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SafeSOLO: Enhancing Women's Safety through Mobile Learning and Augmented Reality

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Abstract

Women's safety has always been a concerning issue in our society. The use of mobile applications as a new approach in response to violence against women has grown significantly yet many focus solely on safety features rather than lasting knowledge. Empowering women with safety knowledge is crucial. Augmented Reality (AR) technology is now widely used in several fields, including the educational industry. This project proposes the SafeSOLO mobile learning application that educates on women's safety through an immersive and engaging learning experience. Since the real-life scenarios can be dangerous, AR simulations provide visualizations and better understandings. Implementation of this project follows the Mobile Content Development (MMCD) approach. Targeting women aged 18 to 34, beta testing shows a positive result of 88.08% based on the System Usability Scale, confirming the app delivers on its claims and accepted by users.

1. Introduction

In today's world, information sharing across institutions, local government, and local efforts that promote women's safety is still lacking [1]. It is crucial to empower every woman with knowledge about safety for their well-beings, especially in risky situations that could potentially harm them or making them feel vulnerable and uncomfortable. With the common use of smartphones nowadays, it is now possible to educate the women community on women's safety effectively through a mobile application. Learning through mobile apps has the power to improve interactivity and engagement throughout the learning process [2]. However, the current applications available in the market lack focus on educational content about women's safety, prioritizing technical safety features instead. Thus, women are still vulnerable when they do not have their mobile phones around whenever they encounter with danger.

Augmented Reality (AR) technology has been implemented in some educational tools and the most common conclusion is that using augmented reality improves learning experiences, inspires, entertains, and draws students' attention, leading them to believe that this technology is appropriate for use in the classroom. Furthermore, because the concepts being taught are three-dimensional, in certain cases the learning process improves [3]. Unfortunately, the existing applications found in the market do not implement AR technology in lesson learning. The applications that come with lessons only deliver their content in the form of text without any graphics, image, or demonstration. By implementing AR technology in the lesson modules of the proposed application, the learning process now becomes interactive and engaging. Especially when this application is to educate on women's safety where the real-life scenarios can be dangerous, implementing AR technology allow users to visualize the intangible situations easily and have better understanding without having to encounter it in real life.

The objective of this development is to design the content of women's safety mobile learning application named SafeSOLO by implementing markerless AR technology. Next, it is to develop the mobile learning application on Android platform using Unity. Then, the proposed application is aimed to be used for performing functional testing and user acceptance test on the target users which are women community of age 18 to 34 years old. The proposed application also has the goal of meeting the requirements as suggested by Ms Aliya who acts as the Subject Matter Expert (SME) in this project.

In this application, the learning content is delivered through the implementation of markerless AR technology in which the demonstration model will appear when the camera detects a flat plane surface. Users can scale, locate, move and animate the displayed model freely. Moreover, this application integrates text, image, video, animation, and audio into the learning content to enhance the overall learning experience. This application focuses on the lessons as well as providing reinforcement activity in the form of quizzes. Moreover, safety features such as SOS button and emergency contact based in Malaysia are also included in the application. In short, the development of this SafeSOLO application can be very beneficial to the public, particularly females.

The rest of this paper is organized as follows: Section 2 includes the literature review of the related work and the existing applications. Section 3 discusses the methodology used in the application development. Then, the process of analysis and design of the project is covered in Section 4. Finally, Section 5 concludes the achievements and tasks completed in overall.

2. Related Work

This section discusses the domain of study, technology used in the development of the application and comparison analysis between the reviewed applications and the proposed application.

2.1 Safety of Women

The safety of women is an issue that needs to be addressed with urgent priority. News reports of women being harassed, raped, and abused are common. Women have worries about their safety both at home and in public settings, such as marketplaces, places of employment and more. In public spaces, harassment of women occurs not only at night or in the evening but also throughout the day. Nearly 80% of women are worried about being insecure all times [4]. The general well-being of society and the state of public health are both affected by women's safety. The act of violence against women has noteworthy implications for public health, including both psychological and physiological effects. In order to foster a society that is healthier and more resilient, women's safety must be addressed [5].

Existing methods in education about women safety includes workshops, self-defense courses, and educational brochures. Conventional workshops and training courses on women's safety frequently take place in-person, teaching participants tactics on how to reduce risk, situational awareness, and self-defense skills. These workshops or courses can be held by self-defense instructors, community associations or law enforcement agencies [6]. As digital technologies come into their own in recent years, websites, social media, and mobile apps are becoming widely used as delivery channels for safety education for women.

2.2 Technology Used

The first technology used in this project is Augmented Reality (AR) technology which mixes the virtual and physical worlds in which information is added to the real world as if they coexist in the same space [3]. Thus, users perceive that virtual and real objects exist in the same space. By improving a user's perspective of and interaction with the real environment, AR can be used for education, entertainment, or both. Like a genuine object, the user can go around the three-dimensional virtual image and observe it from any angle [7].

The two main types of augmented reality technology are marker-based AR and markerless AR. In marker-based AR, the corresponding virtual 3D object will appear overlaying on top of the image target whenever the camera detects the marker. However, the weakness is as the camera moves away from the marker, the virtual object will consequently disappear. Thus, users are restricted in terms of mobility while using this technology. On the other hand, the markerless AR allows the user to choose where to show the virtual objects or models [8]. It uses the Global Positioning System (GPS) technology to determine the location and does not require any physical markers to place 3D objects in a real-world location [9]. Thus, markerless AR was chosen for this project due to its stability, allowing the model to operate consistently irrespective of the presence of any specific image target or marker.

The second technology applied in this application is the visual learning style. It is one of the learning styles in the Visual, Auditory, Reading and Kinesthetics (VARK) model in which information is presented in the form of graphics, including concepts, data, and other ideas [10]. Visual learning aids in better understanding on learning content rather than solely reading the learning content from text. Appealing visuals aid in the retention of information in the long-term memory of individuals with strong visual learning style because emotions are more

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commonly linked to shapes and colours than to plain text [11]. Hence, the visual learning style is chosen for this application.

The third technology employed in the development of this application is the implementation of mobile learning technology. Mobile devices are used in m-learning to enable constant access to the learning process. M-learning is rapidly advancing in the education sector in comparison to more traditional forms of online education. The benefits of mobile learning have been suggested for several reasons, including lower expenses and easy access to location-based services [12]. In comparison to using a personal computer alone or no device at all, integrating mobile devices into the classroom has been shown to improve student learning, according to a 2016 study that analysed 110 studies from 1993 to 2013 [13]. As such, this project is developing a mobile learning application aiming to capitalize on these advantages and foster enhanced educational experiences.

