


Effects of a serious game on knowledge, attitude and practice in vector control and dengue prevention among adults in primary care: A randomised controlled trial

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Abstract

Objective: Dengue is endemic but vaccination against it is optional in tropical Singapore. Despite vector control measures to curb mosquito breeding, dengue infection continues to be prevalent. A serious game has been developed to raise the community awareness of dengue vector control programme among residents in Singapore. The study aimed to evaluate the effectiveness of this serious game on the knowledge, attitude and practice (KAP) in dengue prevention among adults. It also determined their willingness to be vaccinated against dengue.

Methods: A randomised controlled trial was conducted among volunteer adults who were visiting a regional primary care clinic in Sengkang, Singapore. 400 participants were randomly allocated to receive information regarding dengue prevention from either playing a serious game (intervention) or visiting a dengue prevention website (control). Before and after receiving information on dengue prevention, participants completed a self-administered online questionnaire within a two-week interval to assess the KAP score and their interest to vaccinate against dengue. Participants, who played serious game, evaluated the game with the System Usability Scale (SUS).

Results: A total of 374 participants, comprising of 178 participants (89%) from intervention group and 196 participants (98%) from control group, completed both questionnaires. 157 (78.5%) participants in the intervention group completed playing the serious game. Participants in both groups had increased KAP score from baseline, but the mean difference in score (SD) was greater when assessing participants' daily practice towards dengue prevention in the serious game group compared to the control group (1.0 (2.8) vs 0.3 (1.9), $p = .009$). There was a positive correlation ($\rho = 0.275$) between mean change in KAP score and highest achievement attained within serious game ($p = .001$). The mean SUS (SD) was 61.8 (19.2) among participants who played the serious game. 84.2% of the study population was willing to undertake the dengue vaccination at baseline. Participants in both groups had increased proportion of participants who showed interest in dengue vaccination from baseline but the difference between serious game group and control group were not significant (5.6% vs 2.6%, $p = .131$).

Conclusions: Serious game is at least equally effective compared to conventional web-based learning in promoting dengue prevention measures and vaccination intention among adults, and may be considered as a feasible alternative to digitally engage local residents.

Keywords

Dengue, serious game, primary care

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Introduction

The incidence of dengue has grown dramatically around the world, increasing eight-fold over the last two decades.¹ Detecting and removing mosquito breeding habitats and killing larvae and pupae continue to be the most effective vector control measure, as this eliminates the mosquitoes at the most vulnerable stage of their life cycle.¹⁻³ This approach is best carried out with the participation of residents, and improving community awareness is of utmost importance in its success. However, a local study by Dave Ong et al. identified a knowledge-practice gap among residents in Singapore: people who are well-informed may not necessarily be convinced to take up particular actions to prevent mosquito breeding.⁴

Educational interventions have been the panacea in preventing the spread of many infectious diseases,⁵ and dengue is no exception. The knowledge, attitude and practice (KAP) research design is a widely utilised strategy to assess the level of awareness and practices in disease prevention programmes.⁶ Many regional studies have used the KAP surveys to assess the literacy of residents in dengue prevention programmes. However, the translation of any new knowledge acquired through education interventions into attitude changes and real dengue preventive practices remain unclear.

Computer games as a medium for learning have been widely studied in recent years.⁷ Games have the potential to improve attention and motivation as players work on challenges of the game.⁸ 'Serious game' refers to a game designed for a primary purpose other than pure entertainment.⁹ Such games have been used in healthcare to affect knowledge, attitudes and behaviours.¹⁰

Serious games can facilitate adult learning by enhancing user engagement.¹¹ Rather than didactic presentations, serious games promote 'situated learning' where players can learn through exploration and experimentation.¹² An immersive story is often used to enhance motivation to play the game and to allow for deeper information processing.^{13,14} Furthermore, games that incorporate behavioural theory may be more effective at facilitating health communication and behaviour change.¹⁵⁻¹⁷ A recent mixed method study conducted among students in the United Kingdom demonstrated that a serious game, 'e-Bug', significantly increased knowledge about antibiotic use, enhanced appropriate health behaviours and vaccination intention.¹⁸

In Singapore, the cumulative incidence of dengue cases stands at more than 35,315 (621 per 100,000 residents over a year) at the end of 2020.¹⁹ This figure has far exceeded the largest dengue outbreak in Singapore's history since 2013. The National Environmental Agency (NEA) is a local public organisation tasked to step up island wide dengue prevention measures. NEA spearheads the five-step Mozzie Wipeout programme to remove mosquito breeding habitat, conduct indoor spraying of insecticides and outdoor fogging to kill adult mosquitoes, and oiling of stagnant water to kill mosquito larvae and pupae.² However, the daily numbers of

dengue infections and deaths continue to reach new heights even with these labour-intensive practices throughout the year.

Preventive measures are urgently needed to curb an impending dengue epidemic via a dual-pronged strategy, including elevating public awareness of vector control and vaccination to mitigate the viral infection. A team of local primary care researchers and game developers has designed a serious game which aims to raise the local residents' awareness of dengue and influence their attitude towards its vector control. Its effectiveness to improve dengue literacy of local residents and to take vector control measures has yet to be determined.

A licensed dengue vaccine has been approved by the local health authority for the prevention of dengue in individuals aged 12 to 45 years.²⁰ The vaccine is not suitable for those who have not been previously infected. The World Health Organisation recommends pre-screening to avoid vaccinating those who are unsuited and if screening is not feasible, vaccination can be considered in areas with at least 80% prevalence in the population by nine years of age.²¹ The prevalence of dengue in adults aged 18-74 years is 48.6% in Singapore, which is below the threshold for population vaccination without screening.²² Dengue vaccination is therefore not incorporated in the local national vaccination programme. In addition, conducting regular epidemiological study on dengue prevalence is not logistically feasible. Nonetheless dengue vaccine is available at a cost to those who request for it on a need basis. Hence, individual's views of the dengue vaccine influence their willingness to be vaccinated, with lessons gleaned from the implementation of the Covid-19 vaccination programme across the world. Assessing their perception towards the dengue vaccine will identify gaps which have to be addressed before mass dengue vaccination is considered, if local infections escalate into an epidemic.

The study aimed to (1) evaluate the effect of a novel serious game on the KAP of adults in vector control and dengue prevention; (2) assess their perceived usability of this serious game and (3) their willingness to be vaccinated against dengue.

Methods

Study design

From March to August 2021, a single-centre randomised controlled trial was conducted to determine the effectiveness of playing a serious game (intervention) in improving the KAP of participants in vector control and dengue prevention compared to those who viewed a dengue prevention website (control).

