Study on Mobile Application for Earthquake Education Targeting Foreigners Intending to Visit Japan

Doctoral Degree Thesis

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Abstract

Japan is a country prone to various natural disasters. Strong earthquakes and possible resulting tsunamis are the most dangerous natural disasters in terms of unpredictability and destructiveness. Japan is exactly located in the Circum-Pacific Seismic Belt, making it susceptible to strong earthquakes and tsunamis.

Surviving a strong earthquake depends on people's preparation and behavior. People must acquire sufficient knowledge and skills to survive the next possible devastating earthquake. By receiving earthquake education, individuals can improve their survivability in strong earthquakes. Earthquake education teaches people how to prepare before earthquakes, and properly react when a destructive earthquake hits, as well as how to cope with the aftermath.

This study focused on earthquake education for foreigners who plan to study or work to Japan. With over 2.76 million foreigners currently living in Japan and a massive number of tourists each year, some never experienced earthquakes or know little about how to survive strong earthquakes. Such people may be in trouble if a strong earthquake occurs. Thus, earthquake education for foreigners living in or planning to visit Japan is critical.

This study focused on how to improve the earthquake education situation for foreigners to increase their survivability in severe earthquakes in Japan. The subjects of this study are foreigners planning to visit Japan, who should begin receiving earthquake education in their own country before arriving in Japan. Getting earthquake education in advance will strive for more learning time. Foreigners are expected to build awareness of the earthquake crisis and gain more opportunities to master the knowledge of earthquake survival and build confidence in surviving earthquakes in Japan. To achieve this goal, we proposed a learning model called "FOE+G." FOE means the Frequency of Occurrence of Earthquakes in Japan and is considered in this study as a type of arousal mechanism that enables the target group to be exposed to seismic information while triggering learning opportunities. G means gamification, which makes earthquake education more engaging and encourages foreigners to continue learning earthquake survival knowledge that they may ignore.

Based on the "FOE+G" learning model, a prototype system was developed to validate that the learning model improves earthquake education for the research subjects. Every time an earthquake that meets predetermined conditions occurs in Japan, the system sends seismic information notifications to the target group. The high frequency of earthquakes in Japan enables users to be fully exposed to earthquake hazard information, which helps in the development of earthquake awareness. A good earthquake awareness encourages the target group to better understand the importance of earthquake education and to participate more actively in it. Simultaneously, knowledge tips are attached to each earthquake notification, thereby creating a learning opportunity while understanding the details of the earthquake. Furthermore, considering the role of gamification in education, this study also adopted gamification. The application of game elements, such as points, badges, and daily attendance, as well as game mechanics, like reward mechanism, challenge mechanism, and achievement mechanism, are expected to make earthquake education more engaging and motivate users to learn.

An experiment revealed that the prototype system helped the target group in improving the earthquake education situation. The FOE worked to improve learning performance and master basic theoretical earthquake knowledge and skills, as well as increase participation and earthquake awareness to some extent. Gamification worked little on building earthquake awareness, but it did keep individuals motivated to learn for a longer period and improve learning performance. Overall, the learning model "FOE+G" and the related prototype system achieved the expected research goals.

Keywords: Earthquake Education, Foreigners, Earthquake Awareness, Earthquake Preparedness, FOE+G Learning Model, Cross-platform Application

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1 Introduction

1.1 Research Background

Various natural disasters occur every day around the world. However, in terms of human damage, earthquakes (possible resulting tsunamis) are the most dangerous natural disasters. According to the report from United Nations Office for Disaster Risk Reduction (UNDRR) [1], from 1998 to 2017, earthquakes of magnitude 6 or more accounted for approximately 23% of the total natural disasters, causing more than 700,000 deaths and more than 56% of total disaster-related death tolls. The occurrence of earthquakes cannot be accurately predicted, thereby making people's pre-earthquake preparedness vulnerable. Making perfect preparations in advance for the unexpected strike of strong earthquakes is impossible.

Japan is located right in the Circum-Pacific Seismic Belt, making it an earthquake-prone country. Every year, the Japan Meteorological Agency (JMA) reports approximately 2,000 perceptible earthquakes [2]. In history, dozens of strong earthquakes and even destructive earthquakes occurred. In addition, Japan's geographical feature of being an archipelagic country makes it highly vulnerable to tsunamis following strong earthquakes, which is also a key factor in causing severe damage. For example, the Great East Japan Earthquake (GEJE) (9.0–9.1 Mw) and subsequent tsunami resulted in missing and casualties of over 18,000, as well as extensive destruction of buildings and facilities, according to the National Police Agency of Japan (NPA) [3].

Based on the mentioned unpredictability and huge hazard of earthquakes, the work of earthquake risk reduction is critical. Global cooperation and efforts, such as the Sendai Framework for Disaster Risk Reduction, are underway. Researchers implemented many related works and structural measures in many earthquake-prone countries and regions. For example, the use of stronger and lighter build-

[1] https://www.undrr.org/publication/economic-losses-poverty-disasters-1998-2017
[2] https://www.data.jma.go.jp/eqev/data/bulletin/index.html
[3] https://www.npa.go.jp/hakusyo/r03/honbun/html/xf111000.html

ing materials, the construction of breakwaters to deal with possible tsunamis, earthquake-resistant construction, and evacuation shelters. This work can effectively improve the overall seismic capacity and reduce casualties and losses.

