of the built application respectively.

Table 7 *Button Designs*

Buttons	Functions	Buttons	Functions
	• This is the homepage button which navigates user to the home when pressed.		• This is the button in the lesson module, each button represents of each subtopic in the chapter.
	• This is AR button which navigates user to the AR scene.		• This is the button that navigates user to the lesson module
	• This is the animation button.		• This is the button that navigates user to the activity module
	• This is the uniform button used as 'Mula', 'Cuba lagi' dan 'Seterusnya' with respective functions of to start the apps, retry the quizzes, and proceed to next activities.		• This is the button that navigates user to the practical module

Table 8 *Interfaces of the built application*

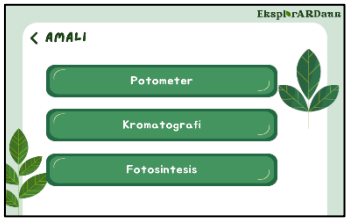
Interface	Description	Interface	Description
	Welcome interface		Practical module interface

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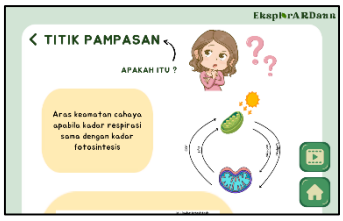
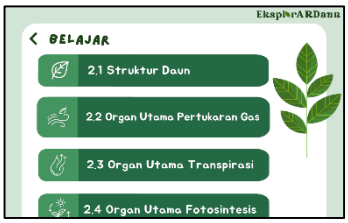
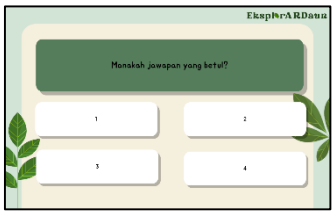
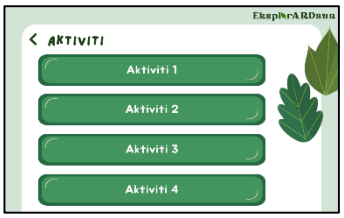
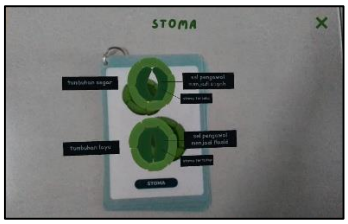
Table 8: *Interfaces of the built application (cont.)*

	Homepage		Submodule in lesson module
	Lesson module interface		Quiz interface
	Activity module interface		AR interface

In the design phase of MMCD, writing a single function prototype is crucial before proceeding to the stage of implementation. In EksplorARDaun application, users can navigate to different scenes by clicking different buttons. The script is written in C# language as can been seen in Figure 4. The script is first attached to a `GameObject` with the `SceneName` specified beforehand. Next, the `GameObject` is assigned to each button for the `On Click ()` function. Then, the `changeScene ()` function was set to be activated when the button is clicked.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;
public class LevelManager : MonoBehaviour
{
   public void changeScene()
      {
      SceneManager.LoadScene(sceneName);
      }
   }
```

Fig. 4 *Code snippet to change scene*

3.4 Develop Main Function

The main function of the EksplorARDaun learning application is the navigation between each module and submodule. The application consists of three main modules with their navigation buttons which is lesson module, activity module and practical. The lesson module consists of five submodules that comprehensively cover key topics in the 'Leaf Structure and Function' chapter in Biology textbook which are the structure of the leaf, its role as the main organ for gaseous exchange, transpiration, and photosynthesis and compensation point. Each submodule includes interactive AR functions and 3D animations, providing an engaging and immersive learning experience for students. All the navigation buttons in the application allow to navigate from one scene to another scene.

Table 9 and Table 10 shows supporting details for the development process by highlighting the assets created and the integration of scripting in Unity. Table 9 outlines the development of 2D and 3D assets used in the application, while Table 10 presents code snippets that represents a portion of the main function in implemented AR features and interactive functions such as crossword input handling and answer processing.