Conceptual framework

The study was designed based on the conceptual framework, adapted from a regional study by Rattanam Ahbi Rami et al.⁶ The use of a novel education intervention,

serious game, was postulated to improve knowledge and increase a person's perceived threat of disease virtually, leading to attitude change and an uptake in dengue preventive measures in reality (Figure 1).

In addition, the COM-B Model of Behaviour was considered in the design of this serious game.²³ Capability, motivation and opportunity were recognised as important factors for behaviour change to occur, and to ensure the sustainability of the learnt behaviour. We aimed to improve opportunity through convenient accessibility of game on major mobile platforms, increase motivation through the use of immersive gameplay, and enhance capability through imparting relevant dengue prevention knowledge to the participants.

Study site

This study was conducted at a regional public primary care clinic (Polyclinic) in Sengkang. Sengkang Polyclinic is located in Sengkang Community Hub, which is an amenity centre in Sengkang, within the North-East region of Singapore. Sengkang is also a residential town, which is the second most populous in the region, being home to 244,600 residents in 2019.²⁴

Study population

The study was conducted among adults, aged 21 to 60 years, who had visited Sengkang Polyclinic. As English literacy is high amongst residents in Singapore,²⁵ participants who were able to understand English, had a mobile phone which was compatible with the serious game, were willing to download and attempt the serious game and able to complete questionnaires in English on the online secured platform, were eligible to participate. Those who were not able to use a mobile phone due to physical or cognitive impairments were excluded.

Sample size calculation

To determine the effect of serious game in the KAP in preventing dengue among adults in Singapore, the sample size was computed based on the study by Nurul Akmar Ghani et al.,²⁶ in which the significant difference in mean and standard deviation of knowledge scores were 14.55 (3.09) and 15.41 (2.75) respectively between the compared groups. To obtain a sample size with 95% confidence level and 80% power for this study, a minimum of 182 participants per group was required. With a possible drop out of 10%, the sample size was increased to 200 per group.

Recruitment and consent process

Recruitment posters, containing registration details of the study, were placed within the clinic's premises from March to August 2021. Adults who were interested to join the study voluntarily could approach the clinical research coordinators (CRCs), who would screen them for eligibility, explained the study intent and procedure to them in a designated room within the study site. The CRCs were trained by the principal investigator (PI) to provide adequate information and address relevant concerns or queries from the participants prior to the start of this study. The latter were informed about the purpose and content of the study based on the approved participant information sheet. After clarifying their doubts and queries, every eligible participant endorsed their written informed consent before randomisation. Enrolment of participants was performed by the CRCs and the participants were assigned an individual unique participant code after randomisation.

Randomisation

The randomisation sequence was created by the biostatistician using computer generated random numbers in a 1:1

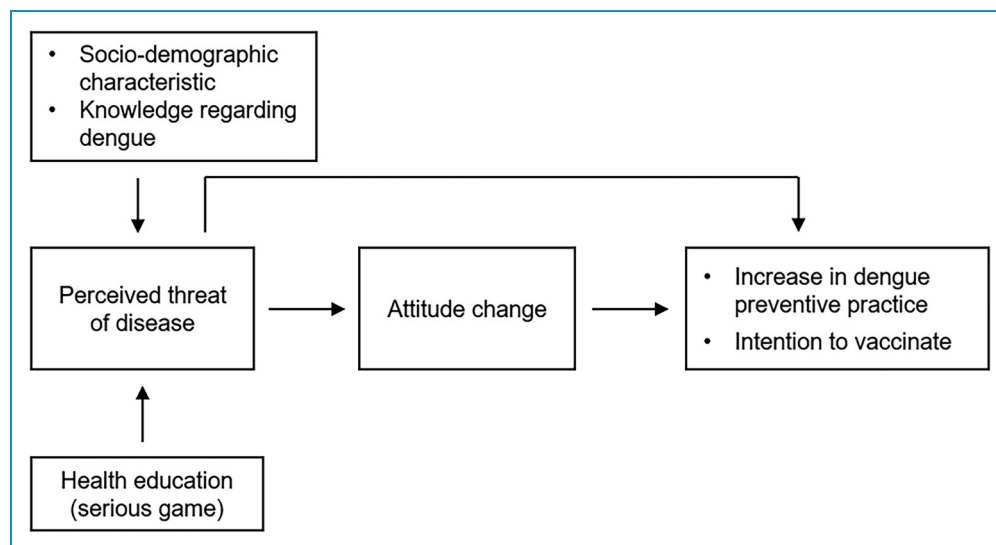


Figure 1. Conceptual framework of the study.

ratio. Random permuted blocks were used to ensure equal number in each group. The randomisation sequence was concealed in sequentially numbered, opaque, sealed envelopes by the PI at the study site, and stored in a secured location that was accessible only by the research assistants. Blinding was not possible for the participants and the CRCs, as the intervention group would be required to download an application into the mobile phone. Both the biostatistician and PI were not involved in the enrolment or allocation of participants into the study arms.

Study procedure

The KAP assessment instrument was adapted from a previous study conducted by Nurul Akmar Ghani et al.²⁶ The questionnaire used in this study was an improved version of the KAP assessment instrument on dengue fever prevention which was validated by Mohammad Nasir et al.²⁷

The questionnaire was divided into six sections; (1) demographic; (2) knowledge (16 items); (3) attitude (15 items), (4) practice (15 items) in preventing dengue, (5) interest to vaccinate against dengue (1 item); and (6) usability of the serious game adapted from the System Usability Scale (SUS) solely by the intervention group.^{28,29}

The knowledge section contained 16 questions to test participants' understanding on the symptoms, transmission, treatment, and prevention of dengue infection. Each correct answer received one point, while incorrect or 'not sure' response would not gain any point.

The attitude section contained 15 questions to assess participants' attitude towards the disease and dengue prevention measures. The acceptable good attitude responses were scored one point and else zero point.

The practice section contained 15 questions to assess daily practice of participants in dengue prevention. The score was based on good practice and none for poor practice or if the participant answered 'not relevant'.

The response of participants' interest to vaccinate against dengue was scored separately.

The first (baseline) questionnaire for all participants contained 56 questions divided into sections 1 to 5.

The second questionnaire for the serious game group contained 58 questions divided into sections 2 to 6, while the control group responded to only sections 2 to 5.

The questions in section 6 were modified from the validated SUS to evaluate the usability of this serious game.²⁸ The SUS had 10 statements, and a 5-point Likert scale was used to indicate the participant's agreement with the statements. The mean score was calculated from the intervention group and analysed. A score above 68 was above average and scores below 68 was below average in terms of system usability.³⁰

Participants in both groups completed all questionnaires with their unique participant codes via a secured online platform, Form.sg.³¹ Form.sg was used to create online

questionnaires that capture classified data for this study. All items within each questionnaire had to be completed before participants could submit their response. Once the submission had been completed, participants would be unable to change their response. The platform does not store participants' response data in its servers and all responses are sent directly to the study team's dedicated email address.