2.3 Comparative Analysis

This section discusses the comparison between three existing applications of Defensive Women, Women Security, I'm Safe and the proposed application, SafeSOLO. Figure 1(a), (b) and (c) shows the homepage interface of the reviewed applications. The features compared between the applications are operating system, learning module, AR technology, internet connection, price, and SOS siren. The comparison can be seen in Table 1.

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

Fig 1 *Module available for (a) Defensive Women; (b) Women Security (c) I'm Safe*

Table 1 *Comparison Between Existing Applications and Proposed Application*

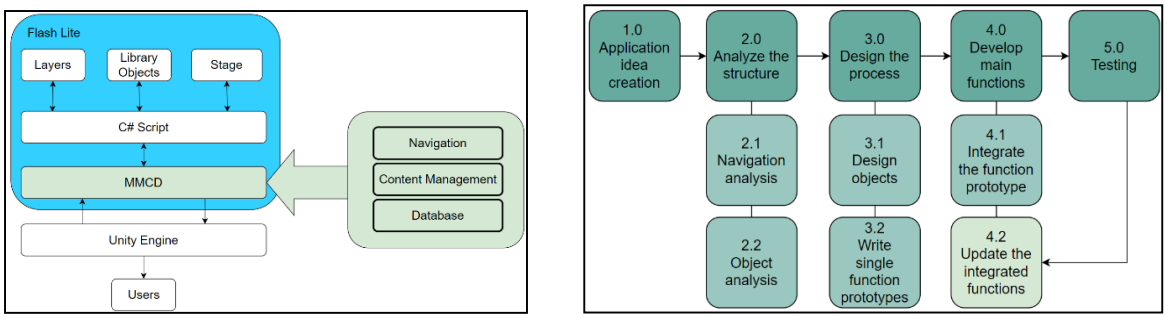
Application Features	Defensive Women	Women Security	I'm Safe	SafeSOLO
Operating System	Android 5.0 and above	Android 7.0 and above	Android 9.0 and above iOS 13.0 or later	Android 12.0 and above
Learning Module	Available	Available	Unavailable	Available
Multimedia Element	Text, image	Text, Audio	Text	Text, Image, Audio, Video
AR technology	Absent	Absent	Absent	Present
Internet Connection	Required	Required	Required	Does not required

Table 1 *Comparison Between Existing Applications and Proposed Application (cont)*

Application	Defensive Women	Women Security	I'm Safe	SafeSOLO
Features				
Price	Pay for premium features	Pay to remove advertisements	Free	Free
SOS siren	Unavailable	Available	Unavailable	Available

3. Methodology

The chosen methodology of this project, Multimedia Mobile Content Development (MMCD) is a methodology in developing multimedia mobile content which is formulated on top of the characteristics of agile development approach. It is a framework and methodology that is designed for the development of multimedia mobile learning applications, also known as m-learning applications. MMCD framework can increase the efficiency and overall speed of the development process. In MMCD framework, it manages the navigation, content, application logic and database which accelerates the development process as well as ensuring the application to function as intended [14]. The MMCD framework can be seen in Figure 2(a). MMCD methodology comprises five phases which are application idea creation phase, structure analysis phase, process design phase, main function development phase and testing phase [14]. Each phase includes different substages that contribute to the complete development process which can be seen as in Appendix A. In this project, the step of updating the structure will not be done thus the modified methodology is as shown in Figure 2(b).



(a) **(b)**

Fig 2 *MMCD (a) Framework* [14]*; (b) Modified Methodology*[14]

3.1 Application Idea Creation

The first stage in MMCD methodology is to generate application ideas before starting to design and develop the application [14]. The information and ideas can be prepared by creating a check list on a table. For this project, the ideas were inspired from the review on existing applications. The Application Idea Creation Check List for the development of the proposed application is presented in Table 2.

Table 2 *Application Idea Creation Checklist*

Item	Note
Type of application	Mobile learning
Target device	Android OS smartphones
Target users	Female of age 18 to 34 years old
Graphical user interface (GUI)	Homepage Safety Lessons Safety Quiz Emergency Contact Page App Info Page SOS Page

Table 2 *Application Idea Creation Checklist (cont)*

Item	Note
Text	Navigational, educational, and instructional message
Image	Educational content, Quiz questions
Video	Action-based educational content
Audio	Voice-over text based educational content
Animation	Demonstration of action-related educational content
Augmented Reality (AR)	Demonstration of educational scenarios in 3D models that are displayed over markerless AR technology.
Application Synopsis	SafeSOLO is a mobile learning application which educates users on safety knowledge about women safety. The application covers 6 lessons. A safety quiz module is included to test users on their learning outcomes from the safety lessons. Safety features of SOS button and list of emergency contacts are included as well.

3.2 Structure Analysis Stage

The stage of analyzing and designing the structure MMCD methodology starts by analyzing several types of requirements. In this project, the user requirements analysis is done by interviewing the Subject Matter Expert (SME), Ms. Aliya. She is the cofounder of the non-profit organization, Stand Up Malaysia, which is dedicated to promoting wellbeing of women from all walks of life. The analysis from the interview session is tabulated in Table 3. The navigation structure can be seen in Figure 3 while the content structure can be referred to in Appendix B. Analysis of functional and non-functional requirements are shown in Table 4 and Table 5 respectively.

Table 3 *User Requirement Analysis*

Stakeholder	Role in product	Design Implications	Actions Needed
Subject Matter Expert (SME)	Content consultant expert in related field	Emergency button	• SOS button. • Emergency contact.
		Reliable informative content	• Implement content-wise application as there is a lack in this
		Easy to use and navigate	• Consistent navigation buttons and structure. • Provide clear instructions.
		Creative and suitable for wide range of target users	• Provide different multimedia elements, interactive elements, and AR technology. • Read-aloud feature
		Reach wider range of users	• Develop the application in English language

Table 4 *Functional Requirement*

Functional Requirements	Module	Description
	Homepage	• The system should display the homepage with different modules once user launch the application.
	Lesson module	• The system should seek the user's permission to access the device's camera on first launch of the application. • The system should display 3D models when the camera detects flat surfaces.
Autonomous Activities	Quiz module	• The system should identify whether the user answer correctly or wrongly and display the respective panels.
User Interactions	Homepage	• The system should navigate users to the accurate module chosen through button selections.

Table 4 *Functional Requirement (cont)*

Functional Requirements	Module	Description
User Interactions	Homepage	• The system should display quitting confirmation panel before allowing users to quit.
	SOS feature	• The system should play the siren as soon as the SOS button is pressed. • The system should stop the siren sound when the user tapped on anywhere of the screen.
	Lesson Topic Module	• The system should navigate users to the accurate lesson module when the corresponding topic is chosen.
	Lesson Content	• The system should play the audio of the text content in the module when the audio button is hit. • The system should be able to play and pause the video on click if there is a video. • The system should navigate users to the AR scene and activate the device's camera when the AR camera button is hit.
	AR	• The system should allow users to interact with the 3D models to locate, rotate, scale, and animate them on finger touches. • The system shall display the correct 3D models related to the lesson.
	Quiz	• The system should be able to take in the inputs of the users when user answers the quiz.

