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Augmented Reality in Tabletop Exercises As An Approach to Sustainable Disaster Preparedness Training: A Pilot Study

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Abstract—**Disaster preparedness training is essential for enhancing the effectiveness and resilience of first responders. Conventional tabletop exercises (TTX) have been widely used for disaster training due to their structured yet low-risk nature. However, limitations such as a lack of realism and engagement necessitate innovative approaches. This study explores the integration of augmented reality (AR) technology into TTX to enhance training effectiveness. This study utilises an exploratory sequential mixed-methods research design in three phases. Phase 1 involved collecting qualitative data through document analysis, in-depth interviews, and non-participatory observations to develop a realistic disaster scenario. Phase 2 transforms the identified disaster scenario into an AR-based TTX application using the Rapid Application Development (RAD) model. Phase 3 assesses the validity and usability of the AR-based TTX through a pilot study involving twenty undergraduate final-year nursing students who had undertaken an elective course (NURD 4412: Elective Disaster Nursing), evaluated using the System Usability Scale (SUS). Results demonstrate that the developed AR application provided an immersive and interactive training experience, fostering better engagement and realism than conventional TTX methods. The pilot study yields a SUS score of 58.4, classifying the application as "Not acceptable" in terms of usability, which indicates that it faces significant usability issues when used in a tabletop exercise as an approach to sustainable disaster preparedness training. Key advantages included improved knowledge retention, real-time interaction, and enhanced decision-making skills among participants. However, limitations such as device compatibility issues and the need for technical support were identified, suggesting areas for future improvements. In conclusion, this study highlights the potential of AR-based TTX as an innovative and sustainable approach to disaster preparedness training. The findings underscore the need for further enhancements to optimise user experience and broaden accessibility, ultimately strengthening the capacity of emergency responders to manage disaster scenarios effectively.**

Keywords—Augmented Reality, Disaster Preparedness Training, Tabletop Exercises, Sustainable

I. INTRODUCTION

In an emergency or disaster, deploying specialised and highly skilled first responders is critical for a rapid response. Having them on the scene could aid the people affected by a disaster. Any setbacks during the events could put both the people they help and themselves at risk. Additionally, disasters could jeopardise the nation's economic, social, and physical elements [1]. Disaster management in Malaysia is governed by a national policy, management system, and disaster aid known as MKN Directive No. 20 (*Majlis Keselamatan Negara*, or National Security Council in English), which was recently upgraded to NADMA No. 1 (*Agensi Pengurusan Bencana Negara*, or National Disaster Management Agency in English). The primary objective of this directive is to establish comprehensive policies and mechanisms for disaster management, encompassing all stages of pre-, during, and post-disaster events. NADMA, as the leading agency in disaster management, is responsible for planning, coordinating, and supervising the implementation of education, training, and awareness strategies among emergency responders to deal with and reduce the risk of disasters [2,3].

This study focuses on disaster preparedness training, which is typically conducted through discussion-based or operations-based exercises. A tabletop exercise (TTX) is a discussion-based approach to disaster training that requires participants to gather in a classroom or small group setting and is carried out face-to-face [4]. It is utilised to train disaster responders, such as police, firefighters, civil defence officers, nurses, and paramedics, who are deployed to disaster sites. This training aims to ensure their sustainability and resilience while responding to disasters. Participants have the opportunity to practise disaster management skills such as communication, prioritisation, teamwork, and delegation [5]. TTX is the most common form of disaster preparedness training due to its low-risk nature and cost-effectiveness, which allows for the testing and validation of plans, policies, and procedures to identify gaps, weaknesses, and strengths. It offers an excellent opportunity to review potential critical incidents with key personnel, as problem areas can be easily identified and discussed. TTX is a comprehensive, sustainable, and economical strategy for disaster planning [4].

Although the conventional method of tabletop exercises has been reported to be effective, this study suggests that the adoption of technology, such as augmented reality (AR), has the potential to overcome the limitations of conventional disaster preparedness training. Recently, augmented reality has garnered significant attention as a technology utilised in disaster management, particularly within the research community [6]. AR has been recognised as one of the great technologies used in many fields, especially in disaster management, by several developed countries [7]. AR has the advantage of enhancing human capacity building in all phases of disaster: mitigation/prevention, preparedness, response, and recovery from its effects. The novel techniques of digital technologies, such as AR, offer privileges in overcoming disaster events, such as the earthquake that devastated Mexico City in 2017. The technologies help the government authorities create computer-generated signals to rescue people affected by the event [8]. A review reported that modern technology, such as AR, could increase participant engagement and overcome the main drawbacks of disaster training, including evacuation drills, by reducing the cost and disruption associated with evacuation training. Additionally, AR produces realism and has positive long-term knowledge effects [9]. Additionally, AR is expected to be a more effective tool than traditional training, as AR training leads to exceptional knowledge retention [10]. Hence, this study aims to adopt augmented reality technology in tabletop exercises for sustainable disaster preparedness training.