Only structural disaster countermeasures to save lives from devastating earthquakes are insufficient. People's ability to survive a strong earthquake depends on their level of preparedness and behavior. However, to survive the next possible devastating earthquake, people must acquire adequate knowledge and skills. Thus, earthquake education, as a type of nonstructural measure, is particularly important for individuals to enhance their ability to survive earthquakes. Implementing earthquake education is a more achievable goal than implementing expensive physical earthquake countermeasures, particularly in underdeveloped countries and regions. Earthquake education raises earthquake risk awareness and teaches how to respond to earthquakes properly, as well as deal with post-earthquake period. Earthquake education and disaster preparedness situations in developed countries are relatively satisfactory. For example, Japan exhibits a systematic earthquake education mechanism in place. Earthquake education and evacuation drills are held regularly, starting in kindergarten. Most Japanese demonstrate adequate earthquake knowledge and evacuation skills, and they can respond promptly if an earthquake occurs. Although Japan is earthquake-prone, the death toll is relatively low. In addition to national and government-level efforts in structural disaster prevention, comprehensive earthquake education contributes significantly too.

1.2 Research Needs

According to the publication of Immigration Services Agency of Japan (ISA) [4], Japan's foreign population exceeded 2.76 million as of December 2021. According to the Japan National Tourism Organization (JNTO) [5], more than 30 million tourists visited Japan yearly before COVID-19. After the COVID-19

[4] https://www.isa.go.jp/en/policies/statistics/toukei_ichiran_touroku.html
[5] https://www.jnto.go.jp/jpn/statistics/since2003_visitor_arrivals.pdf

pandemic, foreigners may keep swarming into Japan. However, many people living in non-earthquake-prone countries may demonstrate little awareness and experience with earthquakes and inadequate earthquake knowledge and evacuation skills. Such foreigners may not have survived strong earthquakes in Japan. Therefore, earthquake education should be provided to foreigners intending to visit Japan.

Japan has been working to provide disaster education to foreigners living in Japan, including earthquake education. Disaster lectures and evacuation drills are regularly organized by the government, universities, communities, and other organizations. Disaster information and prevention knowledge can also be obtained from handbooks, broadcasts, and television. Furthermore, research on how to improve disaster risk reduction and education for foreigners in Japan continues. Given the characteristics of foreigners, language barriers, busy work or study, and so on, earthquake education for foreigners still presentes gaps in some aspects compared to that of locals. Therefore, the implementation of earthquake education for foreigners is still critical, and it is an indispensable part of improving the entire disaster risk reduction (DRR) ecosystem in Japan. Research status and gaps will be discussed in detail in Chapter 2.

1.3 Research Flow

The research followed the methods of pre-research, design, development, and verification. Figure 1 shows the flow of the four research phases.

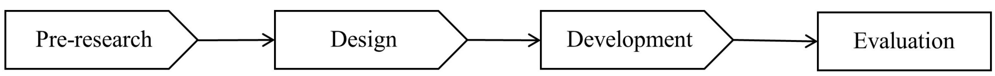

Figure 1: Research flow

1. Pre-research

The steps in this phase are as follows: 1. Preliminary research plan; 2. Research status review; 3. Research needs evaluation; 4. Research topic confirmation.

After setting the initial research topic, to assess the feasibility, preliminary research work was conducted. Research methods were questionnaires, formal or informal interviews, reviews of research work and literature, and so forth. Collecting data and reviewing related materials can help to understand the current research status of the intended research field and obtain specific user needs, as well as determine possible gaps or deficiencies in existing research and how to compensate for this weakness, that is, the research topic. In short, in the pre-research phase, the problem of "what to do" must be solved.

In this research, the outputs of the pre-research phase should be used as follows: identify the research topic, determine the target group, and set the research goals.

2. Design

The following conceptual work will be completed in the design phase based on the pre-research phase outputs: selection and design of research methods, setting and design of research questions, the design of research content, the design of the model, selection of developing technologies, and design of verification method. That is, the problem of "how to do" will be theoretically completed in the design phase.

3. Development

Based on the research goals, the development phase will realize the outputs of the design phase.

In this research, the development phase follows the basic process of development, which is design, implementation, and testing.

4. Evaluation

It is the process of evaluating the research work using certain methods to ensure that the research work achieves the expected research goals.

To verify this research, an experimental method was used. After the experiment, to determine whether the established research goals have been achieved, the experimental results and discussions can be used, thereby verifying the research work.

1.4 Dissertation Structure

The dissertation is organized in 6 chapters, the remainder is organized as follows.

Chapter 2 introduces the pre-research phase. In this chapter, disaster education and its roles are presented from a wider perspective because of a literature review. The current situation of earthquake education for foreigners and locals in Japan is compared and possible weaknesses or gaps existing in foreigners' earthquake education are revealed. Finally, in this section, the refined research topic and target group are identified.

Chapter 3 introduces the design phase. In this chapter, selected research methods and designs, including the application of ICT in earthquake education, are presented. Research goals are set, and research questions are proposed. Next, to achieve these research goals, a learning model was designed.

Chapter 4 introduces the development phase. In this chapter, requirement analysis, application architecture design, and module design of the developed mobile application, as well as user interface screenshots, are presented.