Table 5 *Non-functional Requirements*

Non-functional requirements	Description
Operational	• The application should be able to operate on mobile devices of Android version 12.0 and above.
Performance	• Any navigational interaction between the user and system should not exceed two seconds. • The application should be able to operate even when there is no active internet connection.
Cultural	• The application should be built in English.
Usability	• The application should be accessible at anytime and anywhere on compatible Android devices. • The application should be user-friendly and easy to navigate.

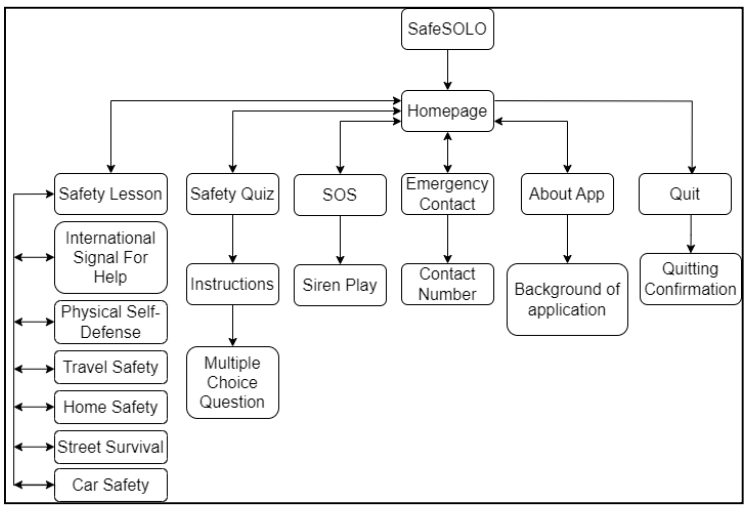


Fig. 3 *Navigation Structure*

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3.3 Process

Designing the process is the third stage in the MMCD methodology, which is to design every component defined in the structure analysis stage. Every item listed in the Content Structure Check List is to be designed and produced in this phase. All the designs are done using design software of Canva, Adobe Illustrator and Blender. After the graphics and objects are created, objects positioning on stage are arranged for each interface to design a complete high-fidelity storyboard. The system flowchart of the application is attached in Appendix C. The button designs are tabulated in Table 6 while some sample interface designs are tabulated in Table 7. The remaining interface designs can be referred to Appendix C.

Table 6 *Buttons Designs*

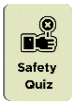
Buttons	Functions	Buttons	Functions
	• This is the read aloud button where it will play the audio of the voiceover of the text content when button is hit.		• This is the button that navigates the user to the interface that shows the user manual.
	• This is the homepage button which navigates user to the home when pressed.		• This is the button that navigates user to the lesson module.
	• This is the uniform button used as “Start”, “Retry” and “Next” display on top of the button with respective functions of to start the quiz, retry the quiz and proceed to next question.		• This is the button that leads user to the quiz module when button is hit.
	• This is the quit button where user can quit the application by pressing this button.		• This is the SOS button that plays loud siren when clicked.
	• This is the return button where user can return to previous page on pressed.		• This is button for confirmation of yes.
	• This is the AR camera button which prompts the camera to activate and display 3D md models using markerless AR technology.		• This is the button for confirmation of no.
	• This is the button to navigate to the emergency contact interface when pressed.		

Table 7 *Sample Interface Designs*

Interface	Description	Interface	Description
	The homepage of the application.		The interface when SOS button has been pressed.
	The sample of a lesson topic of Physical Self-Defense.		A sample of quiz question with image as title of question.