II. METHODS

This study used an exploratory sequential mixed-methods research design. The study was conducted in three phases, beginning with qualitative data collection and analysis, followed by quantitative data collection to validate the primary qualitative results [11].

A. *Phase 1: Discovering the disaster scenario used for a tabletop exercise using an augmented reality approach*

The data collection during Phase 1 was conducted using three qualitative study methods:

- Document analysis: This study will use the literature, published policies, and guidelines for disaster management in Malaysia. The data were collected from March 2023 to December 2023.
- In-depth interviews: From March 2022 to August 2023, Malaysia's disaster management experts were interviewed face-to-face to discover the scenarios for the tabletop exercise using the augmented reality approach.
- Observations: From August 2023 to October 2024, non-participatory observations were conducted to observe the setting of 4 tabletop exercise programmes.

B. *Phase 2: Transformation of the Disaster Scenario(s) into an Augmented Reality Approach.*

A Rapid Application Development (RAD) model is the most suitable for this project. It consisted of four main phases for project development [12]:

- Requirement planning phase: Various information gained through document analysis, in-depth interviews and observations
- User design phase: Storyboard created based on the information collected to visualise the development of the project
- Construction phase: The AR application is developed based on the storyboard
- Cutover phase: The final product of the AR application is tested, and the effectiveness is evaluated.

C. *Phase 2: Transformation of the disaster scenario(s) into an augmented reality approach.*

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D. *Phase 3: Determine the validity and usability of the augmented reality-based tabletop exercise for disaster preparedness training through a pilot study*

A pilot study of 20 nursing students targeted students interested in tabletop exercise training using AR applications. Four (4) tabletop exercise sessions with five players, each using a developed AR application, were conducted as part of a pilot study. The evaluation process uses the System Usability Scale (SUS) through Google Forms. The findings of the quantitative data from SUS were calculated using SUS scoring [13]:

1. Step 1: Convert the user ratings from the 10 questions into points.
   - For odd-numbered questions 1, 3, 5, 7, 9: [User Rating] – 1 = ___ points

- For even-numbered questions 2, 4, 6, 8, 10: 5 – [User Rating] = ___ points

2. Step 2: Add the points from the 10 questions to a user's total points.
   - Question 1: __ points] + [Question 2: ___ points] + … [Question 10: ___ points] = ____ total points from user 1
3. Step 3: Multiply the user's total points by 2.5 to get an individual user's score (the SUS score has ranged from 0 to 100).
   - [Total points from user 1] x 2.5 = ¬¬ ____ User 1 SUS score
4. Step 4: Repeat steps 1-3 for all users and then average all users' scores together to get a SUS score.
   - User 1 score + user 2 score + user 3 + ….. / Number of users = SUS Score

The final SUS score for all users was then compared with the standard letter grade scale of 'Exceptional' (90-100 score), 'Good' (80-89 score), 'Acceptable' (70-79 score), and' not acceptable' (below 70 score) [14].

III. Results and Discussions

The findings from Phase 1 to Phase 3 are as follows:

A. Disaster scenario for AR-based tabletop exercise

The formats of tabletop exercises are flexible, depending on the scenarios of the exercise. Generally, the exercise begins with an introduction and briefing, followed by exercise play, a wrap-up, a hot wash, and a follow-up [4]. This study will focus on the participation of leading agencies responsible for planning, coordinating, and supervising the implementation of education, training, and awareness strategies among emergency responders in addressing and reducing disaster risk, as outlined in MKN No. 20 and NADMA No. 1 [2, 3].

The heavy rainfall scenario for the east coast area of Malaysia is developed based on information gathered from data collection. Malaysia experiences heavy rainfall yearly, especially during the northeast monsoon season from November to March [15]. This situation led to flood disasters, which heavily affected the nation, causing significant property damage, loss of life, and hindrance to economic development [16]. A storyboard has been created using Microsoft PowerPoint to visualise the tabletop exercise content, which serves as a reference for developing augmented reality-based tabletop exercises that will later be transformed into an augmented reality approach.