Chapter 5 introduces the verification phase. In this chapter, an experiment selected as the verification method is explained. The experimental data, such as the application usage log and questionnaires, are analyzed to determine whether the application works to achieve the research goals.

Chapter 6 includes the conclusion and future work. In this chapter, the research is summarized, and the results are introduced. Furthermore, some future work is introduced.

And followings are bibliography and publications.

2 Earthquake Education for Foreigners: Status Quo and Issues in Japan

The initial research idea was to improve the earthquake education situation for foreigners in Japan. The main research method in the pre-research phase is a review of related research works and literatures.

2.1 Categories and Definitions

Related definitions and categories in the research are obtained, mainly from UNDRR.

1. Disaster Risk Reduction

   Disaster Risk Reduction (DRR) refers to the concept and practice of reducing disaster risks through systematic efforts to analyze and manage disaster causal factors, such as reduced exposure to hazards, lessened vulnerability of people and property, wise land and environmental management, and improved preparedness for adverse events. If not otherwise specified, in this study and thesis, the term “disaster” refers to a “natural disaster.”.

2. Disaster Preparedness

   Disaster preparedness (DP) refers to the knowledge and capacities developed by governments, professional response and recovery organizations, communities, and individuals to effectively anticipate, respond to, and recover from the impacts of likely, imminent, or current hazard events or conditions. In short, the term “Readiness” refers to a high level of preparedness and the ability to quickly and appropriately respond when required. While considering experiences from mega earthquakes in Japan, the international standards for DP were created as the Hyogo Framework for Action (HFA) or Sendai Framework for Disaster Risk Reduction (SFDRR).

3. Earthquake Preparedness

Earthquake preparedness (EP) is a part of DP, with the same definition and specific scope of only earthquakes.

Under the situation that earthquakes occupy a large portion of total disasters, the importance of EP is self-evident in Japan.

4. Disaster Education

   Disaster education (DE) essentially refers to DRR education. A study proposed three conceptualizations of DE based on temporal distinction, modes of learning and teaching, and a sub-discipline in the education field [1]. DE is a type of nonstructural measure to raise the level of DP and a central means of DRR for pre-disaster prevention and preparedness.

5. Earthquake Education

   Earthquake education (EE) is a subset of DE.

   EE is an essential means to improving public EP. In a nutshell, it teaches individuals how to increase their EP for possible unpredictable strong earthquakes.

   In this study, individual EP is divided into two parts, psychological preparedness and behavioral preparedness.

6. Psychological Preparedness

   Psychological preparedness is a psychological state of understanding the devastation of strong earthquakes and attempting to mitigate adverse effects, that is, building earthquake crisis awareness.

7. Behavioral Preparedness

   Behavioral preparedness is the state of mastering earthquake survival knowledge and skills, preparing emergency kits, well-knowing evacuation, and so on.

2.2 Earthquake Knowledge

Within a smaller semantic scope, common earthquake knowledge can be divided into three parts pre-, in-, and post-earthquakes from the phase perspective.

1. Pre-earthquake knowledge

   This includes building fine earthquake awareness and learning to prepare emergency kits, checking and fixing easily falling objects in the home, keeping smooth space to the door, getting familiar with the evacuation route, and practically drilling.

2. In-earthquake knowledge

   This includes responding correctly when an earthquake occurs, learning to take corresponding behaviors in different scenarios to ensure self-safety first, correctly handling possible secondary disasters after the shaking stops, and following the instructions to quickly evacuate to a shelter when receiving tsunami warnings.

3. Post-earthquake knowledge

   This primarily focuses on how to smoothly spend the shelter life after the earthquake, such as learning how to use various emergency supplies, how to help oneself and each other, how to avoid possible disaster epidemics, and how to reduce stress reactions to maintain mental health.

The above knowledge is expected to be mastered after participating in EE. In this study, EE covers two aspects, which help to build solid earthquake awareness and deliver basic earthquake survival knowledge. Furthermore, considering Japan's geographical characteristics, strong earthquakes are likely to induce tsunamis, which are also extremely destructive. Between 1900 and 2012, 90% of tsunamis in Japan were caused by earthquakes [2]. Therefore, in this study, EE covers the category of tsunami education. The categories and relationships between these items and the definitions are shown in Figure 2.

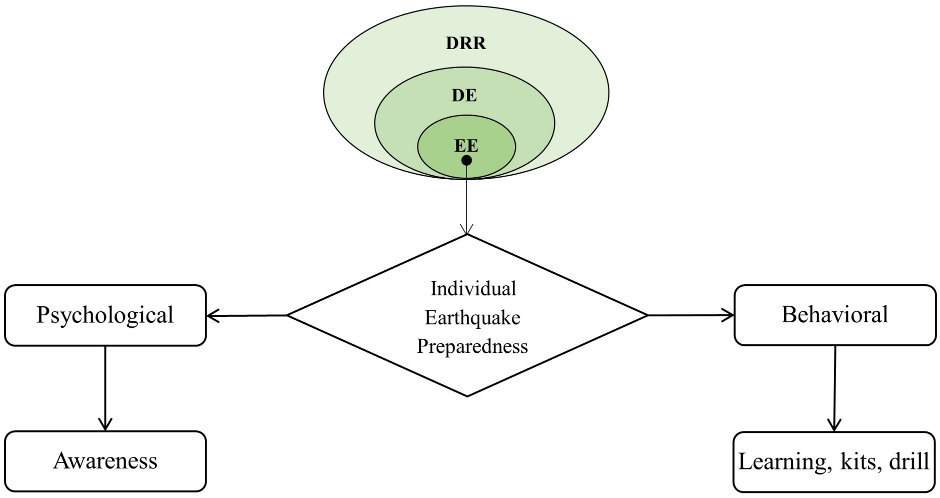

Figure 2: Categories and relationships

As shown in Figure 2, EE and DE share the same policy support and semantic definitions in many aspects under the DRR framework. For better contextualization, this thesis does not strictly split DE and EE, even though the research mainly focuses on EE.