In the design phase of Multimedia Mobile Content Development (MMCD), writing a single function prototype is crucial before proceeding to the stage of implementation. In SafeSOLO application, users can navigate to different scenes by clicking on different buttons. The script is written in C# language as can be 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 string sceneName;
    public void changeScene()
    {       SceneManager.LoadScene(sceneName);
       }}
```

Fig 4 *Code snippet to change scene*

3.4 Main Function Development Stage

The main development of development stage includes implementation of assets and integration into Unity through scripting. Vuforia SDK is used for implementing augmented reality in Unity. Table 8 shows the development and implementation of assets used in SafeSOLO. Integration of C# script in Unity is required to control some main features in SafeSOLO application such as in SOS module, AR lesson, video playing, play 3D animations and more. In the SOS module, it requires the siren to stop playing when tapping anywhere on the screen. The functions, scripts and explanation are tabulated in Table 9.

Table 8 *Assets Development and Implementation*

Assets	Development	Description
3D Models		The demonstration 3D models are modeled 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.
3D Animations		The 3D animations of models are created in Blender. The models are first rigged with armature and apply weight to the model. Then, the animations are created by inserting keyframe of different poses at Pose Mode in Blender. The animation is baked and exported into Unity along with the .fbx file.
Narrative Audio		All the narrative audios are generated and taken from the TTSMaker by using the text-to-speech function and imported into Unity. In TTSMaker, the entered text can be narrated using preferred voice style. The audio files are imported into Unity in the form of MPEG Audio Layer-3 (MP3) format.

Table 8 *Assets Development and Implementation (cont)*

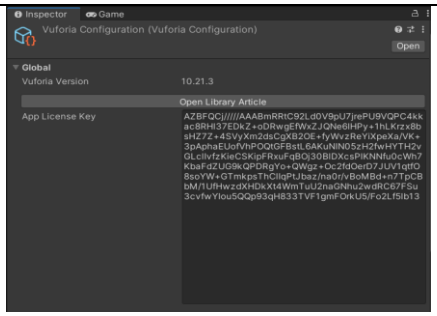
Assets	Development	Description
AR Implementation		An app license key is required for Vuforia and Unity to communicate. The license key for the app needs to be copied and put into the Vuforia Configuration under the AR camera inspector.
2D Assets		2D assets such as graphics, buttons, logo, and background are first designed in Canva. Then, they are exported as .SVG files to be imported into Adobe Illustrator 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.

Table 9 *Integration with scripting in Unity*

Function	Development	Description

Control siren playing	`using UnityEngine;`
	`public class PlaySound : MonoBehaviour`
	`{ private AudioSource audioSource;`
	`private bool isAudioPlaying;`
	`void Start()`
	`{`
	`audioSource = GetComponent<AudioSource>();`
	`isAudioPlaying = audioSource.isPlaying; }`
	`public void ToggleAudio()`
	`{ if (isAudioPlaying)`
	`{`
	`audioSource.Stop();}`
	`else{`
	`audioSource.Play();}`
	`isAudioPlaying = !isAudioPlaying;`
	`}}`
		In this `PlaySound` script, private variables of `AudioSource` and boolean of `isAudioPlaying` that check if the audio is playing are declared. In `Start ()` method, the `audioSource` is initialized and referred to the `AudioSource` and check whether the audio is playing. In the `ToggleAudio ()` method, if there is audio playing it will stop the siren audio. Otherwise, it will play the audio source which is the siren.

Animate 3D models	`using UnityEngine;`
	`public class animate : MonoBehaviour`
	`{`
	`public Animator anim;`
	`void Update()`
	`{`
	`for (int i = 0; i < Input.touchCount; ++i)`
	`{`
	`if (Input.GetTouch(i).phase == TouchPhase.Began && anim.GetCurrentAnimatorStateInfo(0).IsName("none") )`
	`{`
	`anim.Play("stancee");`
	`}}}}`
		In this `animate` script, a public variable of Animator is declared with the `Update()` method. Inside the `Update()` method, it will loop to check the touch input on the screen where if there is a touch input and the current animation state to none, it will triggers the animation named stance to play using the method `anim.Play("stancee")`.

Table 9 *Integration with scripting in Unity (cont)*

Function	Development	Description

Video playing	`using System.Collections;`
	`using System.Collections.Generic;`
	`using UnityEngine;`
	`using UnityEngine.Video;`
	`using UnityEngine.Sprites;`
	`using UnityEngine.UI;`
	`public class StartStop : MonoBehaviour`
	`{`
	`private VideoPlayer player;`
	`public Button button;`
	`public Sprite startSprite;`
	`public Sprite stopSprite;`
	`// Start is called before the first frame update`