B. Development of AR application for tabletop exercise

The content of this application focuses on a more realistic environment, enhancing participants' immersion throughout the tabletop exercises. The marker-based augmented reality is applied due to its higher accuracy, lower complexity, and logical features, which require the camera to scan the QR code to display the three-dimensional (3D) model above it [17]. This application was developed based on the nature of discussion-based training among multiple agencies responsible for disaster management in Malaysia. The five leading agencies, including the PDRM (Royal Malaysian Police), JBPM (Fire and Rescue Department of Malaysia), APM (Malaysian Civil Defence Force), KKM (Ministry of Health Malaysia), and NADMA [2, 3], are included as players or characters in this AR application. Hence, this project adopted a multiplayer system that synchronised all players' devices to provide real-time interaction in all scenes. This system can facilitate communication and coordination among the players [18].

AR application has been tested on mobile phones and tablets that use Android software. Based on the input data from the device's camera, the AR features of 3D models from the Unreal Engine software are displayed on the mobile phone screen. The mobile phone utilises the touch screen by clicking a button to continue the TTX scenes throughout the AR application.

C. Evaluation of SUS

A total of 20 undergraduate final-year nursing students from the elective course (NURD 4412: Elective Disaster Nursing) managed to answer the SUS questionnaire during the testing and evaluation process of the pilot study. The questionnaire consisted of 5 scales: Scale 1 (Strongly Disagree), Scale 2 (Disagree), Scale 3 (Neutral), Scale 4 (Agree) and Scale 5 (Strongly Agree). The SUS score is calculated using the formula presented in the previous section [13]. Fig. 1-10 reporting the frequency of scale for each item of the SUS items is reported as follows:

- Item 1: In Fig. 1, 40% of the respondents agree, and 40% are neutral that they want to use the application frequently. This is followed by 15% who strongly agree, 5% who disagree, and no respondent voted strongly disagree. The result shows that the application will be used moderately by the users.
- Item 2: In Fig. 2, 40% of the respondents disagree that the AR application is unnecessarily complex, followed by 25% neutral, 20% agree, 10% strongly disagree, and 5% strongly agree. The result confirms that the AR application is uncomplicated.
- Item 3: In Fig. 3, 40% of the respondents think the application is easy to use, followed by 30% agree, 25% strongly agree, 5% disagree, and none voted strongly disagree. The result indicates that the application is moderately easy to use, supporting the finding in Item 2, which states that it is uncomplicated.
- Item 4: In Fig. 4, 40% of the respondents are neutral that they would need the support of a technical person to be able to use this application, followed by 25% strongly agree, 20% agree, 15% disagree, and no respondents voted for strongly disagree. A technical person is someone who has knowledge of an application and how to use it effectively. The results show that the technical person must assist the user in using the application.
- Item 5: In Fig. 5, 40% of the respondents agree that the application's functions are well integrated, followed by 30% neutral, 20% strongly agree, 10% disagree, and none voted strongly disagree. The result indicates that this AR application is well-integrated.

- Item 6: In Fig. 6, 50% of the respondents are neutral about this application's inconsistency, followed by 30% disagreeing, 10% agreeing, and 5% voting strongly agreeing and strongly disagreeing. This result demonstrates that the application falls somewhere between being consistent and inconsistent.
- Item 7: In Fig. 7, 40% of the respondents agree that most people would learn to use this AR application very quickly, followed by 35% neutral, 25% strongly agree, none voted for disagree, and none voted for strongly disagree. The result reveals that most people can learn this application promptly.
- Item 8: In Fig. 8, 45% of the respondents are neutral that this AR application is cumbersome, followed by 35% disagree, 10% agree, and 5% strongly agree and strongly disagree. The result shows that this application is moderately challenging to use.
- Item 9: In Fig. 9, 50% of the respondents are neutral and very confident using the AR application, followed by 40% who agree, 10% who strongly agree, and none who disagree or strongly disagree. The result indicates that this application is, on average, confident.
- Item 10: In Fig. 10, 50% of the respondents are neutral that they needed to learn a lot of things before they could get going with this AR application, followed by 40% agree, 10% strongly agree, none voted disagree and strongly disagree. The result shows that some users need to learn many things beforehand, while others do not.