Participants who completed both questionnaires were reimbursed with a grocery voucher valued at SGD 10.

Intervention using a specially designed serious game.

Participants in the intervention group installed a mobile application, 'Sam's Mozzie Adventure'. They were inducted with a walkthrough of the serious game by the CRC, who assisted them in installing the game and performing a trial run on their phones. The participants were instructed to complete the game within two weeks.

'Sam's Mozzie Adventure' is a locally designed serious game which was co-created between SingHealth Polyclinics and AI Innovation Labs (AI2 Labs) Private Limited, specifically for this study. The PI reviewed existing publicly available information on dengue prevention, including those on the NEA 'Stop Dengue' website, and provided the relevant content and pedagogical knowledge to the team of app developers from AI2 Labs. After creating the syllabus, the developers deployed their technological knowledge to integrate the dengue prevention information into the serious game. The serious game was revised after pilot trials and were conducted in several cycles amongst the study team members to enhance the user interface.

'Sam's Mozzie Adventure' version 0.5.30 was uploaded to both Apple App Store and Google Play Store and used solely for this study. As this mobile application was made intentionally inaccessible without a unique passcode, only participants who had been verified by the CRCs would be able to play this game on their mobile phones and participate in this study. De-identified data containing the progress of gameplay, such as the highest achievement (maximum game stars) attained by the participants, was recorded and uploaded to the developer's secured data server at the completion of the serious game.

The game story was centred around the character Sam. As Sam travelled through four different everyday scenarios at home, bus-stop, school and workplace, the goal was to help Sam identify potential dengue breeding sites and learn about dengue prevention measures so as to create a 'Mozzie-free world' (Figure 2).

Through each scenario, the game was designed to trigger the participant to click on potential dengue breeding sites such as vase, potted plants, and water containers without lids. When correctly selected, Sam would be activated to do an animated action to rectify the problem and a pop up containing the relevant dengue information would be presented to the participant (Figure 3).

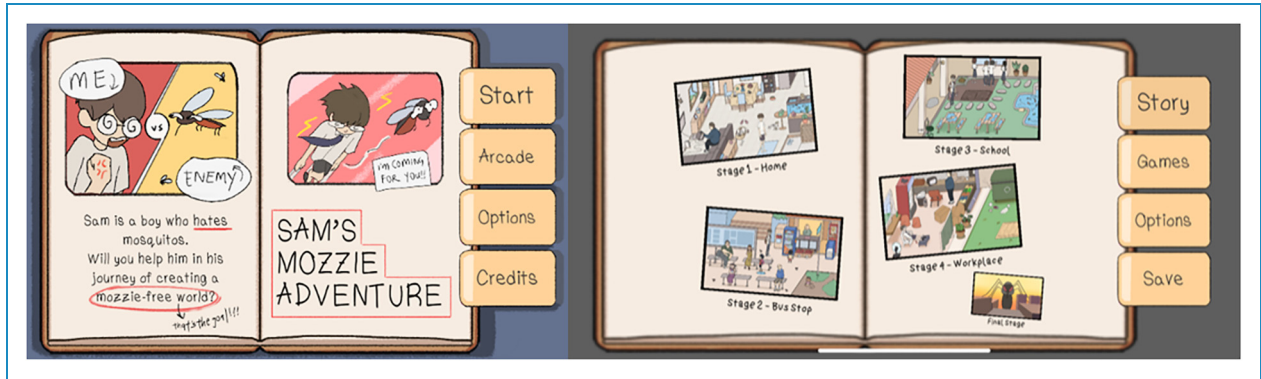


Figure 2. Overview of Sam's Mozzie adventure.

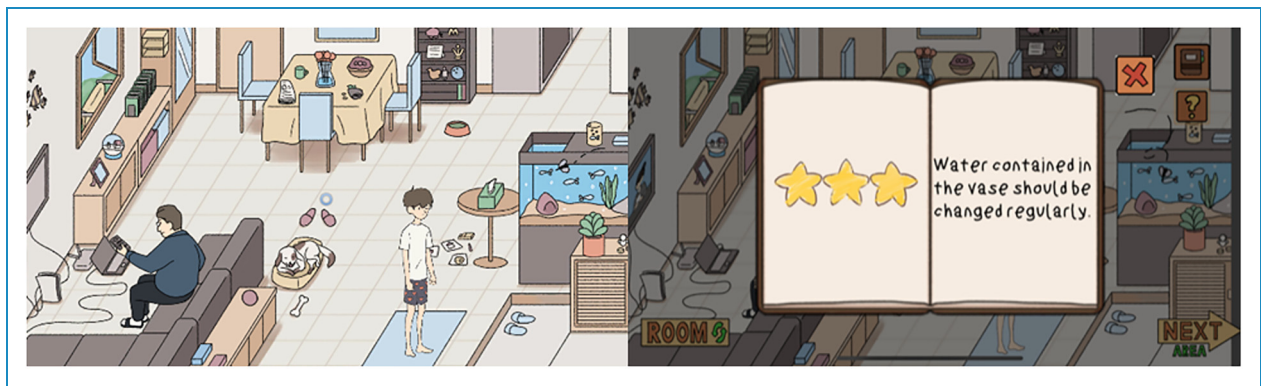


Figure 3. Home scenario with potential dengue breeding sites and activated trigger.



Figure 4. Class quiz time and interactive game.

Behavioural change technique using reward and threat was used in the design of 'Sam's Mozzie Adventure'. A correct answer or action would earn the participant more 'stars', while an incorrect move would result in a lower score or require the participant to repeat the task.

Participants could also view dengue posters or participate in quiz while exploring the interactive environment to learn about dengue prevention measures (Figure 4).

To improve the user interface, hints were prompted at the start of each scenario to lead the participant towards identifying the triggers within the game so as to achieve the maximum desired outcome with minimum effort on the participant's part (Figure 5).

Control group procedure. The control group accessed the NEA 'Stop Dengue' website³² which contained dengue prevention information in the forms of online articles,

posters and video. The participants were instructed to complete reading the online resources within two weeks.

Completion of the study. A reminder via SMS (Short Message Service) was sent to both groups to complete the second questionnaire at the end of the study. The second questionnaire assigned to the intervention group consisted of an additional 10 questions to assess the usability of the serious game.