Table 9 *Development of Assets*

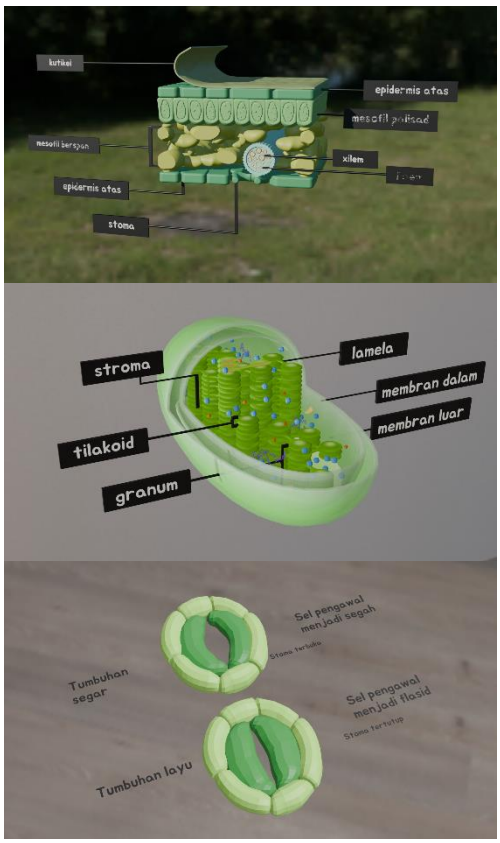
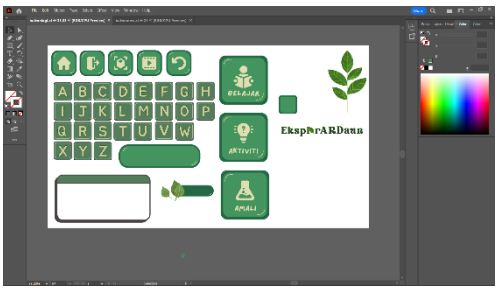
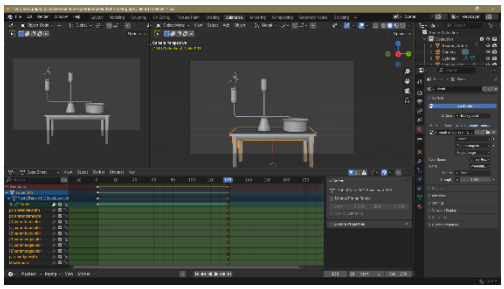
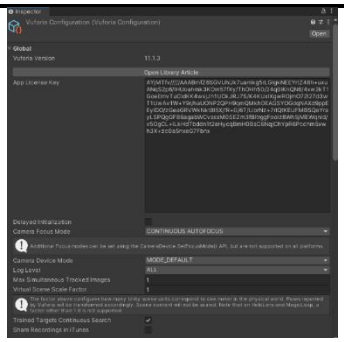
Assets	Development	Description
3D Models		All the 3D models are created in Blender with appropriate materials assigned to each mesh. Then, the file is packed and exported into Unity as .fbx file. The materials are extracted in Unity, so it appears the same as in Blender.
2D assets		2D assets such as graphics, buttons, logo, and background are designed in Adobe Illustrator. Some icons are from Flaticon and Freepik, then imported to .ai file to be further refined and designed. Then, every asset is exported singly as single asset in .png file that can be readily imported into Unity. The assets are then converted into sprite in Unity
3D Animation		3D animations of models are created in Blender by inserting keyframe of different position (scale, translate, rotate) at different time. The animation then exported into Unity along with the .fbx file.

Table 10 *Integration with scripting in Unity*

Function	Development	Description
Develop AR functionalities		Vuforia Engine 11.1.3 is used to develop AR functionalities by configuring the AR Camera, image targets, and interactive 3D content. It enables recognition of real-world markers for accurate virtual overlays and interactions.
Crossword answer input	`public void FillActiveSlotWithLetter(char letter) { if (activeSlot != null && activeSlot.isActive) { activeSlot.SetLetter(letter); OnSlotFilled(); MoveToNextSlotInClue(); } }`	`FillActiveSlotWithLetter(char letter)` function is an important part of the crossword game. It places the player's letter into the active slot, checks if the clue is correct, updates the score, and moves to the next slot. If the puzzle is complete, it shows either a win or penalty screen. This function links player input to game progress and puzzle checking.
Answer processing function	`public void Answer() { Image img = GetComponent<Image>(); if (isCorrect) { img.color = Color.green; Debug.Log("Correct Answer"); StartCoroutine(ProceedAfterDelay(true)); } else {img.color = Color.red; Debug.Log("Wrong Answer"); StartCoroutine(ProceedAfterDelay(false)); } }`	The `Answer()` function is triggered when the player selects an answer in a quiz. It checks whether the selected answer is correct (`isCorrect`). If it is, the button turns green; otherwise, it turns red. It then starts a short delay before telling the `QuizManager` whether the answer was right or wrong, allowing time for visual feedback.
Answer selection and feedback logic for quiz	`public void OnPointerClick(PointerEventData eventData) { if (manager != null) { manager.SetActiveSlot(this); // Prefer to show across clue first if both exist if (acrossClueNumber >= manager.SelectClueByNumber(acrossClueNumber, false); } else if (downClueNumber >= 0) { manager.SelectClueByNumber(downClueNumber, true); } } }`	The `OnPointerClick` function is called when the player clicks on a puzzle slot (tile) in the crossword grid. It notifies the `CrosswordManager` that this slot has been selected and sets it as the active slot. If the slot is linked to a clue (across or down), it also tells the manager to highlight and display that clue.