2.3 Cases of EE

High levels of EP can greatly reduce casualties when suffering an unexpectedly strong earthquake. Disaster risks, such as earthquakes, can certainly be minimized by disseminating valid and reliable knowledge of such disasters to both personnel involved in disaster management and the public. Sharing such knowledge will help citizens better understand the risks they might be exposed to and consequently better protect themselves against disasters [3]. The 2010 Canterbury earthquake exhibited a Richter scale of 7.1 and a focal depth of 10 km, and it affected 300 thousand people in New Zealand. No fatalities occurred (from UNDRR) because of the high building seismic standards and public EP. The 2016 Kaikoura Earthquake with a magnitude of 7.8 (Mw) in the South Island of New Zealand resulted in 2 deaths and 618 medically treated injuries, a relatively low casualty for the intensities (as high as MMI9) observed in such a large earthquake [4]. Nonstructural measures, including EE, also contribute greatly. In comparison, the 2010 Haiti earthquake resulted in huge casualties due to exposure to fragile DRR environments (from UNDRR). Participating in tsunami drills in advance of catastrophes can significantly facilitate evacuation behavior. The planning and execution of disaster drills to promote effective evacuation behavior in schools, workplaces, and municipalities is critical [5]. A study compares two countries with highly similar natural disaster situations, Japan and Indonesia, in which the trend of the average death and missing (D&M) from tsunamis in Japan exhibit a declining trend, whereas in Indonesia it shows an increasing trend. Besides structural measures, the author attributed the reduction in D&M and related losses to the high level of EE and training in Japan [6].

The best case of the role of EE is the “Kamaishi Miracle.” In the catastrophe of 2011 Great Earthquake in Japan East (GEJE), approximately 1,300 people died or went missing in Kamaishi City, Iwate Prefecture. Also, the Unosumai district was devastated by the tsunami. However, approximately 570 children and students from Unosumai Elementary School and Kamaishi Higashi Junior High School in this district were evacuated safely. This is called the “Kamaishi Miracle.” It was not because the children were simply lucky but because the children who learned about disaster prevention education that was practiced daily in this area did what they normally do [7].

EE is a top priority, particularly in Japan. Japan, as one of the countries with the most severe situation of earthquakes and tsunamis, exhibits good earthquake resilience. The national earthquake crisis awareness nurtured over a long disaster history and high-level EP also contribute greatly. However, many foreigners in Japan are in an unsatisfactory situation with EE. Also, some researches and surveys revealed a similar situation. In a later section, a detailed explanation is provided. With a resident foreign population of more than 2.7 million and an annual tourist population of more than 30 million yearly, the significance of strengthening foreigners’ EE is obvious. In addition, even though earthquakes cannot be accurately predicted at present, related research is progressing. According to a report on the “Estimation of damage in the event of an earthquake directly hitting Tokyo” [6], the probability of an earthquake of magnitude 7 or higher in the Tokyo Metropolitan area is up to 70% in the next 30 years, and a mega-earthquake of magnitude 9 or greater (70%–80%) may occur in the Nankai Trough. This situation necessitates the implementation and improvement of EE for foreigners.

Based on the above statement, this study assesses EE in Japan, targeting foreigners to improve their EE situation and to raise individual EP levels.

2.4 Literature Review

To assess the feasibility of this study, a review of relevant research work and literature was performed.

2.4.1 DE for Japanese

The level of DE (including earthquake and tsunami education) in Japan is highly systematic and comprehensive. Several relevant DRR studies cover aspects of reducing disaster losses. Much attention has been paid to vulnerable groups, the elderly, children, women, foreigners, and so on, to increase their disaster resilience. Also, related researches covered different functional fields, such as tourism, medicine, and education. From policy frameworks, such as HFA and SFDRR to government efforts and from community-based to individuals, a relatively completed DE ecosystem has been established.

Several studies on disaster-vulnerable groups, the elderly, children, and women have been conducted to reduce their vulnerability and improve personal resilience [8] [9] [10].

Research on disaster reduction covered various industries, such as the medical industry and tourism, to improve disaster awareness and enhance disaster reduction capabilities [11] [12].

[6] https://www.bousai.metro.tokyo.lg.jp/_res/projects/default_project/_page_/001/021/571/20220525/n/001.pdf

Community-based DRR (CBDRR) is the core of any risk reduction approaches. Disaster risks exhibit local and specific characteristics that must be understood to devise measures that reduce disaster risk [13]. Schools and staffs play a critical role in DRR. DRR education and management is currently of high relevance in schools, not just in Japan but globally. A study project known as YUI was used to develop a motivational typology of DRR education. A DRR lesson has been delivered to approximately 310 schools and over 18,000 participations, including students and teachers. Even though schoolteachers are engaged only for a short time in DRR education in schools, they are always the main players in school DRR education [14].