	`void Start()`
	`{`
	`player = GetComponent<VideoPlayer>();`
	`}`
	`public void ChangeStartStop()`
	`{`
	`if (player.isPlaying == false)`
	`{`
	`player.Play();`
	`button.image.sprite = stopSprite;`
	`}`
	`else`
	`{`
	`player.Pause();`
	`button.image.sprite = startSprite;`
	`}}}`
		In this `StartStop` script, the private variable of `VideoPlayer` named `Player` is used to control the video playback, whether to pause or play the video. Next, the public variable of `button`, `startSprite`, and `stopSprite` are used to store the assigned UI elements and sprites. Then, the `Start()` method initializes the `player` variable with the video component attached to the `GameObject`. Finally, the `ChangeStartStop()` method checks whether the video is playing. If the video is not playing, the video will be played with the sprite of pausing the video being displayed, else the playing video will be paused and displaying sprite of playing the video.

3.5 Testing

Testing is the last phase in MMCD methodology. Two types of testing, alpha and beta testing, are involved in this project. Alpha testing is conducted by developers to test the functionality and identify issues. Beta testing requires involvement of the target users of this application, which are women from age 18 to 34 years old. In this project, the testing is conducted and evaluated on 10 questions using the System Usability Scale (SUS) on 30 respondents. It is conducted both physically and online. For the online testing, users need to download and play around with the application before answering the questionnaire whereas physical testing requires users to play around with the readily available application on prepared device as can be seen in Appendix D. Three additional questions are also included in the questionnaire to analyze the overall user acceptability. The feedback from the users is collected through Google Form. The SUS results are evaluated using the 5-Points Likert scale that asks respondents to rate their level of agreement or disagreement where 5=Strongly agree and 1=Strongly disagree. The results of the testing are discussed in the next section.

4. Results and Discussion

The result of alpha testing is as shown in Table 10 with several corrective actions done for safety lesson scene, SOS scene. Pausing video and AR scene. For beta testing, this project evaluates usability of the application by using the System Usability Scale (SUS). The questionnaire, consisting of 13 questions across 3 sections, measures the application's usability and acceptability. This testing was carried out to identify user acceptance levels. The feedback received from beta testing can help in identifying the weaknesses and limitations of the application, thus providing suggestions for future improvements. The analysis of the result for odd-numbered questions (1, 3, 5…) are positive-toned questions and even-numbered questions (2, 4, 6…) are negative-toned questions from the SUS questionnaire are as shown in Figure 5 and Figure 6 respectively while Figure 7 shows the results of the acceptance level.

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Table 10 *Results of Alpha Testing*

Scene	Testing	Expected Result	Actual Result	Corrective Action
Homepage	Safety Lessons button	Navigate user to the lesson menu scene.	Works as expected.	Not required.
	Safety Quiz button	Navigate user to the quiz instructions scene.	Works as expected.	Not required.
	Emergency Contact button	Navigate user to the emergency contact scene.	Works as expected.	Not required.
	About App button	Navigate user to the application background and tips.	Works as expected.	Not required.
	SOS button	Navigate user to the SOS scene.	Works as expected.	Not required.
	Close button	Displays a panel that confirms user on the exit.	Works as expected.	Not required.
Safety Lessons	International Signal For Help button	Navigate user to the lesson about international signal for help.	Works as expected.	Not required.
	Physical Self-Defense button	Navigate user to the lesson about physical self-defense.	Works as expected.	Not required.
	Travel Safety button	Navigate user to the lesson about travel safety.	Works as expected.	Not required.
	Home Safety button	Navigate user to the lesson about home safety.	Works as expected.	Not required.
	Street Survival button	Navigate user to the lesson about street survival.	Works as expected.	Not required.
	Car Safety button	Navigate user to the lesson about car safety.	Works as expected.	Not required.
	Home button	Navigate user to the homepage.	Works as expected.	Not required.