3.5 Testing

The MMCD methodology's last stage, testing is essential to the development process. It is primarily for bug detection and make sure that the system is operating as smoothly as possible. There are two types of testing, alpha and beta testing that are involved in this project. Alpha testing is conducted by developers to test the functionality and identify issues. Table 11 shows the result of alpha testing for EksplorARDaun application. Beta testing requires involvement of the target users of this application, which is Form 5 students who studied Biology. In this project, the testing conducted and evaluated data regarding target users' satisfaction with the produced application will be gathered to make sure the program has met their expectations. Finally, all of the respondents' comments would be examined, and more steps would be taken for improving the application.

Table 11 *Alpha Testing*

Scene	Testing	Expected Results	Actual Results	Correction Action
Homepage	Belajar button	Navigate user to the lesson module	Works as expected	Not required
	Aktiviti button	Navigate user to the activity module	Works as expected	Not required
	Amali button	Navigate user to the practical module	Works as expected	Not required
Belajar	Struktur Daun button	Navigate user to the lesson about leaf structure	Work as expected	Not required
	Organ Utama Pertukaran Gas button	Navigate user to the lesson about gaseous exchange	Work as expected	Not required
	Organ Utama Transpirasi button	Navigate user to the lesson about transpiration	Work as expected	Not required
	Organ Utama Fotosintesis button	Navigate user to the lesson about photosynthesis	Work as expected	Not required
	Titik Pampasan button	Navigate user to the lesson about compensation point	Work as expected	Not required
Aktiviti	Aktiviti 1 button	Navigate user to the first activity which is trivia quiz	Work as expected	Not required
	Aktiviti 2 button	Navigate user to the second activity which is crossword	Crossword scene does not update the score when the user submits incorrect answers	Check the scoring script to ensure it updates marks for wrong answers correctly
	Aktiviti 3 button	Navigate user to the next activity which is second trivia quiz	The question-and-answer template is incorrectly duplicated from Aktiviti 1	Create new function in new scripts instead of duplicate the existing script
	Aktiviti 4 button	Navigate user to the last activity (second crossword)	The clue for the crossword does not appear	Check and fix the clue visibility in the script for Aktiviti 4
Amali	Potometer button	Navigate user to potometer practical video	The button is unable play the related video	Check video link or file path and ensure the video is accessible
	Kromatografi button	Navigate user to chromatography practical video	The button is unable play the related video	Check video link or file path and ensure the video is accessible
	Fotosintesis button	Navigate user to photosynthesis practical video	The button is unable play the related video	Check video link or file path and ensure the video is accessible

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Table 11: *Alpha Testing (cont.)*

Struktur Daun	Back button	Navigate user to go back to lesson module	Work as expected	Not required
	AR button	Navigate user to the related 3D model	Work as expected	Not required
	Animation button	Navigate user to the related animation	Work as expected	Not required
	Home button	Navigate user to the homepage	Work as expected	Not required
Pertukaran Gas	Back button	Navigate user to go back to lesson module	Work as expected	Not required
	AR button	Navigate user to the related 3D model	Work as expected	Not required
	Animation button	Navigate user to the related animation	Work as expected	Not required
	Homepage button	Navigate user to the homepage	Work as expected	Not required
Transpirasi	Back button	Navigate user to go back to lesson module	Work as expected	Not required
	AR button	Navigate user to the related 3D model	Work as expected	Not required
	Animation button	Navigate user to the related animation	Work as expected	Not required
	Homepage button	Navigate user to the homepage	Work as expected	Not required
Fotosintesis	Back button	Navigate user to go back to lesson module	Work as expected	Not required
	AR button	Navigate user to the related 3D model	Work as expected	Not required
	Animation button	Navigate user to the related animation	Work as expected	Not required
	Homepage button	Navigate user to the homepage	Work as expected	Not required
Titik Pampasan	Back button	Navigate user to go back to lesson module	Work as expected	Not required
	AR button	Navigate user to the related 3D model	Work as expected	Not required
	Animation button	Navigate user to the related animation	Work as expected	Not required
	Home button	Navigate user to the homepage	Work as expected	Not required

4. Result and Discussion

By obtaining and examining feedback and comments from the target users, user acceptability testing aims to determine whether the application is useful and acceptable to the intended users, and whether further improvements to the its functionality are needed. A total of 25 target users participated in the testing, including SME and Form 5 students from Sekolah Menengah Kebangsaan Tun Ismail using the System Usability Scale (SUS) [14] survey method. The overall analysis of the SUS questionnaire indicates positive feedback, as most users agreed with the positive-toned questions and disagreed with the negative-toned questions, as shown in Figure 5 and 6.