Governments and research institutes publish DRR information and knowledge, as well as hold DRR lectures and activities in factories, companies, communities, schools, and other places. Following the 2011 GEJE, several studies emerged to fill in the shortcomings and weaknesses exposed by this huge disaster. In Japan, a relatively systematic and complete DRR ecosystem has been built from top to bottom and organization to individual, covering age levels, gender, functional areas, and various natural disasters.

2.4.2 DE for Foreigners in Japan

Several DE courses for foreigners, including EE, have been performed. Various disaster information is delivered timely to foreigners through TV, radio, online news, social media, and so forth. Next, DE lectures for foreigners are held in communities and schools. Sometimes, evacuation drills are also available.

To disseminate disaster information in Japan, the Cabinet Office created explanatory materials in 15 languages, which are available when conducting disaster prevention drills and training for foreigners [7].

To identify sources of vulnerability and disaster management lessons, a study was performed on the response of international students at Tohoku University's School of Engineering in 2011 GEJE. The results show that deeper links with

[7] https://www.bousai.go.jp/kokusai/training.html

Japanese society influence behavior after a disaster and can positively influence future reactions during the extended phase of a similar emergency. In theory, helping students to integrate more with Japanese society might also improve their decision-making during a crisis [15]. In disaster times, knowledge-sharing barriers for international residents are reported as a limited relationship with the local community and Japanese proficiency [16]. Henry and Kawasaki reported that foreigners living in Japan faced confusing and conflicting messages from different information sources [17] [18] [19].

A study revealed that international students at Utsunomiya University were better prepared for disasters than their Japanese peers living alone. However, they exhibited less disaster experience and knowledge. To a much lesser degree than their Japanese counterparts, they were familiar with local evacuation shelters and hazard maps. International students who only just arrived in Japan might be more vulnerable in terms of their lack of experience regarding disasters. Universities should encourage their international students to be involved in seminars and training. Alternatively, to enhance their knowledge of disasters, they can provide their students with information, workshops, and seminars [20]. Although an extensive body of research exists examining the DP behavior of the general public in Japan, only a handful of studies examine its foreign resident population. A study investigates the extent to which foreign residents in Japan engage in disaster prevention activities, as well as possible reasons for any differences. The influence of Japanese language ability, nationality, and demographic factors on family DP behavior was analyzed. Results reveal that participation in disaster training and exposure to disaster information play a significant role in promoting foreign household DP behaviors [21].

2.5 Evaluate Research Needs

Although DRR education in Japan is at a high level, the 2011 GEJE and tsunami exposed some problems, resulting in a new boom in DRR research. To fill the revealed gaps, relevant studies including studies aimed at foreigners in Japan emerged.

Table 1 shows a simple comparison of DE status between Japanese and foreigners after filtering and reviewing related literature, including those referenced above.

Table 1: Comparison of research status between Japanese and foreigners

Feature	**Japanese**	**Foreigner**
Disaster category	Full coverage	Earthquake, Tsunami, Typhoon
Starting time	Kindergarten	After landing
Nature	Compulsory	Non-compulsory for adults
Target group	All people	International students, resident, visitors
Stage	All stages	preparedness reaction
Level	Policy, community, individual	Policy, community, individual
Functional field	Full coverage	Mainly in education, tourism, resident

The table shows that DE coverage for foreigners in Japan is quite complete. The Japanese government and society strive to provide nondiscriminatory DE for foreigners. Despite Japan's top-down great efforts, from the support at the policy level to the implementation at the level of community, school, and factory, the situation of DE for foreigners is still not as satisfactory as local people. Also, studies revealed some weak points in the DE situation for foreigners in Japan presently. The main problems are listed as follows:

1. Busyness

   Most adult foreigners in Japan either study at universities or work. Because of their busy schedules, DE is often overlooked, despite the importance of knowing them. Sometimes a lecture or exercise takes so much time that busy people may give up attending.

2. Not mandatory

Unlike compulsory education students and young children, who regularly participate in DE, non-compulsion is sometimes a reason for low participation.

3. Language issues

   For many foreigners who just arrived in Japan, Japanese remains a barrier to receiving information, and other languages, such as English and Chinese, are provided in DE. However, for some foreigners, language is still a barrier to participation in DE.

4. Insufficient communication with local communities

   Foreigners exhibit a low level of connection to the community and neighbors, as well as a willingness to participate in community DE and drills. For example, some international students are more dependent on their university or friends from the same country during and after disasters.

5. Low level of disaster awareness

   Many people from non-earthquake countries never experienced earthquakes or experienced an earthquake for the first time in Japan, so they have not built good earthquake awareness. Even knowing that “Japan is a country prone to earthquakes” remains a relatively abstract concept, and insufficient motivation exists to learn what type of preparations should be made for earthquakes.

6. Less exposure to disaster information

   As mentioned, many people demonstrate no earthquake experience or sufficient earthquake knowledge before coming to Japan. They cannot get enough detailed Japanese earthquake information in their own countries, although large earthquakes, such as the 2011 GEJE, have also been reported.