Analysis

The KAP scores varied from 0–16, 0–15, to 0–15 respectively, with a maximum score of 46 points. The highest achievement attained by the participants in serious game group were measured by the number of stars awarded in-game, which varied from 0 to 48 stars.

The data were audited and errors were rectified before analyses. Descriptive statistics in terms of frequency (n), percentage (%), mean and standard deviations (SD) were used to express the data. The socio-demographic variables between the two groups were compared using Chi-Square test for categorical variables and independent t-test for continuous variables. Independent t-test was used to compare the baseline, follow up and change in KAP scores between the control and intervention group. Paired t-test was used to determine the difference in scores from baseline and follow up. The Spearman's correlation was used to determine the association between change scores and maximum game stars awarded in the intervention group. SUS score was presented in frequency and percentages. A p -value of less than .05 is considered statistically significant. All analyses were performed using IBM SPSS 27.0.

Results

Within the study period from March to August 2021, 400 eligible participants had volunteered for the study. Eventually, a total of 374 participants (93.5%) completed both questionnaires (Figure 6). Among the 178 participants

in the serious game group who had completed both questionnaires, 21 participants (11.8%) started but did not complete playing serious game. The mean duration taken to complete serious game was 29.5 minutes among the 157 participants who completed the game. As the gameplay data from the intervention group was designed to be captured only when participants complete the 'final stage' of the serious game, participants could complete the second questionnaire to reflect the usability of the serious game even if they did not manage to complete the serious game.

No significant differences were noted in the socio-demographic characteristics and KAP mean score at baseline in both groups (Table 1). Drop out cases were significantly more from the intervention group compared to the control group although they were similar in demographic profiles in both groups (Appendix 1).

Knowledge, attitude and practice score of dengue prevention among adults

Participants in both groups increased the total KAP score significantly from baseline. Both the change in mean (SD) score of 2.1 (4.2) in the intervention group, and 1.7 (3.1) in the control group were statistically significant ($p < .001$). However, no statistical difference was found in the change in total KAP mean score between the intervention and control group ($p = .206$) (Figure 7).

The change in mean score in knowledge and attitude items showed no statistical difference between the intervention and control group. However, the mean score was significantly increased in practice regarding dengue prevention in the intervention group compared to those in the control group. The change of practice score from baseline to follow up was 1.0 (2.8) in intervention group and 0.3 (1.9) in control group, was statistically significant ($p = .009$, with a Bonferroni-calculated significance level of <0.0125) (Table 2).

Tables 3 and 4 showed similar distribution in responses of participants for knowledge and attitude items for both intervention and control groups. However, Table 5



Figure 5. Improving user interface with hints.

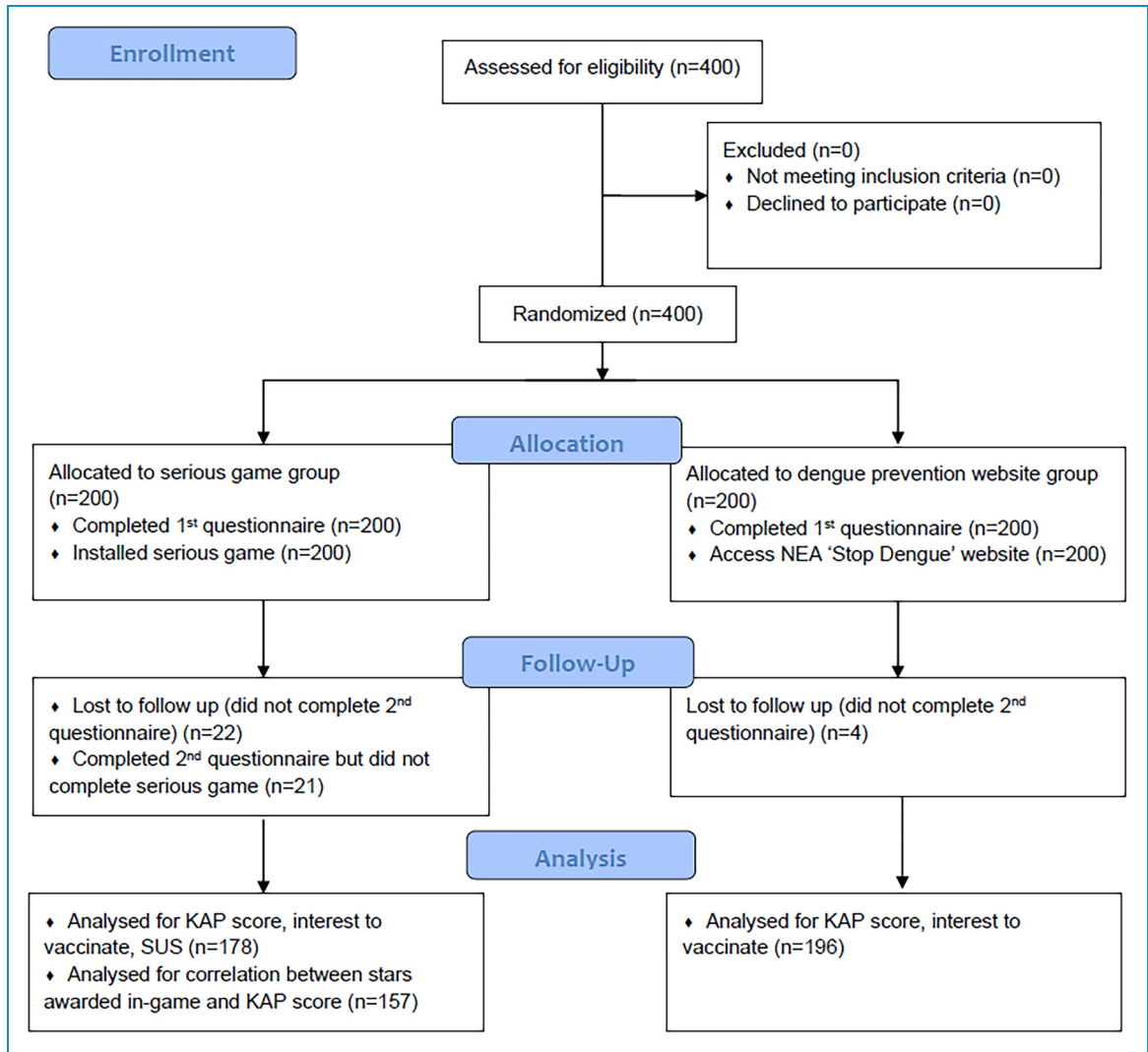


Figure 6. CONSORT diagram showing participant flow through the study.

showed a higher proportion of participants in the serious game group who would conduct ‘check for any garbage or rubbish that can block the drainage system around the house’ and ‘check for Aedes larvae in the toilet tank’, as part of their dengue preventive measures compared to participants who accessed dengue prevention website at follow up.