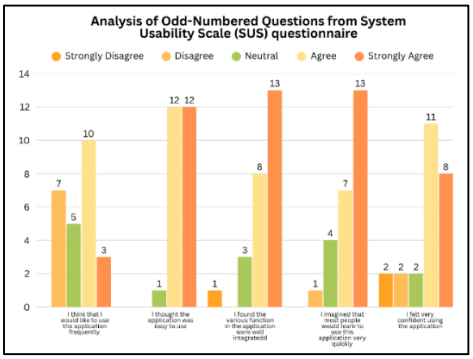

Fig. 5 *Analysis of Odd-Numbered questions from System Usability Scale (SUS) questionnaire*

Figure 5 displays the result of analysis of the positive-toned questions from the SUS questionnaire of SUS questionnaire. Firstly, 13 of the respondents agree or strongly agree that they would like to use the application frequently, while only 5 respondents feel neutral towards the statement and 7 respondents feel slightly disagree. Next, most respondents, specifically 24 of them, agree or strongly agree that the application is easy to use and that the functions are well integrated, with only 1 respondent feeling neutral towards both statements. Next, 21 respondents agree or strongly agree that the application is easy to use and that the functions are well integrated, with only 3 respondents feeling neutral towards both statements. This indicates excellent usability, and the application's features work seamlessly together. Then, a total of 20 respondents agrees or strongly agrees that most people would learn to use the application quickly, while 4 respondents feel neutral, and 1 respondent disagrees with the statement. Finally, 19 respondents agree or strongly agree that they felt confident using the application, with 2 respondents feeling neutral and 4 others feel disagree or strongly disagree. In conclusion, the responses from the SUS questionnaire indicate positive feedback to the application. The overall result of the beta testing shows positive feedback as the majority of the users agree with the positive-toned questions. Users find it easy to use, well-integrated, quick to learn, and confidence-inspiring, with the majority expressing a willingness to use it frequently.

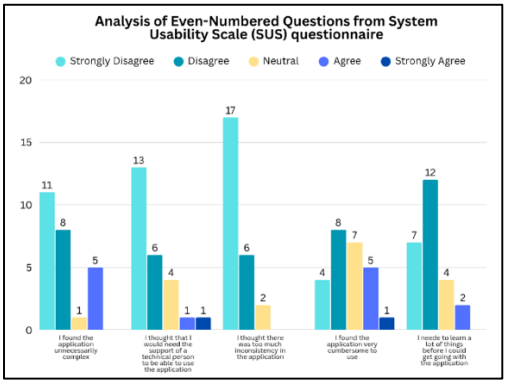

Fig. 6 *Analysis of Even-Numbered questions from System Usability Scale (SUS) questionnaire*

Figure 6 shows the analysis of negative-toned questions. Firstly, a significant number of respondents, 19, strongly disagree or disagree that the application is unnecessarily complex, with only 1 respondent feeling neutral, and 5 others agrees, indicating that users find the application straightforward and not overly complicated. Next, 19 respondents strongly disagree or disagree that they would need technical support to use the application, while the other 6 respondents feel neutral and agrees with the statement. Then, a total of 23 respondents strongly disagree or disagree that there is too much inconsistency in the application, with only 2 respondents feeling neutral, indicating that users find the application to be consistently design. Then, 12 respondents strongly disagree or disagree that the application is cumbersome to use, and the remaining 7 respondents feel neutral towards it. Lastly, a total of 19 respondents strongly disagrees or disagree that they needed to learn a lot before using the application, while 4 respondents feel neutral, and 2 respondent agrees with the statement. In conclusion, the overall result of the beta testing shows positive feedback as most of the users disagree with the negative-toned questions. Users do not find the application complex, inconsistent, cumbersome, or difficult to use without technical support.

Then, the SUS scoring was applied to derive a quantitative measure of usability for the EksplorARDaun application. The formula used for SUS scoring is shown in Figure 7. The results of the calculation are presented in Table 12.