	Close button	Displays a panel that confirms user on the exit.	Works as expected.	Not required.
	Safety lessons scene	The lessons can be scrolled throughout the scene to reveal the bottom lesson.	The lessons cannot be scrolled through and remained as static when scrolled.	Rescaled the sliding area and make sure everything is included within the sliding area.
Safety Quiz	Safety Quiz scene	Displays the instructions to play the game.	Works as expected.	Not required.
	Start button	Start the quiz.	Works as expected.	Not required.
	Home button	Navigate user to the homepage.	Works as expected.	Not required.
	Close button	Displays a panel that confirms user on the exit.	Works as expected.	Not required.
Quiz Questions	Return button	Navigate user to the previous question.	Works as expected.	Not required.
	Home button	Navigate user to the homepage.	Works as expected.	Not required.
	Win panel	Displays a win panel when user chooses the correct answer.	Works as expected.	Not required.
	Lose panel	Displays a lose panel when user chooses a wrong answer.	Works as expected.	Not required.
	Next button in Win Panel	Navigate user to the consecutive question.	Works as expected.	Not required.
	Retry button in Lose Panel	Navigate user to return to the same question and let user try again.	Works as expected.	Not required.
	Correct Answer Sound Effect	Plays the correct sound effect when user choose the correct answer.	Works as expected.	Not required.
	Wrong Answer Sound Effect	Plays the wrong sound effect when user choose the wrong answer.	Works as expected.	Not required.

Table 10 *Results of Alpha Testing (cont)*

Scene	Testing	Expected Result	Actual Result	Corrective Action
Emergency Contact	Emergency contact scene	Displays 5 Malaysia's emergency contact number.	Works as expected.	Not required.
	Home button	Navigate user to the homepage.	Works as expected.	Not required.
	Close button	Displays a panel that confirms user on the exit.	Works as expected.	Not required.
About App	About application scene	Displays the background and tips of using the application.	Works as expected.	Not required.
	Home button	Navigate user to the homepage.	Works as expected.	Not required.
	Close button	Displays a panel that confirms user on the exit.	Works as expected.	Not required.
SOS	SOS scene	Plays a loud siren upon entering the SOS screen. The siren should stop when user clicks on anywhere on the screen.	The siren does not stop when tapping on the SOS text.	Set the texts as children of the screen.
	Home button	Navigate user to the homepage.	Works as expected.	Not required.
	Close button	Displays a panel that confirms user on the exit.	Works as expected.	Not required.
International Signal For Help Lesson	Return button	Navigate user to the Safety Lesson scene.	Works as expected.	Not required.
	Read Aloud button	Play the audio of voiceover of the content in the lesson.	Works as expected.	Not required.
	AR Camera button	Navigate user to the related 3D model.	Works as expected.	Not required.
	Pause Video button	Pause the play on awake video.	Video does not stop when pause button is pressed.	Check the changes of state in Play Mode and set the button's `On Click()` event to call the `PauseVideo()`.
	Play Video button	Resume the paused video.	Works as expected.	Not required.
Physical Self-Defense Lesson	Return button	Navigate user to the Safety Lesson scene.	Works as expected.	Not required.
	Read Aloud button	Play the audio of voiceover of the content in the lesson.	Works as expected.	Not required.
	AR Camera buttons	Navigate user to the related 3D models.	Works as expected.	Not required.
Travel Safety Lesson	Return button	Navigate user to the Safety Lesson scene.	Works as expected.	Not required.
	Read Aloud button	Play the audio of voiceover of the content in the lesson.	Works as expected.	Not required.
Home Safety Lesson	Return button	Navigate user to the Safety Lesson scene.	Works as expected.	Not required.
	Read Aloud button	Play the audio of voiceover of the content in the lesson.	Works as expected.	Not required.
	AR Camera button	Navigate user to the related 3D model.	Works as expected.	Not required.
Street Survival Lesson	Return button	Navigate user to the Safety Lesson scene.	Works as expected.	Not required.
	Read Aloud button	Play the audio of voiceover of the content in the lesson.	Works as expected.	Not required.
	AR Camera buttons	Navigate user to the related 3D models.	Works as expected.	Not required.

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Table 10 *Results of Alpha Testing (cont)*

Scene	Testing	Expected Result	Actual Result	Corrective Action