7. Normalcy bias

It is a cognitive bias that leads people to dismiss or minimize threat warnings and refuse to plan for or react to a disaster that never happened before. Consequently, individuals underestimate the likelihood of a disaster and its potential adverse effects. The normalcy bias causes many people to not adequately prepare for natural disasters. Normalcy bias exhibits a prevalence and harmful influence on disaster management by underestimating the probability of the disaster or the disruption involved in it [22]. This study does not address this bias because it is attenuated with increasing levels of disaster education.

Some factors are not isolated but demonstrate certain internal correlations. The correlations are sorted out as shown in Figure 3.

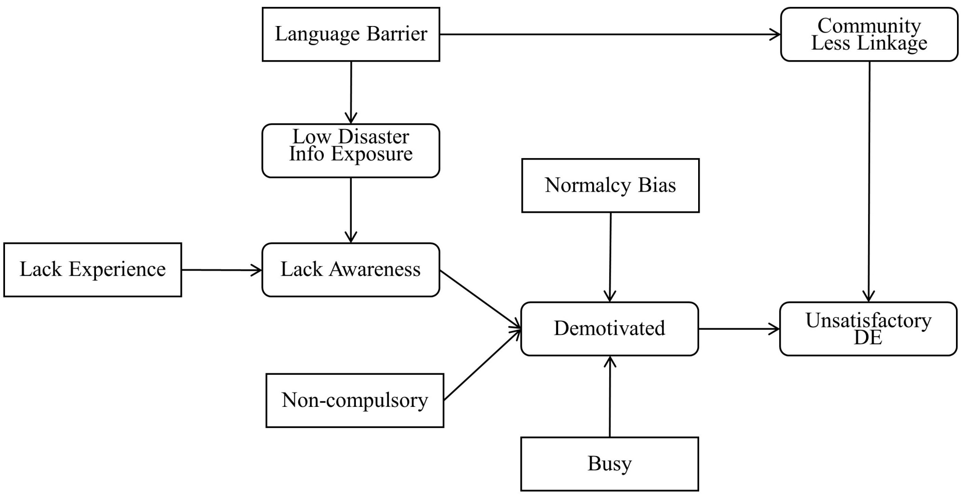

Figure 3: Factors and internal correlations

Rectangles refer to independent factors, and round rectangles mean dependent factors that are affected by independent factors. The direction of the act is indicated using an arrow. Language barriers, for example, can partly lead to little community outreach, inadequate exposure to disaster information, and unreliable information sources (Figure 3). Insufficient exposure to disaster information is part of the reason for the lack of disaster awareness. Normalcy bias demotivates participation in disaster education. In addition, busyness and noncompulsory are reasons for the lack of motivation to engage in DE.

Tracing back from the result, that is, unsatisfying DE, the influencing factors are finally attributed to four main factors: 1. Language barrier; 2. Insufficient disaster experience; 3. Busy schedule; and 4. Noncompulsory DE for foreigners in Japan. Among them, whether setting some compulsory DE for foreigners is a policy-level issue in Japan; however, trying to make the DE more engaging may offset the negative impact. Consequently, research is needed to determine how to overcome these negative factors existing in foreigners' DE situation. In summary, research must focus on four research needs as follows:

RN1. Break the language barrier.

RN2. Shift the time in their own countries as learning opportunities instead of their busy situation in Japan.

RN3. Increase learning opportunities that are meaningfully related to disasters in the real world.

RN4. Make DE as attractive as possible to motivate learning because DE entails serious topics (for example, death).

RN1 can be satisfied by providing a system that supports multiple languages. RN2 can be satisfied by providing foreigners with learning opportunities before visiting Japan. These RNs are fundamental from this research's standpoint (policy):

Standpoint for RN1: Aim at developing a system that supports multiple languages.

Standpoint for RN2: Aim to develop a system that enables foreigners to learn easily when they live in their home countries or areas.

From these standpoints and the realities of global situations such as language population and smartphone spread, a mobile (smartphone) system supporting multilingualism was developed to satisfy RN1 and RN2.

Regarding RN3 and RN4, RNs should be satisfied by the mobile application.

However, these supporting functions should be implemented carefully in the application and assess whether the research expectations can be achieved based on the supporting functions.

2.6 Identification of Research Topic

The research topic is identified on the basis of the literature review and research needs: improving the EE situation for foreigners who intend to visit Japan. The research content is EE, which shortens the entire education process and is convenient for busy foreigners. The target group was foreigners intending to visit Japan. Intending means starting EE in your own country before landing in Japan, which is another approach to relieve the situation of EE that may be neglected because of a busy schedule after arriving in Japan. Next, multilingual support is a basic need in this study. Gamification is introduced to make EE more engaging. The research covers all research needs, and how to meet the research needs and achieve the expectations of the research topic is explained in detail in the following chapters.

Unlike most existing research, this study focuses on EE, where foreigners acquire earthquake knowledge before arriving in Japan. The current education occurs after arriving in Japan, which may conflict with their busy schedules. Most adults who have just arrived in Japan attend colleges or work. Busy study or work, as well as the need to adapt to the new environment, may make them at a loss, resulting in neglect of DE. In this study, the implementation of EE is advanced before arriving in Japan, that is, foreigners who intend to come to Japan start receiving Japan-related DE when they are in their own country. In a relatively stable period before arriving in Japan, receiving EE in advance can gain ample study time. In addition, mastering adequate knowledge of earthquake survival in advance enables the target objects to be more confident in dealing with possible strong earthquakes in Japan.