For overall findings, all of the results from the evaluation are calculated to determine the usability of the application [13]. Table 1 presents the results of the SUS evaluation, which were calculated based on the total individual SUS scores and then divided by 20, corresponding to the number of respondents, to obtain the SUS score. The final SUS score for 20 respondents is 58.4, and this AR application is graded as a ‘Not acceptable’ grade (below 70 score) [14]. This result suggests that the AR application is experiencing significant usability issues when used in a tabletop exercise as a method for sustainable disaster preparedness training. However, this AR application still succeeded in creating an immersive, interactive and more realistic training experience among the participants.

Several limitations were identified during the development and pilot testing phases of this AR application. The first limitation is that some AR features in the application do not function fully and run smoothly on several tablet devices and older mobile device versions. Hence, the application must be enhanced by developing a more advanced AR system compatible with both Android devices and iOS. Besides that, the training was limited due to a lack of knowledge and experience among the nursing students in the tabletop exercise training. Nursing students should be widely exposed to and familiarised with this type of training for future purposes.

In conclusion, this AR application effectively demonstrated its function as a learning and training tool, meeting the current demand for the adoption of AR technology. Due to certain limitations, this study presents an excellent opportunity to enhance the application for future work, thereby increasing user engagement and overall user experience.

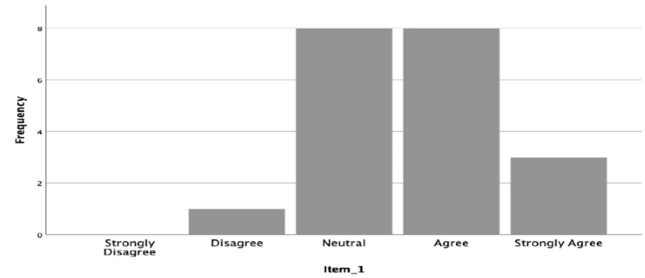

Fig. 1. Result of Item 1: I would like to use this AR application frequently.

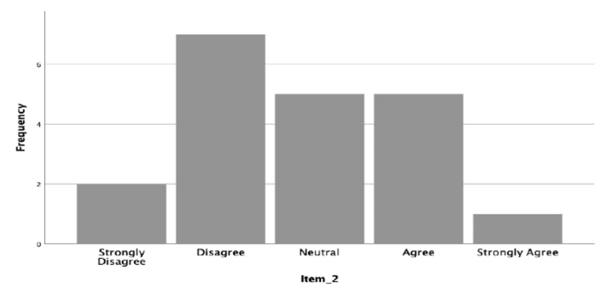

Fig. 2. Result of Item 2: I found the AR application unnecessarily complex

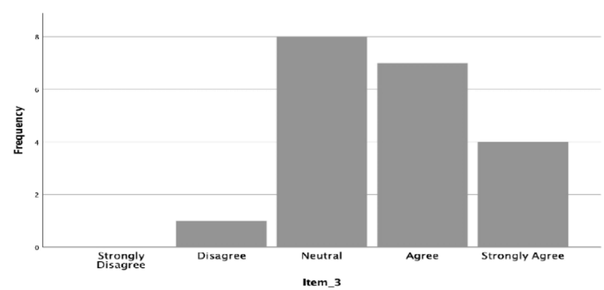

Fig. 3. Result of Item 3: I thought the application was easy to use.

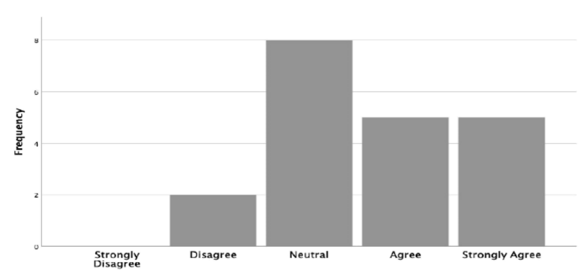

Fig. 4. Result of Item 4: I need technical support to use this AR application.

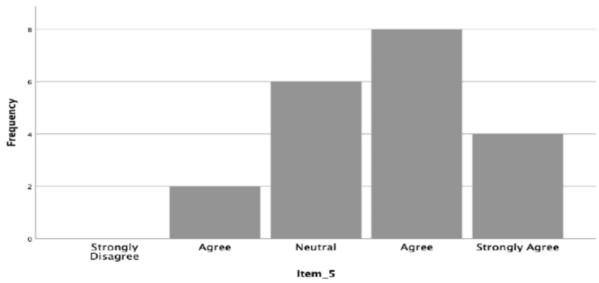

Fig. 5. Result of Item 5: I found the various functions in this AR application were well integrated.