Car Safety Lesson	Return button	Navigate user to the Safety Lesson scene.	Works as expected.	Not required.
	Read Aloud button	Play the audio of voiceover of the content in the lesson.	Works as expected.	Not required.
	AR Camera buttons	Navigate user to the related 3D models.	Works as expected.	Not required.
AR Scene	Return button	Navigate user to the related lesson of the 3D model.	Works as expected.	Not required.
	AR scene	Displays the corresponding title of the related 3D models.	Works as expected.	Not required.
	3D model	Able to be rotated, scaled, located and animated on finger touches.	The 3D models appeared without animation.	Reset the default layer state at Animator and edit the C# script in Unity.

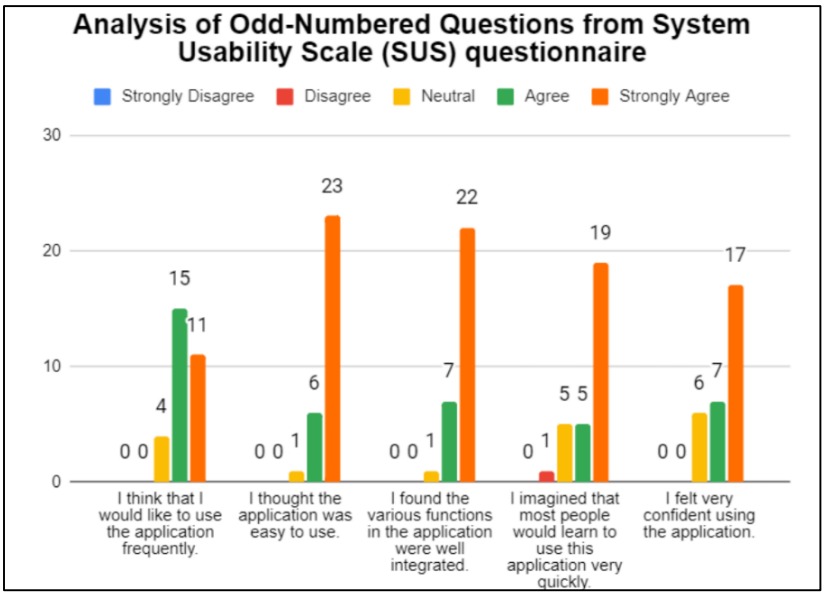

Fig. 5 *Analysis of Odd-Numbered questions from System Usability Scale (SUS) questionnaire*

Figure 5 displays the result of analysis of the positive-toned questions from the SUS questionnaire on 30 respondents. Firstly, most respondents, specifically 26 of them, agree or strongly agree that they would like to use the application frequently, while only 4 respondents feel neutral towards the statement. Next, 29 respondents 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. This indicates excellent usability, and the application's features work seamlessly together. Then, a total of 24 respondents agrees or strongly agree that most people would learn to use the application quickly, while 5 respondents feel neutral, and 1 respondent disagrees with the statement. Finally, 24 respondents agree or strongly agree that they felt confident using the application, with 6 others feeling neutral. In conclusion, the responses from the SUS questionnaire indicate highly 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.

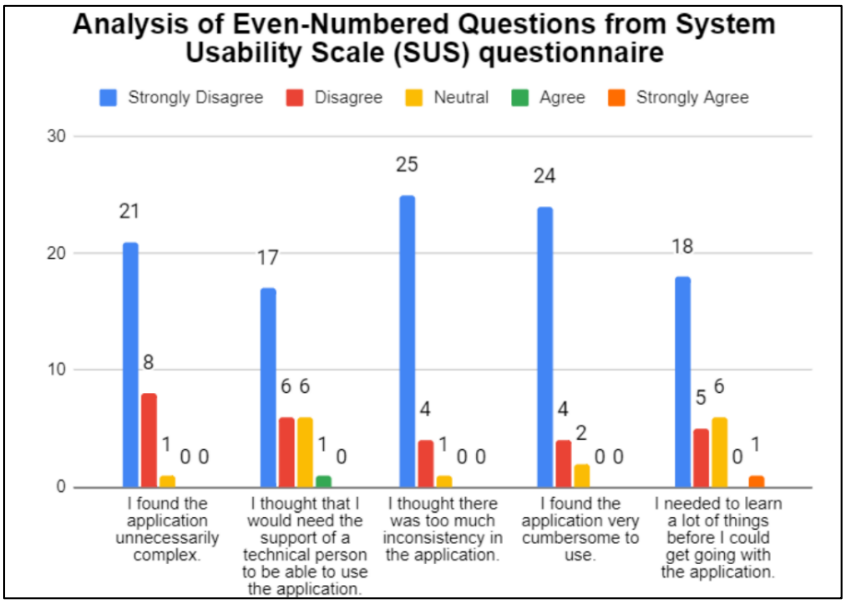

Fig. 6 *Analysis of Even-Numbered questions from System Usability Scale (SUS) questionnaire*

Figure 6 shows the analysis of negative-toned questions. Firstly, a significant number of respondents, 29, strongly disagree or disagree that the application is unnecessarily complex, with only 1 respondent feeling neutral, indicating that users find the application straightforward and not overly complicated. Next, 23 respondents strongly disagree or disagree that they would need technical support to use the application, while 6 respondents feel neutral and 1 agrees with the statement. Again, a total of 29 respondents strongly disagrees or disagree that there is too much inconsistency in the application, with only 1 respondent feeling neutral, indicating that users find the application to be consistently designed and coherent. Then, 28 respondents strongly disagree or disagree that the application is cumbersome to use, and the remaining 2 respondents feel neutral towards it. Lastly, a total of 23 respondents strongly disagrees or disagree that they needed to learn a lot before using the application, while 6 respondents feel neutral, and 1 respondent strongly 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.

Table 11 *Total Score of System Usability Scale Testing*

Respon-dent	Score										Odd-Numbered Question's Score	Even-Numbered Question's Score	Total
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10			
R01	4	1	5	3	4	1	5	2	3	3	16	15	77.5
R02	4	2	4	2	4	2	3	1	4	1	14	17	77.5
R03	5	1	5	1	5	1	5	1	5	1	20	20	100
R04	4	2	4	2	4	2	4	2	4	2	15	15	75
R05	4	2	5	1	5	1	5	1	5	1	19	19	95
R06	5	1	5	2	5	1	5	1	5	1	20	19	97.5
R07	4	1	5	1	5	1	5	1	5	1	19	20	97.5
R08	4	1	5	1	5	1	5	1	5	1	19	20	97.5
R09	4	1	5	1	4	1	5	1	5	1	18	20	95
R10	3	1	5	3	5	1	3	1	4	3	15	16	77.5
R11	4	1	5	1	5	1	5	1	4	2	18	19	92.5
R12	5	1	5	1	5	1	5	1	5	1	20	20	100
R13	4	1	5	1	5	1	5	1	5	1	19	20	97.5
R14	5	1	5	1	5	1	5	1	5	1	20	20	100
R15	5	1	5	1	5	1	5	1	5	1	20	20	100
R16	4	1	5	2	5	1	4	1	4	2	17	18	87.5
R17	5	2	4	3	4	1	3	1	3	1	14	17	77.5
R18	4	1	5	1	5	1	5	1	5	1	19	20	97.5
R19	4	2	5	3	5	1	3	1	3	3	15	15	75
R20	5	1	5	1	5	1	5	1	5	1	20	20	100

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Table 11 *Total Score of System Usability Scale Testing (cont)*

Respon-dent	Score										Odd-Numbered Question's Score	Even-Numbered Question's Score	Total
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10			
R21	5	2	4	2	5	1	4	1	3	2	16	17	82.5
R22	3	3	3	3	3	3	3	3	3	3	10	10	50
R23	5	1	5	1	5	1	5	1	5	1	20	20	100
R24	5	1	5	1	5	1	5	1	5	1	20	20	100
R25	4	2	4	2	4	2	4	2	4	2	15	15	75
R26	3	1	5	1	5	1	5	1	5	1	18	20	95
R27	3	2	4	4	4	2	2	3	3	3	11	11	55
R28	4	1	5	3	5	1	4	2	4	3	17	15	80
R29	4	1	5	1	5	1	5	1	5	5	19	16	87.5
R30	5	1	5	1	5	1	5	1	5	1	20	20	100
Average Score (%)													88.08