Furthermore, in this study, enhancing individual earthquake awareness is emphasized. Earthquake awareness is an integral part of EE. Individual earthquake awareness is the commonsense level of reducing earthquake exposure and vulnerability, and it is a critical factor in effective earthquake risk reduction.

In summary, according to the research topic, two research goals are set to access the improvement: RG1. help the target group to build earthquake awareness in advance; RG2. help the target group to master core earthquake survival knowledge in advance.

3 Research Designs

The research topic identified in the pre-research phase is to improve the EE situation for foreigners who intend to visit Japan. It includes the following three key points:

KP1. Target group: foreigners intending to visit Japan

KP2. Research content: earthquake education (EE)

KP3. Research goals: improve earthquake education (earthquake awareness and knowledge)

To achieve the four research needs (RNs) mentioned in the pre-research phase, designs must cover these key points.

3.1 Use of ICT in Disaster Education

Implementing Japan-related EE for the target group in their own country means that earthquake education is remote without space limits. ICT is considered to achieve this.

ICT-based systems are not new stuff in disaster (including earthquake) education and prevention [23]. In recent years, ICT was critical to DE, benefiting from the increasing popularity of the internet and affordable electronic equipment. ICT-based DE, as a complement to conventional methods, demonstrates advantages in terms of accessibility, traceability, personalization, knowledge sharing, user experience, and more. ICT was mainly used in the form of PC, mobile (smartphone/tablet-based), and virtual/augmented reality (VR/AR) applications.

3.1.1 PC Applications

Japan is a pioneer in exploring ICT in DE. Even back in 2008, an interactive disaster simulation system for DE, known as DIGTable, enabled users to interact with maps or Geographical Information System data to learn more about their towns [24].

Currently, many international students with uneven earthquake crisis awareness and knowledge are studying in Japan, and video-based learning is a popular approach for delivering disaster education. However, filtering meaningful information in long videos is time-consuming. A user-responsive video learning tool supports dividing long videos into meaningful chunks for faster skimming and re-watching, as well as determining students' preferences/attention and retention processes within the video parts, which helps conduct DE among international students [25].

3.1.2 Mobile Applications

With the popularization of smart terminals, mobile applications emerged in DE.

Mobile applications in DE enable knowledge to be accessed anywhere and anytime because of the popularity of mobile devices and the Internet. With the wide acceptance of social media among young people, an application with the help of Twitter conducts disaster prevention and mitigation education among them [26]. Children are a vulnerable group in earthquakes; consequently, enhancing EE for children is critical. A mobile learning application is available for children to improve their EE via an interesting game-based method [27].

To enhance the traditional evacuation drill, a study developed a mobile application prototype as an educational tool in a drill exercise. And experiment results in this study showed that the decisions of route selection were improved, and the application prototype allowed the participants to understand their risk [28].

A program targets children with limited memories/experiences of the disaster and is based on the issues of DRR education in tsunami-affected areas, which is a learning program to educate children about the risks of an earthquake-related tsunami and impart disaster response skills to enable children to make decisions and evacuate in the event of a tsunami [29].

3.1.3 VR/AR Applications

In recent years, simulation systems have gained increasing attention and played a role in DE because of the development of VR/AR technology. Using VR/AR technology and some wearable intelligent devices, some systems can simulate disaster scenarios. For example, the system simulates earthquake scenarios to assist evacuation drills [30]. Next, earthquake safety training through virtual reality devices has been designed to teach individuals how to survive earthquakes in common indoor environments [31]. Tsunamis claim the lives of many coastal residents every year. Therefore, to survive a tsunami, tsunami evacuation drills are important for coastal residents. A tsunami evacuation drill system enables the simulation of tsunami scenarios and evacuation tasks using mobile devices, as well as evacuation route records and traceback [32].

Compared with traditional evacuation drills, such systems create an immersive experience for users, making drills less time-consuming. Furthermore, some systems support the traceability by logs or other types of records. In the case of failure, to determine the cause and to make improvements, the evacuation drill process can be traced back.

3.1.4 Use of Mobile Applications

By using ICT, remote EE for the target group can be achieved. A mobile system is designed to support the target group and start EE when they are still in their own countries. The mobile system is designed in the form of a cross-platform application, that is, it supports both iOS and Android mobile operating systems because they are widely accepted.

ICT-based remote EE enables EE in advance, achieving EE in a relatively stable period before arriving in Japan, and starting education in advance can gain more ample time, which meets the research need RN2, that is, help in improving the situation of ignoring EE because of busyness after arriving in Japan.

3.2 Research Content Design

The research content design must consider the following reasons.

3.2.1 Targeted Knowledge

Given that the target group does not live in Japan, the research content design focused on filtering and presenting core earthquake and tsunami survival knowledge from a large number of learning materials, for example, to react properly during a strong earthquake in various scenarios, the principle of "Drop, Cover, Hold on," to know the possible dangerous items in the room and to understand emergency kits. More practical skills, such as preparing emergency kits, consulting building anti-seismic standards, handling dangerous items, fixing fall-prone objects, and participating in evacuation drills, which are what must be done after arriving in Japan, are not the focus of this study. The practice can be done in advance in home countries. However, some of the knowledge and rules may not apply to other countries and regions considering that this study is based on the earthquake situation in Japan. If any conflicts or differences are found, the local principles will prevail.