Interest to vaccinate against dengue infection

315 participants (84.2%) were interested to vaccinate against dengue infection if there was a ‘safe and effective vaccine’ at baseline. At follow up, the increase in number (%) of participants who were interested to be vaccinated against dengue was 10 (5.6) in the intervention group, and 5 (2.6) in dengue prevention website group. However, the change between both groups was not statistically significant ($p = .131$).

Correlation between change in KAP score and serious game

The correlation between the mean change in KAP score and the maximum number of game stars awarded to the participants who played serious game revealed a significant positive correlation ($p = .001$). However, the degree of correlation was found to be low ($\rho = 0.275$) (Figure 8).

Usability of ‘Sam’s Mozzie adventure’ as a serious game in dengue prevention

The mean score (SD) was 61.8 (19.2), with only 38.8% of participants in the intervention group grading it with a score of ≥ 68 (Table 6). A mean score of less than 68 indicate that the participants might have less than average user experience with the serious game, and improvements to the user interface would be recommended.

Table 1. Baseline characteristics of study participants.

	Serious game group	Dengue prevention website group	<i>p</i> -value
Total	178	196	
Age, median (IQR)	33.5 (30.0–40.0)	35.0 (30.0–43.0)	.522
Gender, <i>n</i> (%)			.637
Male	72 (40.4)	84 (42.9)	
Female	106 (59.6)	112 (57.1)	
Ethnic group, <i>n</i> (%)			.783
Chinese	129 (72.5)	139 (70.9)	
Malay	24 (13.4)	28 (14.3)	
Indian	14 (7.9)	20 (10.2)	
Others	11 (6.2)	9 (4.6)	
Marital status, <i>n</i> (%)			.819
Married	46 (25.8)	49 (25)	
Single/divorced/separated/ widowed	128 (71.9)	144 (73.5)	
Education, <i>n</i> (%)			.653
Up to secondary school	17 (9.6)	21 (10.7)	
Junior college/polytechnic/institute of technical education	59 (33.1)	72 (36.7)	
University/post-tertiary	102 (57.3)	103 (52.6)	
Housing, <i>n</i> (%)			.386
Public housing (1–5 room)/rental/apartment	136 (76.4)	157 (80.1)	
Executive apartment/maisonette/executive condominium/private condominium/private house/others	42 (23.6)	39 (19.9)	
Income, <i>n</i> (%)			.252
Less than S\$1000	12 (6.7)	12 (6.1)	
S\$1000–S\$3999	75 (42.1)	85 (43.4)	
S\$4000–S\$7999	63 (35.4)	62 (31.6)	
More than S\$8000	18 (10.1)	32 (16.3)	
Not applicable (retired/student/housewife, etc.)	10 (5.6)	5 (2.6)	

(continued)

Table 1. Continued.

	Serious game group	Dengue prevention website group	p-value
Had dengue infection before, n (%)			.602
Yes	12 (6.7)	16 (8.2)	
No	166 (93.3)	180 (91.8)	
Baseline KAP score (SD)			
Total score	29.3 (4.3)	29.1 (4.3)	.629
Knowledge section	10 (2.3)	10 (2.3)	.737
Attitude section	12.5 (1.2)	12.3 (1.5)	.193
Practice section	6.7 (3.2)	6.8 (3.2)	.879

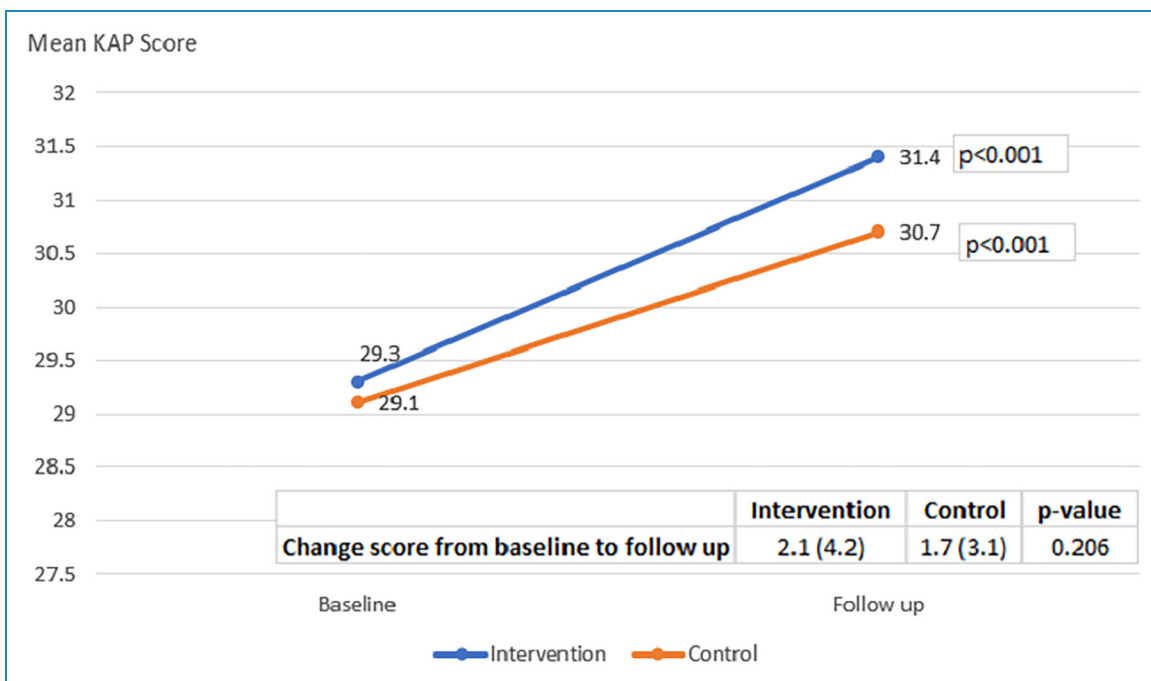


Figure 7. Comparison of mean score from baseline to follow up.

Discussion

This study shows that introducing serious game to the community improves the KAP, and in particular the practising of dengue preventive measures, in the local population. Although participants in both groups had similar increase in total KAP score after being provided dengue prevention educational materials, there was a higher proportion of participants in the serious game group who would translate the acquired knowledge into actual practices such as ‘checking for any garbage or rubbish that can block the drainage

system around the house’ and ‘checking for Aedes larvae in the toilet tank’. This finding may suggest that serious game can be an equally effective alternative compared to conventional web-based learning in improving community awareness regarding dengue and empowering residents to be more pro-active in participating in dengue source reduction activities at their residential areas.