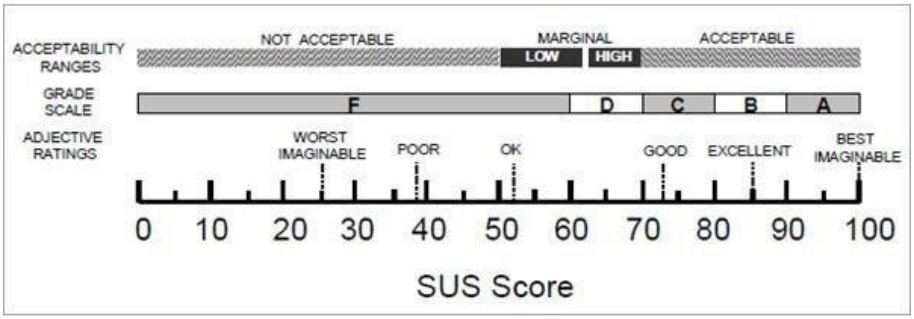

Fig. 7 *SUS grading and acceptability range* [15]

As can be seen in Table 11, the developed application has achieved an average score of score of 88.08% for the beta testing based on SUS. Thus, the result is graded with 'B' which is highly acceptable in terms of grading and acceptability range as in the SUS Score scale as shown in Figure 7.

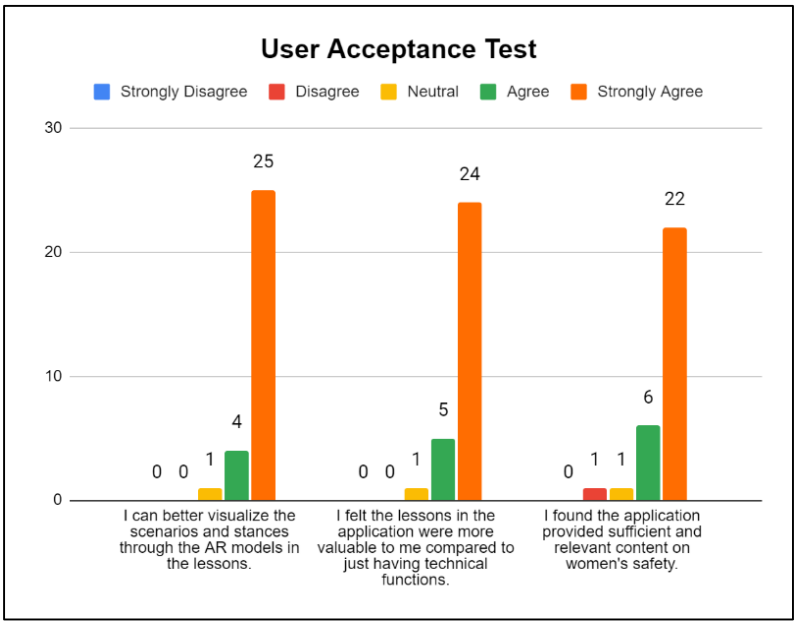

Fig. 8 *Analysis of user acceptance test*

Figure 8 shows the analysis of user acceptance from the collected feedback. In overall, most users strongly agree that the AR models help them understand scenarios better (83.3%), find the lessons valuable compared to just technical stuff (80%), and feel the app provides enough content on women's safety (73.3%). Thus, the overall positive result indicates high acceptance with the application's features and content.

5. Conclusion

In conclusion, the SafeSOLO application has been successfully developed. The positive results of testing on the developed application have again proven the project's success. Moreover, 3 objectives of the project have been achieved successfully. SafeSOLO is an innovative mobile learning application that promotes women's safety. Using markerless AR technology, SafeSOLO offers a dynamic learning environment in which users interact with virtual 3D objects displayed on their real-world surroundings using the cameras on their smartphones. 3D models and Vuforia SDK are integrated with Unity to implement the AR scenes that allow users to locate, resize, rotate, and animate the 3D objects, making the lesson both useful and entertaining. The two main sections of the application are the Safety Quiz and Safety Lessons. Safety Quiz reinforces knowledge by giving tips on correct or incorrect responses, while Safety Lessons give both visual and auditory learning experiences by allowing the text to be read aloud.

While SafeSOLO offers many advantages, it has several limitations such as the AR features are limited to people with newer and more capable devices. Furthermore, it might not cover all situations related to women's safety, therefore users will need to look for additional materials to gain full knowledge. To conclude, although alpha and beta testing have been conducted and received positive feedback from that, they might somehow be biased and unreliable. Also, there are still spaces for improvements that can be considered and improved in the future. Thus, the performance and accessibility of the application must be enhanced by regular updates.

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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**: Lee Ling Yi, Rahayu A Hamid; **data collection**: Lee Ling Yi; **analysis and interpretation of results**: Lee Ling Yi, Rahayu A Hamid; **draft manuscript preparation**: Lee Ling Yi, Rahayu A Hamid. All authors reviewed the results and approved the final version of the manuscript.

Appendix A

Appendix A shows the complete MMCD methodology in Section 3.

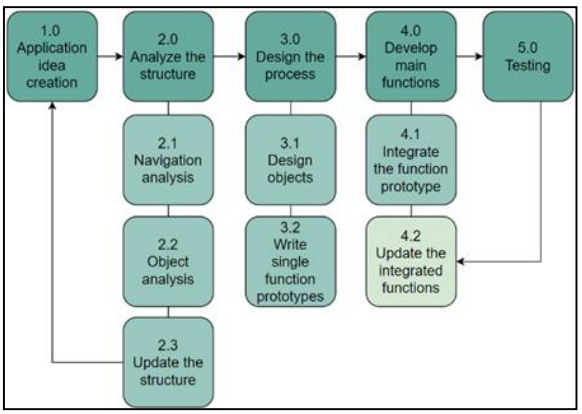

Fig. 9 *Complete MMCD methodology* [14]

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Appendix B

Appendix B shows the content structure in Section 3.2.

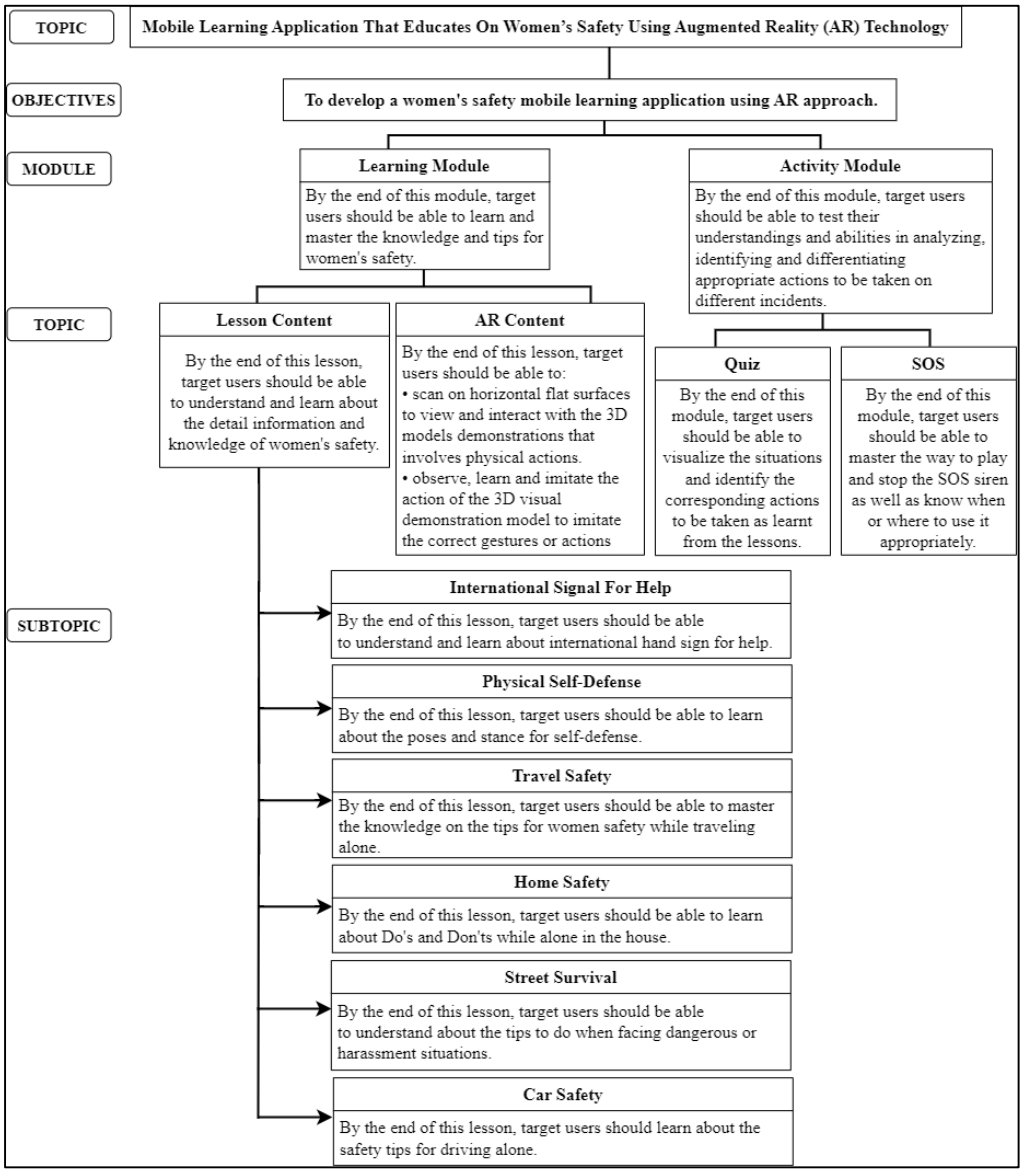
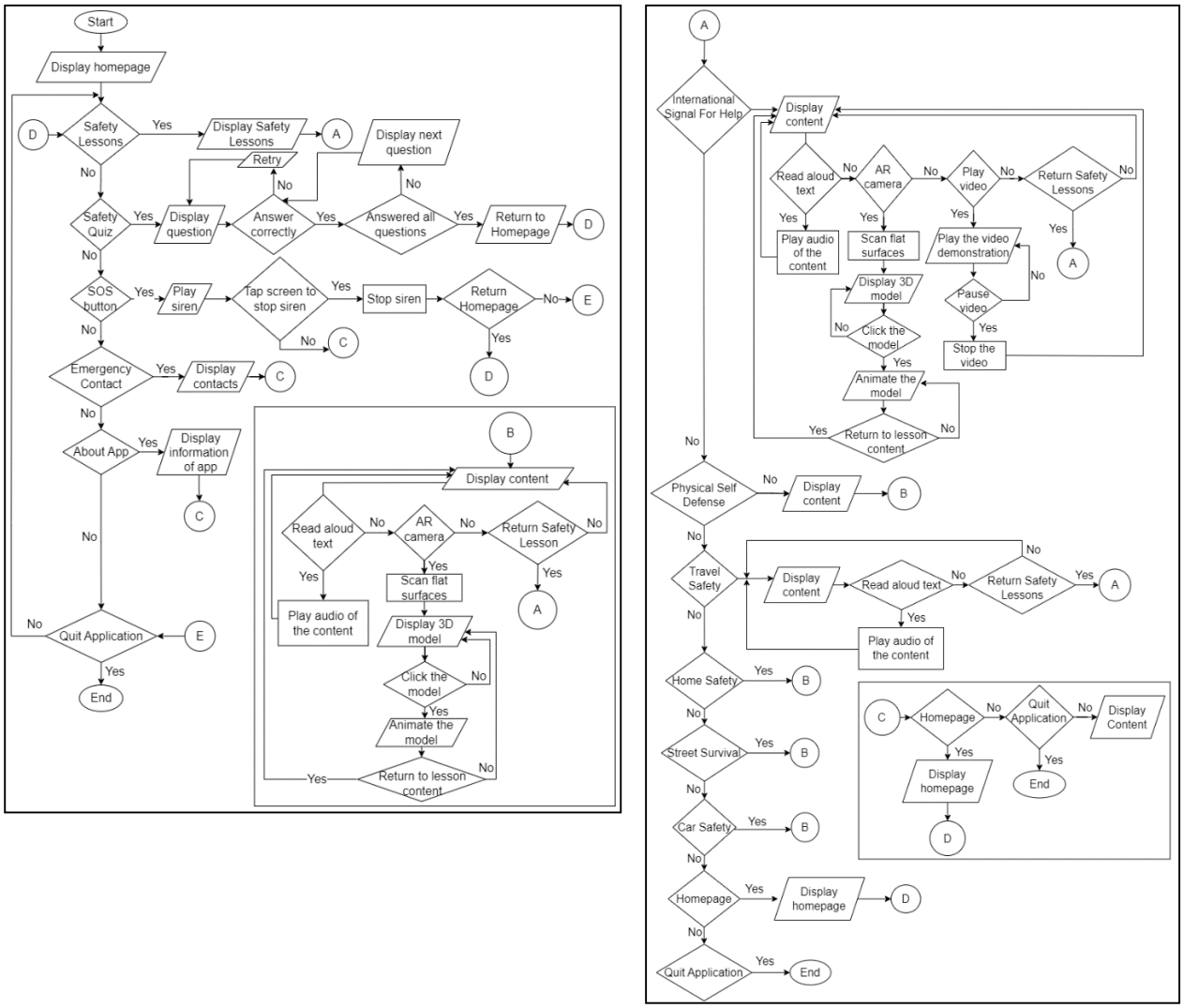


Fig. 10 *Content Structure*

Appendix C

Appendix C shows the main system flowchart and remaining interface designs in Section 3.3.



(a) **(b)**

Fig. 11 *Main system flowchart*

Table 12 *Remaining interface designs*

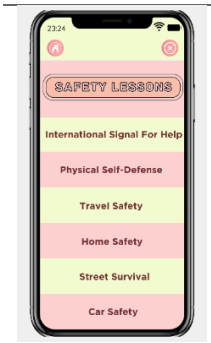
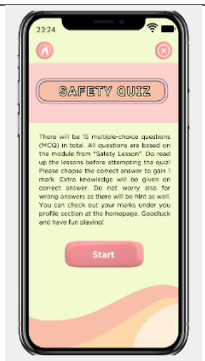
Interface	Description	Interface	Description
	The lesson topics in the Safety Lesson module.		The instruction to play the quiz when user click onto "Safety Quiz" module.

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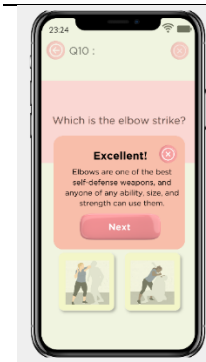
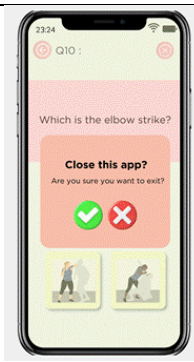
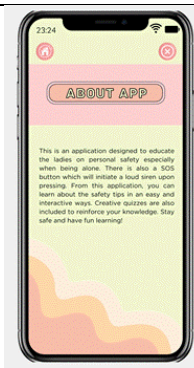
Table 12 *Remaining interface designs (cont)*

Interface	Description	Interface	Description
	Another sample of quiz question with image to choose from as answering method.		The panel that appears when user answer the quiz wrongly.
	The panel that appears when user answer the question correctly.		The panel that pops out when user hits the exit button.
	The interface of module Emergency Contact.		The interface of "About App" module.

Appendix D

Appendix D shows the physical testing conducted in Section 3.5.

Fig. 12 *Conduct beta testing on target users*

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