```
X = Sum of the points for all odd-numbered questions
Y = Sum of the points for all even-numbered questions
                    Calculate:

 X = (Q1, Q3, Q5, Q9 scores - 1) = 221 - (25 x 1) =
                          196
 Y = (5 - each score from Q2, Q4, Q6, Q8, Q10) = 107

            SUS Score = (X + Y) x 2.5
            = (196 + 107) x 2.5
            = 757.5

      Average SUS Score (%) = 757.5 ÷ 25 = 75.5 %
```

Fig. 7 *SUS formula [14]*

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Table 12 *Total Score of SUS Testing*

Respondent	Score										Odd-number questions score	Even-number questions score	Total
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10			
R01	5	2	5	1	4	1	5	2	5	3	19	16	87.5
R02	5	3	4	1	5	1	5	2	5	1	19	17	90
R03	3	1	4	1	3	1	5	1	2	1	12	20	80
R04	4	4	3	3	3	3	3	3	3	3	11	9	50
R05	2	4	4	3	3	3	3	3	3	4	10	8	45
R06	5	2	5	2	5	1	5	1	5	1	20	18	95
R07	4	1	4	2	4	2	4	2	4	2	15	16	77.5
R08	3	2	4	1	4	2	5	1	4	2	15	17	80
R09	4	1	5	1	4	1	4	2	5	1	17	19	90
R10	4	2	4	2	4	2	4	2	4	2	15	15	75
R11	2	4	4	3	5	1	3	3	4	2	13	12	62.5
R12	4	1	5	1	5	1	5	1	5	1	19	20	97.5
R13	2	1	4	3	1	2	4	2	4	2	10	15	62.5
R14	4	2	4	2	4	1	4	3	4	3	15	14	72.5
R15	2	1	4	1	5	1	5	4	5	2	16	16	80
R16	4	1	4	1	5	1	5	4	4	2	17	16	82.5
R17	3	1	5	1	5	1	5	3	5	2	18	17	87.5
R18	3	2	5	1	5	1	4	4	4	2	16	15	77.5
R19	2	2	5	2	5	1	3	2	4	3	14	15	72.5
R20	2	4	5	5	5	1	2	4	4	1	13	10	57.5
R21	4	4	5	4	5	1	5	2	5	2	19	12	77.5
R22	4	1	5	1	5	1	5	5	2	1	16	16	80
R23	2	1	5	1	4	1	4	3	1	2	11	17	70
R24	4	2	4	2	5	2	5	3	1	4	14	12	65
R25	3	1	5	1	4	2	5	4	4	2	16	15	77.5
												Average Score (%)	75.7

Table 12 shows the results of the SUS testing for the developed EksplorARDaun application with an average score of 75.7%. Based on the SUS score scale as displayed in Figure 8, the application received a grade of 'C' indicating the application is acceptable. However, the result also suggests that there is room for improvement in enhancing the user experience.

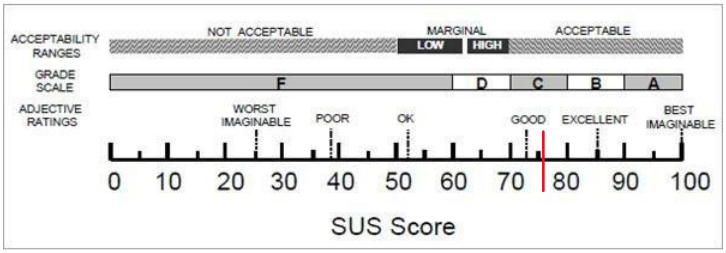

Fig. 8 *SUS Score Scale [14]*

5. Conclusion

In conclusion, EksplorARDaun application was developed as an interactive platform focused on the structure and function of leaves, aiming to support Biology education for Form 5 students through the use of augmented reality (AR) technology. Moreover, 3 objectives of the project have been achieved successfully. EksplorARDaun project involved creating a prototype mobile application, integrating basic AR learning features, and conducting functional and user acceptance testing. Findings from the implementation and testing phase showed that the application was well-received by students. The result of the user acceptance testing indicated that students found the application engaging, easy to navigate, and helpful in understanding difficult biology concepts. This confirms that the project objectives were successfully achieved. EksplorARDaun application contributes to the field of digital education by offering an alternative learning approach that supports self-paced study, increases

visualization of abstract content, and complements traditional classroom teaching. It benefits teachers as well as students by serving as an support teaching tool that is in line with the KSSM curriculum.