However, the effect of intervention may be difficult to assess three items within practice section of the KAP questionnaire as a longer period of follow up may be required

Table 2. KAP score of participants at baseline and follow up.

	Serious game group	Dengue prevention website group	
	Mean, SD	Mean, SD	<i>p</i> -value
Baseline			
Total score	29.3 (4.3)	29.1 (4.3)	.629
Knowledge	10 (2.3)	10 (2.3)	.737
Attitude	12.5 (1.2)	12.3 (1.5)	.193
Practice	6.7 (3.2)	6.8 (3.2)	.879
Follow up			
Total score	31.4 (4.4)	30.7 (4.2)	.121
Knowledge	11 (2.1)	11.2 (1.9)	.532
Attitude	12.7 (1.3)	12.4 (1.5)	.104
Practice	7.7 (3.7)	7.1 (3.3)	.107
Change score from baseline to follow up			
Total score	2.1 (4.2)	1.7 (3.1)	.206
Knowledge	1 (2.2)	1.2 (1.9)	.329
Attitude	0.2 (1.3)	0.1 (1.2)	.703
Practice	1 (2.8)	0.3 (1.9)	.009

for opportunities to arise before participants could perform these dengue preventive measures. These practice items include ‘having a lid for water tank’, ‘being involved in dengue campaign’ and ‘checking and cleaning the house drain and roof during rainy season’.

The results are in agreement with those of other studies that highlight the impact of health educational studies on KAP score in dengue prevention of participants. Knowledge score increased while attitude score maintained, when the study population was supplied with health educational materials.⁶ However, practice score was significantly increased in participants who played serious game compared to the control group in our study. This may be explained by the conceptual framework where the immersive story of serious game enabled participant to role play the in-game character, triggering a perceived threat of disease virtually, leading to behavioural change and an uptake in dengue preventive measures in reality.

In addition, this study shows that participants who attained a higher level of achievement in the serious game

tend to have a greater improvement in scores for the KAP assessment. As this serious game was designed based a behavioural change technique using reward and threat, participants were enticed to obtain the maximum stars at each task by executing only the most appropriate dengue preventive measures. Immersed in a stimulated interactive learning environment, the participants may have felt competitive to attain the best possible scores through deliberate practice, where the task is repeated to improve performance. Hence, participants who were awarded higher number of stars in games were likely to have greater improvement in total KAP scores. The results are also in line with systematic reviews of gamification and serious games, where it was found that gamification can have a positive impact in health behaviours in the general population.^{18,33,34}

However, the study did not show a significant change in interest to vaccinate against dengue among the participants in both groups. As the dengue affects among almost half of the local adults (48.6%) population, it is below the threshold for population vaccination without screening based on WHO recommendation.²¹ As a result, dengue vaccination has not been actively promoted within the country and has not been included in the national immunisation schedules. Hence, local residents might be hesitant to agree for dengue vaccination without first consulting their primary care providers. Although 84.2% of the study population indicated interest to be vaccinated against dengue infection, only 28 (7.5%) participants had a previous dengue infection and fulfilled the eligibility for dengue vaccination. Future adaptation of this serious game should focus on identifying suitable vaccination candidates and be fitted with in-game features to enable collaborations with nearby primary care clinics to provide the necessary vaccinations.

Strengths and limitation

The findings are novel in providing casual evidence that KAP in dengue prevention of adults can be modified by introduction of serious game in the community, without the need of consultations by medically trained professionals or conventional health educations such as classroom-based tutorials. Second, an adequate sample size was conducted at a regional primary care clinic which serves the second most populous residential town in the region. There was high retention of participants with full data obtained for 93.5% of the cohort. Randomization sequence was prepared by the biostatistician who was not involved in the enrolment of the participants, and allocation concealment was maintained throughout the study. The outcome data was collected via a participant-administered questionnaire on an online secured platform, without contact with the study members. Finally, all data were de-identified and the statistical analysis was performed by the biostatistician, who was blinded to group allocation, only after the completion of enrolment of all participants.

Table 3. Responses of participants for knowledge items at follow up.

Knowledge items	Serious game group		Dengue prevention website group	
	n (%)		n (%)	
	Wrong answer	Correct answer	Wrong answer	Correct answer
Dengue is spread by <i>Aedes aegypti</i> or <i>Aedes albopictus</i> .	17 (9.6)	161 (90.4)	19 (9.7)	177 (90.3)
A person can get dengue more than once.	6 (3.4)	172 (96.6)	4 (2)	192 (98)
Dengue fever is an infectious disease.	104 (58.4)	74 (41.6)	83 (42.3)	113 (57.7)
Dengue fever is a severe flu disease that can affect babies, kids, and adults.	122 (68.5)	56 (31.5)	134 (68.4)	62 (31.6)
Dengue outbreak only happens during rainy season.	23 (12.9)	155 (87.1)	25 (12.8)	171 (87.2)
Symptoms of dengue may include the following:				
High fever	1 (0.6)	177 (99.4)	0	196 (100)
Cough	137 (77)	41 (23)	137 (69.9)	59 (30.1)
Joint, muscle, and bone pain	5 (2.8)	173 (97.2)	12 (6.1)	184 (93.9)
Pain behind eyes	80 (44.9)	98 (55.1)	98 (50)	98 (50)
Vomiting	57 (32)	121 (68)	62 (31.6)	134 (68.4)
Loss of appetite	56 (31.5)	122 (68.5)	55 (28.1)	141 (71.9)
Rashes	41 (23)	137 (77)	48 (24.5)	148 (75.5)
Headache	35 (19.7)	143 (80.3)	53 (27)	143 (73)
<i>Aedes</i> mosquitoes only spread dengue virus during the day.	30 (16.9)	148 (83.1)	48 (24.5)	148 (75.5)
<i>Aedes</i> mosquitoes only reproduce in dirty water.	24 (13.5)	154 (86.5)	20 (10.2)	176 (89.8)
<i>Aedes</i> mosquitoes reproduce in clean water found in old tires, rubbish bins, and flower pots.	13 (7.3)	165 (92.7)	17 (8.7)	179 (91.3)
Dengue virus spread among humans via infected female <i>Aedes</i> mosquitos' bites.	20 (11.2)	158 (88.8)	19 (9.7)	177 (90.3)
The only way to combat dengue is to fight <i>Aedes</i> mosquitoes.	128 (71.9)	50 (28.1)	149 (76)	47 (24)
There is no treatment available to cure dengue fever.	100 (56.2)	78 (43.8)	110 (56.1)	86 (43.9)
Paracetamol is very effective to fight dengue fever.	78 (43.8)	100 (56.2)	95 (48.5)	101 (51.5)

(continued)

Table 3. Continued.