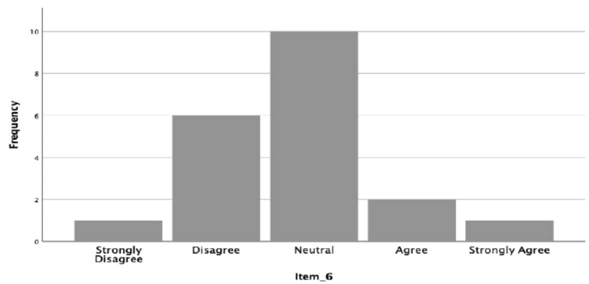

Fig. 6. Result of Item 6: I thought this AR application had too much inconsistencies

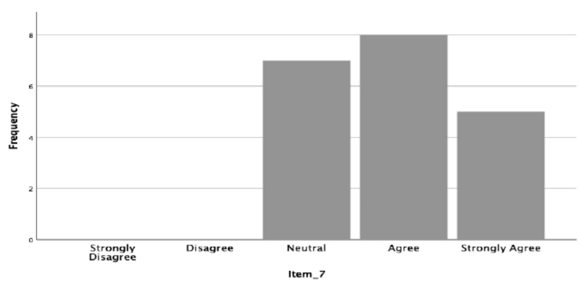

Fig. 7. Result of Item 7: I would imagine that most people would learn to use

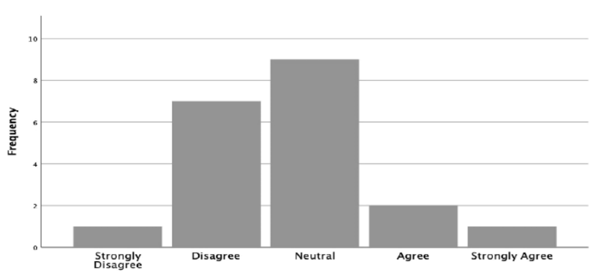

Fig. 8. Result of Item 8: I found the AR application very cumbersome to use

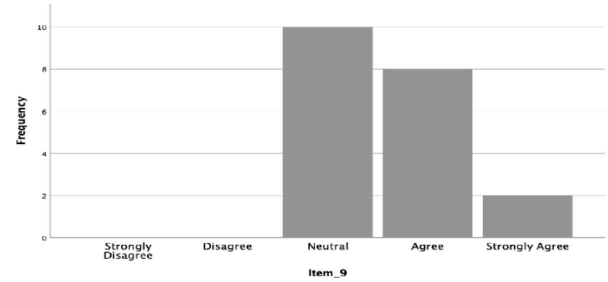

Fig. 9. Result of Item 9: I felt very confident using the AR application

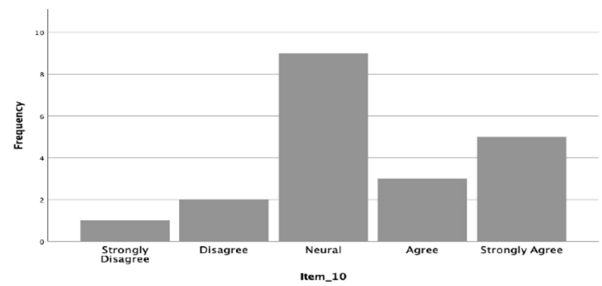

Fig. 10. Result of Item 10: I needed to learn a lot of things before I could get going with this AR application

TABLE I. SYSTEM USABILITY SCALE RESULT (N=20)

Respondent	**Total Individual Points**	**Individual SUS Score**
User 1	33	82.5
User 2	20	50
User 3	18	45
User 4	28	70
User 5	26	65
User 6	26	65.0
User 7	17	42.5
User 8	30	75.0
User 9	25	62.5
User 10	23	57.5
User 11	28	70.0
User 12	25	62.5
User 13	21	52.5
User 14	22	55.0
User 15	19	47.5
User 16	26	65.0
User 17	21	52.5
User 18	19	47.5
User 19	20	50.0
User 20	20	50.0
Total SUS Score (N=20)		1167.5
Final SUS Score (Total Score / 20)		58.4

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