Among the advantages of the are its attractive user interface, AR-based 3D interactivity, and the ability to function without internet access. However, several limitations were identified, such as limited quiz content and the use of AI-generated voice-over that may lack natural expression and clarity. For future improvement, it is recommended to enhance the quiz module with more questions, improve the narration quality using real human voices, optimize file size, and include multilingual support to widen its accessibility. Overall, although EksplorARDaun is limited in scope, it marks an important step in integrating AR into science education and sets the foundation for future enhancements in digital learning tools.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Engku Nur Aisyah Che Ku Daik, Norhanifah Binti Murli;* ***data collection:*** *Engku Nur Aisyah Che Ku Daik, Norhanifah Binti Murli;* ***analysis and interpretation of results*** *Engku Nur Aisyah Che Ku Daik, Norhanifah Binti Murli;* ***draft manuscript preparation:*** *Engku Nur Aisyah Che Ku Daik, Norhanifah Binti Murli. All authors reviewed the results and approved the final version of the manuscript.*

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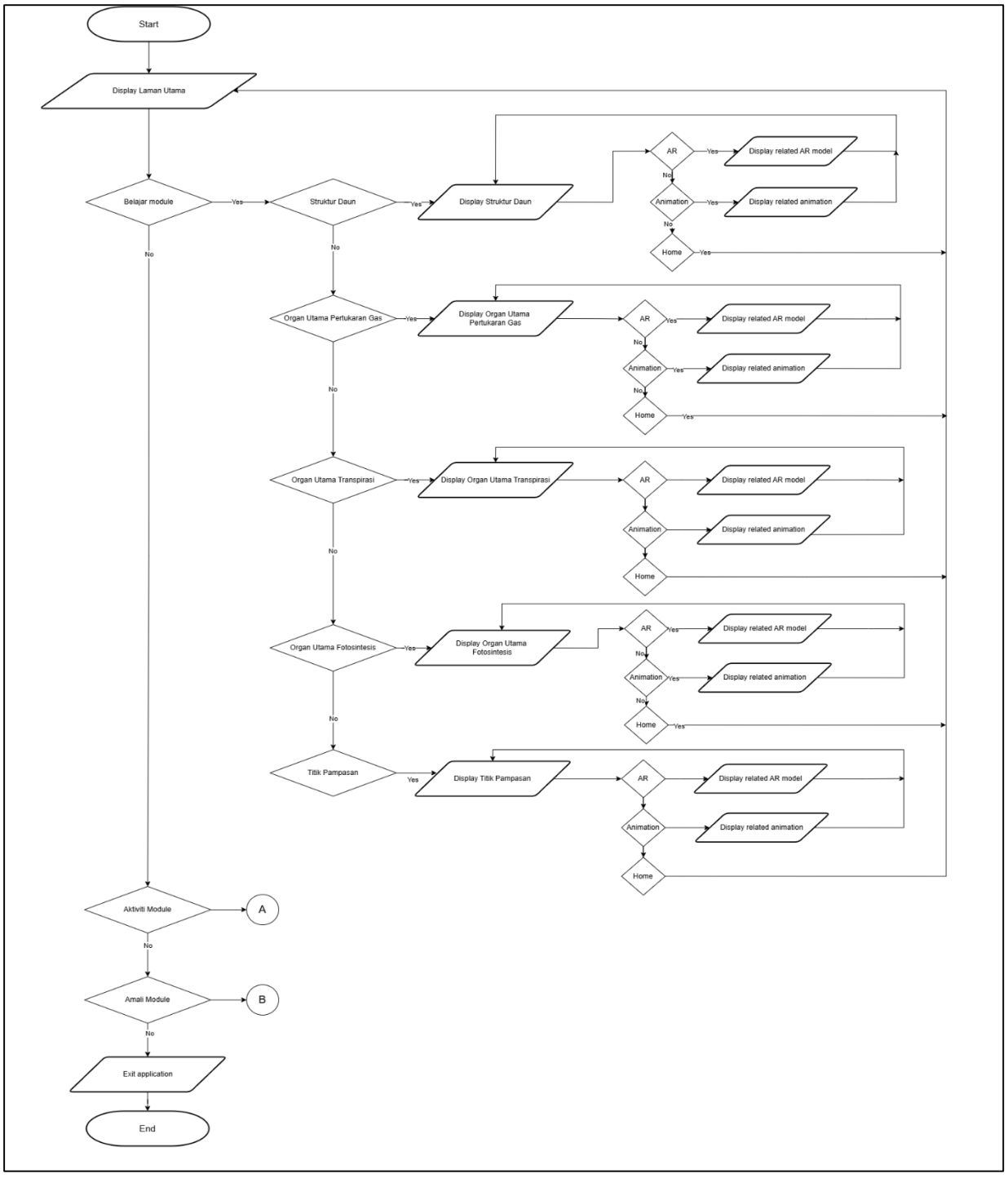
Appendix A

Appendix A shows the main system flowchart in section 3.2.