Knowledge items	Serious game group		Dengue prevention website group	
	<i>n</i> (%)		<i>n</i> (%)	
	Wrong answer	Correct answer	Wrong answer	Correct answer
Larvae killer, such as Bti pesticides, can help in killing Aedes larvae.	30 (16.9)	148 (83.1)	32 (16.3)	164 (83.7)
Water containers and tanks without lids should be cleaned every seven days.	16 (9)	162 (91)	16 (8.2)	180 (91.8)
Insecticides can kill adult Aedes mosquitoes.	33 (18.5)	145 (81.5)	27 (13.8)	169 (86.2)

Table 4. Responses of participants for attitude items at follow up.

Attitude items	Serious game group		Dengue prevention website group	
	<i>n</i> (%)		<i>n</i> (%)	
	Wrong answer	Correct answer	Wrong answer	Correct answer
Dengue fever cannot be prevented.	17 (9.6)	161 (90.4)	32 (16.3)	164 (83.7)
Dengue fever cannot be treated.	142 (79.8)	36 (20.2)	152 (77.6)	44 (22.4)
Only healthcare workers and volunteers are responsible for clearing Aedes mosquitoes breeding sites.	1 (0.6)	177 (99.4)	4 (2)	192 (98)
Killing Aedes mosquitoes is the only way to prevent dengue.	96 (53.9)	82 (46.1)	116 (59.2)	80 (40.8)
Fogging is enough to avoid dengue.	14 (7.9)	164 (92.1)	22 (11.2)	174 (88.8)
Everybody has the probability to be infected by dengue.	4 (2.2)	174 (97.8)	2 (1)	194 (99)
If I have dengue symptoms, I will quickly see a doctor.	0	178 (100)	1 (0.5)	195 (99.5)
I am so afraid to be infected by dengue.	25 (14)	153 (86)	18 (9.2)	178 (90.8)
A person cannot get dengue twice.	10 (5.6)	168 (94.4)	21 (10.7)	175 (89.3)
I will not visit dengue patient in hospital.	23 (12.9)	155 (87.1)	30 (15.3)	166 (84.7)
All dengue patients have the chance to heal after infected by dengue virus.	19 (10.7)	159 (89.3)	12 (6.1)	184 (93.9)
Killing Aedes mosquitoes' breeding sites is wasting time and hard to do.	7 (3.9)	171 (96.1)	9 (4.6)	187 (95.4)
Healthy people will never get dengue.	4 (2.2)	174 (97.8)	7 (3.6)	189 (96.4)
Using mosquito net can prevent dengue.	53 (29.8)	125 (70.2)	73 (37.2)	123 (62.8)
You are an important person to fight dengue spread.	0	178 (100)	4 (2)	192 (98)

Table 5. Responses of participants for practice items at follow up.

Practice items	Serious game group			Dengue prevention website group		
	n (%)			n (%)		
	Yes	No	Not relevant	Yes	No	Not relevant
Do you close the container lid quickly after using it?	160 (89.9)	2 (1.1)	16 (9)	170 (86.7)	2 (1)	24 (12.2)
Does your house water tank have a lid?	86 (48.3)	17 (9.6)	75 (42.1)	76 (38.8)	15 (7.7)	105 (53.6)
If you see Aedes larvae in the water tank, do you clear it?	146 (82)	1 (0.6)	31 (17.4)	146 (74.5)	1 (0.5)	49 (25)
Do you change the water in the container of your home garden every week?	98 (55.1)	2 (1.1)	78 (43.8)	96 (49)	1 (0.5)	99 (50.5)
Have you changed the water in your flower vase?	101 (56.7)	1 (0.6)	76 (42.7)	113 (57.7)	0	83 (42.3)
Have you checked for Aedes larvae in your vase?	98 (55.1)	7 (3.9)	73 (41)	115 (58.7)	6 (3.1)	75 (38.3)
Do you check for any garbage or rubbish that can block the drainage system around your house? (Question 47)	111 (62.4)	13 (7.3)	54 (30.3)	95 (48.5)	29 (14.8)	72 (36.7)
If you answered 'Yes' to Question 47, have you put the garbage into its bin to clear the drain?	87 (48.9)	5 (2.8)	86 (48.3)	85 (43.4)	4 (2)	107 (54.6)
Do you use any mosquito repellent in your house?	96 (53.9)	76 (42.7)	6 (3.4)	122 (62.2)	68 (34.7)	6 (3.1)
Do you use mosquito net to sleep?	13 (7.3)	158 (88.8)	7 (3.9)	8 (4.1)	180 (91.8)	8 (4.1)
Do you get involved in any dengue campaign in your area?	22 (12.4)	143 (80.3)	13 (7.3)	22 (11.2)	167 (85.2)	7 (3.6)
Have you checked Aedes larvae in your toilet tank?	101 (56.7)	60 (33.7)	17 (9.6)	84 (42.9)	91 (46.4)	21 (10.7)
Do you check and clean your house drain and roof during the rainy season?	56 (31.5)	19 (10.7)	103 (57.9)	52 (26.5)	29 (14.8)	115 (58.7)
Do you use any cream, oil, gel or bangle to avoid Aedes mosquitoes?	94 (52.8)	70 (39.3)	14 (7.9)	94 (48)	96 (49)	6 (3.1)
Do you believe in traditional medicine to fight dengue?	43 (24.2)	103 (57.9)	32 (18)	54 (27.6)	117 (59.7)	25 (12.8)