(a)

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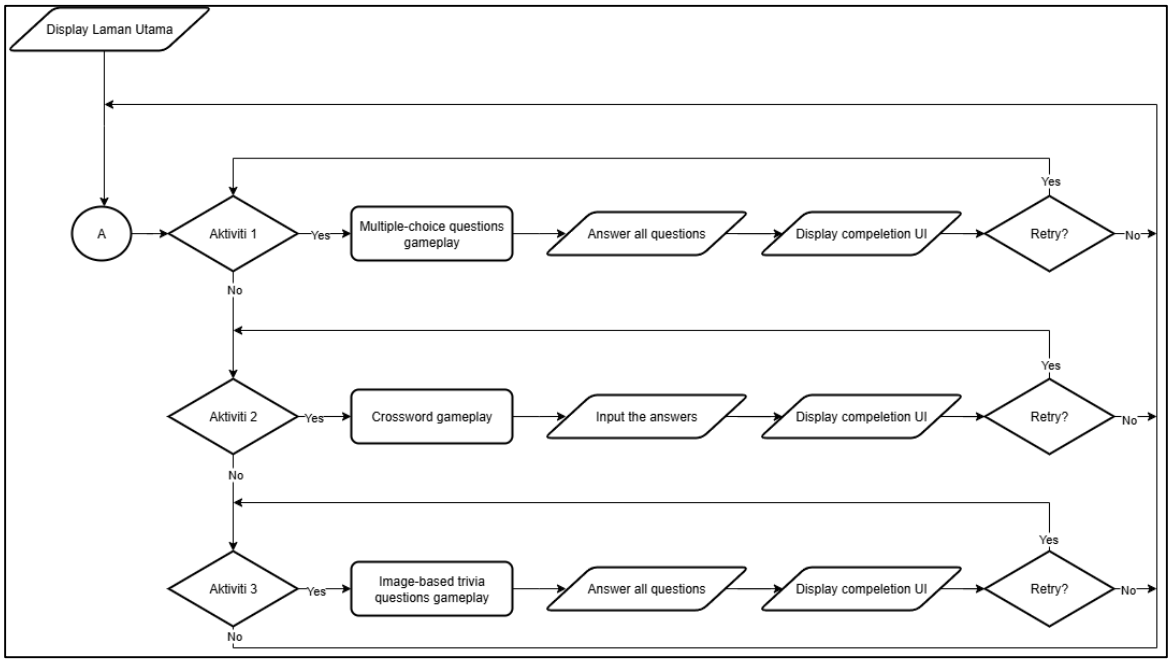
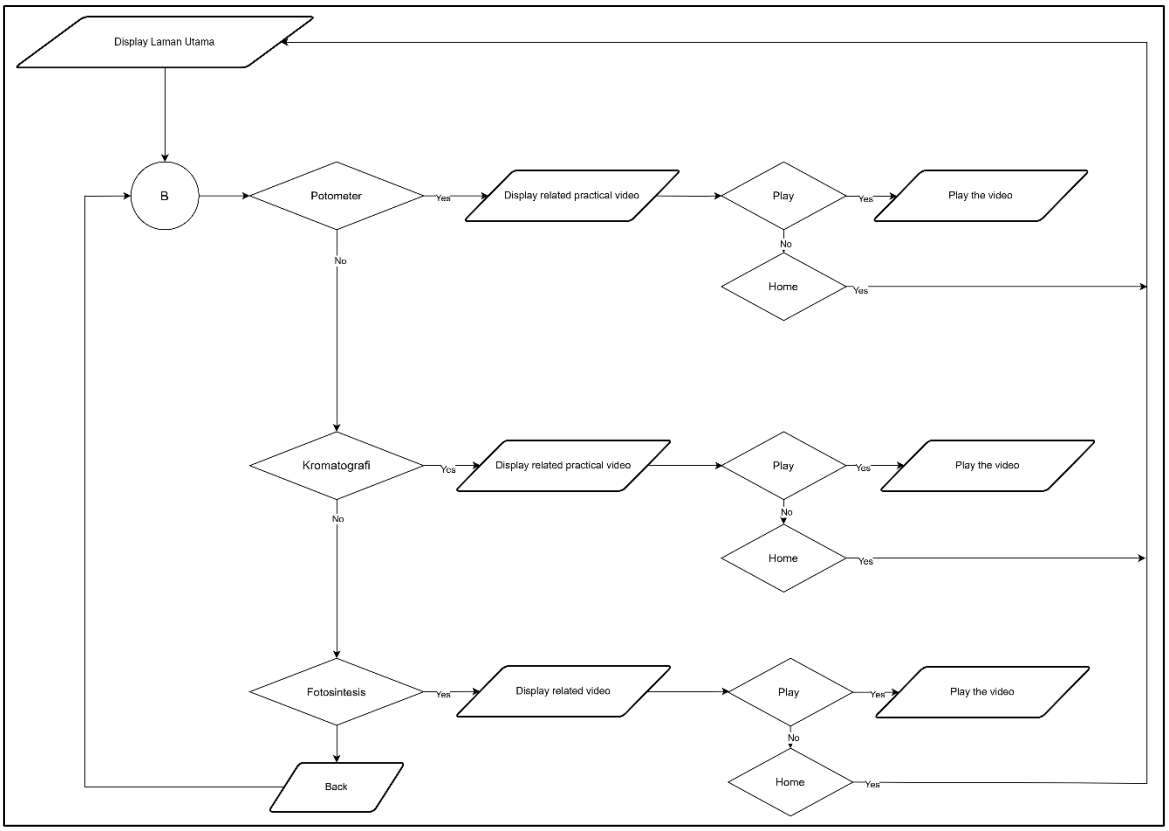


(b)



(c)

Fig. 9 *Main app flowchart (a) Belajar module flowchart; (b) Aktiviti module flowchart; (c) Amali module flowchart*

Appendix B

Appendix B shows the content structure in Section 3.2.

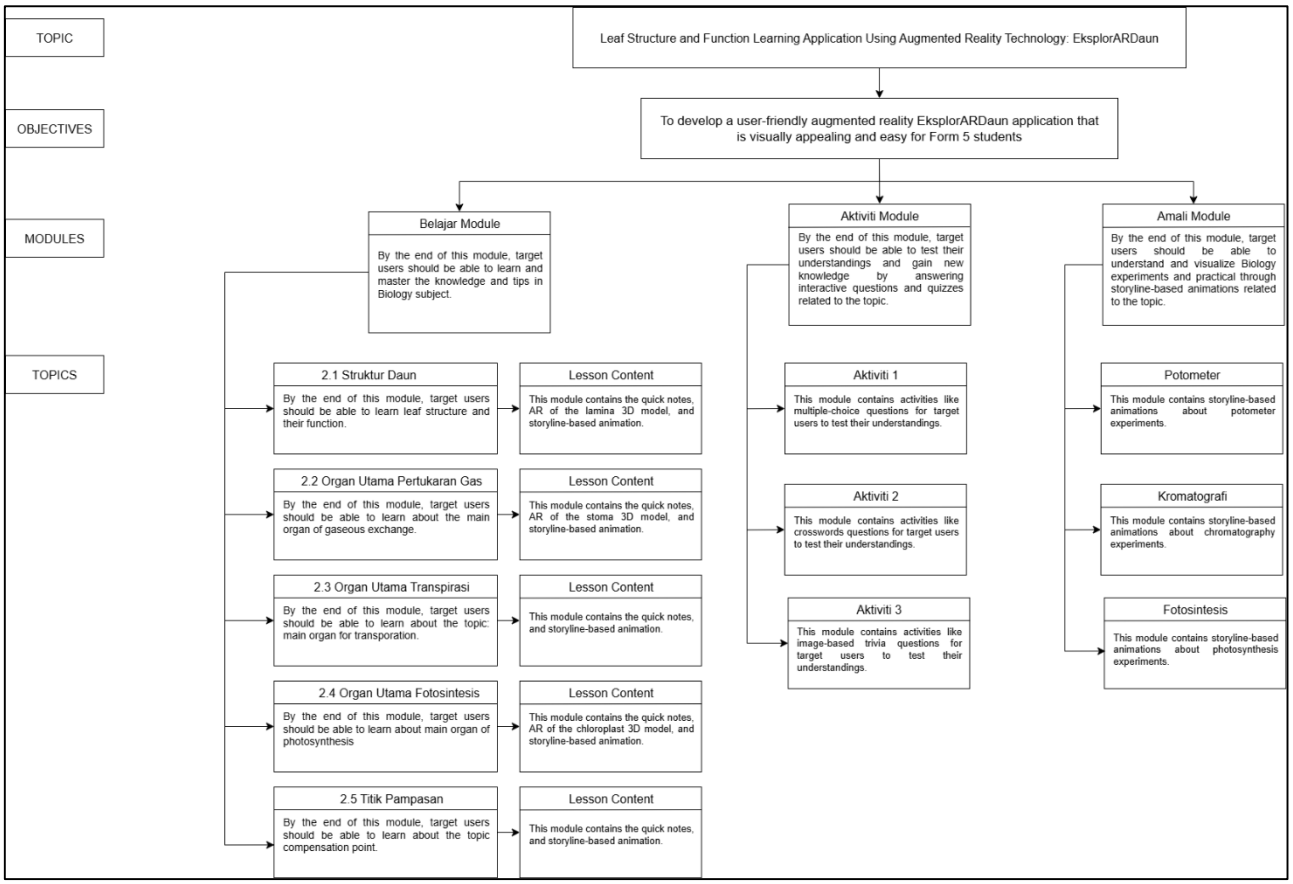


Fig. 10 *Content Structure*