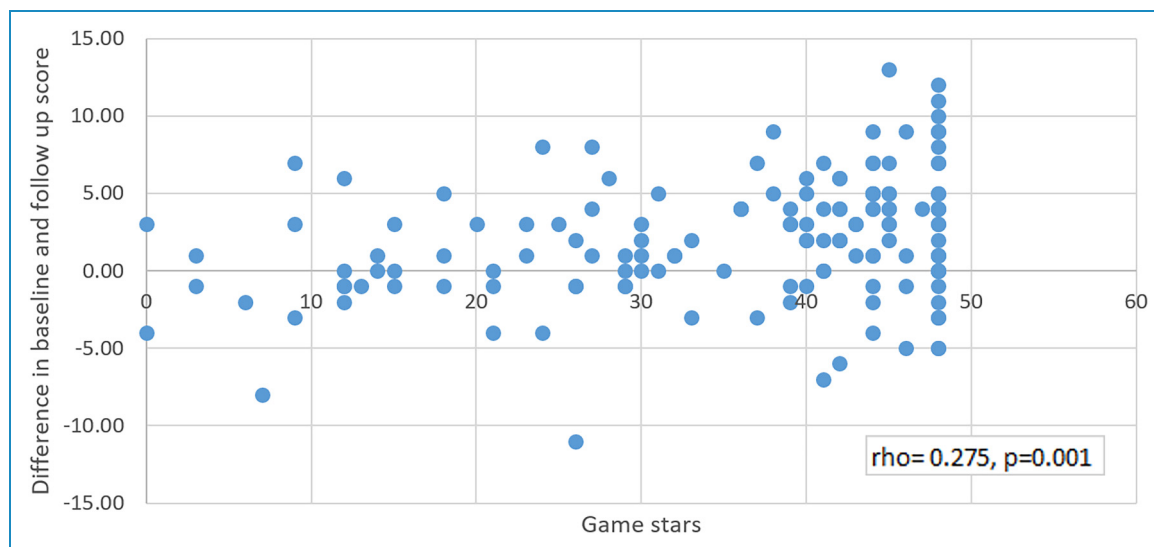


Figure 8. Association between total KAP change score and maximum stars awarded.

Table 6. Frequency and percentage of responses from participants regarding usability of serious game, ‘Sam’s Mozzie adventure’ (System Usability Scale).

	Strongly disagree, <i>n</i> (%)	Disagree, <i>n</i> (%)	Neutral, <i>n</i> (%)	Agree, <i>n</i> (%)	Strongly agree, <i>n</i> (%)
I think that I would like to use this game frequently.	18 (10.1)	17 (9.6)	54 (30.3)	43 (24.2)	46 (25.8)
I found this game unnecessarily complex.	42 (23.6)	43 (24.2)	47 (26.4)	30 (16.9)	16 (9)
I thought this game was easy to use.	15 (8.4)	18 (10.1)	52 (29.2)	44 (24.7)	49 (27.5)
I think that I would need the support of a technical person to be able to use this game.	75 (42.1)	26 (14.6)	36 (20.2)	21 (11.8)	20 (11.2)
I found the various functions in this game were well integrated.	11 (6.2)	18 (10.1)	57 (32)	51 (28.7)	41 (23)
I thought there was too much inconsistency in this game.	52 (29.2)	34 (19.1)	61 (34.3)	21 (11.8)	10 (5.6)
I would imagine that most people would learn to use this game very quickly.	14 (7.9)	18 (10.1)	51 (28.7)	46 (25.8)	49 (27.5)
I found this game very cumbersome to use.	36 (20.2)	30 (16.9)	57 (32)	36 (20.2)	19 (10.7)
I felt very confident using this game.	11 (6.2)	18 (10.1)	60 (33.7)	47 (26.4)	42 (23.6)
I needed to learn a lot of things before I could get going with this game.	52 (29.2)	36 (20.2)	50 (28.1)	22 (12.4)	18 (10.1)
Tabulated overall SUS score					
SUS score, Mean (SD)	61.9 (19.2)				
Score ≥ 68 , <i>n</i> (%)	69 (38.8)				
Score < 68 , <i>n</i> (%)	109 (61.2)				

The study also has limitations. Participants were recruited at only one regional primary care clinic where the median age group is 30–39 years, while median age of resident population in Singapore is 41.1 years.²⁴ Hence, the study participants were relatively younger and may have higher technology acceptance and adoption. This difference may limit the generalizability of the intervention effects to other regional primary care clinics or communities. The upscaling of the ‘Sam’s Mozzie Adventure’ in the rest of the community will need to be evaluated using implementation science to assess its reach, effectiveness, level of adoption and sustainability.

The participants were not blinded to the allocated group. Although the study was designed for the control group to be engaged in a similar IT related health education measure of accessing NEA ‘Stop Dengue’ website with the use of their mobile phone via QR code, it would still be apparent to the participants that they were not allocated to play serious game.

Systemic bias is unavoidable as participation was entirely voluntary among the study participants, which could also limit the generalizability of the study’s results.

Finally, the mean SUS score of the serious game was 61.8, signifying that majority of users had below average experience with its usability. This could have resulted in 21 participants (11.8%) in the intervention group who failed to complete the serious game. As this serious game was developed through a collaboration with only technology experts and healthcare specialists, opinions from the end-users (residents) were not included. The suboptimal SUS scores reflect the potential shortcomings in its design and delivery. Co-design with the target game users will be a key measure in the development of the next prototype. In addition, in-depth understanding of their barriers faced will be sought in the next phase of the trial using qualitative research method. Such an approach to integrate gaming and pedagogy will align to the co.LAB framework for its successful application in healthcare.³⁵

Implications in deployment of serious games in dengue prevention

As Singapore is one of the most wired countries and technological advanced Information Communication and Technology markets in the world, Singaporeans are highly connected, avid users of technology and voracious consumers of data.³⁶ With more than 90% of her population owning a smartphone and the push for digital engagement and transformation of healthcare in Singapore in the post pandemic era, serious game is a feasible option to deliver important health and disease preventive information to the masses while minimising physical contact with the health care professionals in a clinic setting. With its interactive features and an immersive story embedded with the relevant content knowledge and behavioural theory, serious game can enhance the user’s motivation to play the game and facilitate behaviour change endpoints.

As this is the first locally developed serious game in dengue prevention, refinement will be required to improve the perception of its usability and adoption among residents. Enabling gameplay in a variety of common languages and the addition of a voice-over are potential upcoming upgrades which can enhance the user’s in-game experience. The creation of an improved version of ‘Sam’s Mozzie Adventure’ in the near future will enable the local health authority to embed it in mobile applications, such as ‘Healthy 365’ and ‘LumiHealth’ to ease its dissemination to target users.^{37,38}

Conclusion

This randomised controlled trial shows that the KAP in dengue prevention of adults can be modified by introduction of serious game in the community. The effect of serious game is at least equally effective compared to conventional web-based learning in promoting dengue preventive measures and can be considered as a feasible alternative to digitally engage the masses. However, the usability of this serious game was below average in terms of user experience. In addition, the intention to vaccinate against dengue among adults did not show significant change with the use of serious game.

Nonetheless, this study provides a primer to guide local authorities and health officials to develop novel IT related health promotion strategies, such as serious games, to better engage its residents in improving health behaviours and outcomes of not only dengue prevention but also, possibly, other domains of disease prevention such as vaccinations and healthy lifestyle.

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Declaration of conflicting interests: The authors, AT, NCT, JT, CKG, are co-developers of the serious game, ‘Sam’s Mozzie Adventure’, which was evaluated for its effect in this study. The authors declare that there is no other conflict of interest in executing the study.

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