This study focuses on only EE. Considering the time cost, the content design abandons the theoretical knowledge about the causes of earthquakes and tsunamis and retains only the kernel part, which is knowing the huge destructiveness, preparing for unpredictable earthquakes and tsunamis as much as possible, responding properly and quickly, and going through post-earthquake. The intention of this study is to narrow the scope, filter, and deliver earthquake/tsunami survival knowledge more accurately.

The targeted knowledge is presented in various forms, picture, text, link, video link, quiz, to meet different user preferences. In addition, except link and video link, types of text, picture, and quiz are organized into small pieces. This mode enables flexible learning time for long-time or fragmented learning. A brief knowledge point even can be mastered in a few seconds.

3.2.2 Targeted Languages

Furthermore, considering the implementation of EE for foreigners, multilingual support is required (RN1). Among the foreigners in Japan, the main groups include Chinese, Vietnamese, Filipinos, and Koreans. Taking into account the proportion of the population, Chinese and English can cover more than half of the foreign population. Therefore, the minimum multilingual set must include Chinese and English. Also, in the follow-up plan list, other foreign languages in a larger proportion are included.

Earthquake and tsunami information comes from JMA, and educational knowledge mainly comes from Japanese official portal websites at all levels, ensuring the credibility of disaster information sources to a certain extent.

Overall, the content design follows the principles of usefulness, simplification, diversity, and user orientation. The design of the research content aids in breaking down language barriers (RN1) while avoiding low-credibility sources of information.

3.3 Learning Model Design

To achieve RN3 and RN4, a learning model is designed. The structure of this learning model is shown in Figure 4

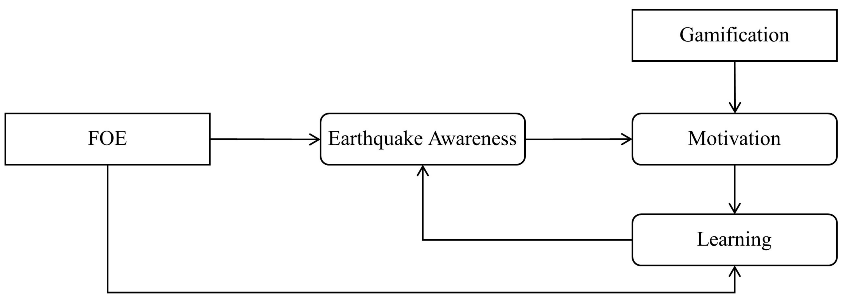

Figure 4: Learning model structure

The learning model includes five elements, namely, Frequency of Occurrence of Earthquake (FOE), earthquake awareness (EA), gamification (abbreviated as G), motivation, and learning (knowledge acquisition). Among them, FOE and gamification belong to the independent parameters and the others are dependent parameters. Arrows represent the direction of the "effect." For example, FOE works on EA, and EA helps to create motivation. Gamification works to generate motivation. Motivation works on learning, propelling better learning performance. FOE also directly helps to learn. The conceptual explanations of these five elements are provided as follows.

3.3.1 FOE

In this learning model, FOE is an arousal event of earthquake crisis with the following logic: Earthquake Occurrence ->Notifying Earthquake Reality (in Japan) ->Arousing awareness. Videlicet, every time an earthquake occurs, the reality (earthquake occurrence) is delivered to the target group, and earthquake awareness gets awakened. This process is called an arousal event, that is, FOE.

As mentioned above, an important factor affecting the EE status of foreigners is the lack of earthquake experience, which produces the research need for RN3. For the target group in this research, who are foreigners planning to visit Japan and still living in their own countries, no way exists to enable them to experience the earthquake situation happening in Japan. FOE is expected to meet the research need for RN3. FOE can create a near-real earthquake scenario of Japan for the target objects who do not live in Japan. The frequent occurrence of earthquakes in Japan leads to intensive FOE, converting "Japan is an earthquake-prone country" from an abstract concept to dense arousal events. Next, timely and dense earthquake information enables a clear understanding of the real earthquake situations in Japan. Even if the real shaking is not experienced, exposure to sufficient earthquake information will gradually change research objects' psychological tendency toward earthquake crisis and aid in establishing earthquake crisis awareness.

The FOE is a type of motivation source for learning in this model. It is currently presented mainly in the form of notifications in the prototype application. In addition to earthquake information, the notification comes with a tip of knowledge of learning material, being a URL, a choice question, or a picture. the tip or link carried makes every FOE simultaneously a potential learning opportunity. Intensive earthquake information creates a situated learning environment where target objects are under high relevance and pay great attention, enabling effective learning. However, with the intense earthquake information comes negative emotions, such as anxiety or disgust, which can demotivate people. To maintain a balance between effectiveness and negative sentiment, a threshold and a filtering mechanism are used. In the development phase, the concrete design and implementation are completed.

3.3.2 Gamification

It is defined as the use of game-design elements in non-game contexts [33]. Also, it is defined as using game elements and game-design techniques in non-game contexts [34]. In brief, gamification is learning from games, learning what makes the games successful and engaging, and then applying some of those techniques to nongame fields. Gamification has been extensively used and proven its effectiveness in many fields, including business, medicine, and health, as well as education.

Education or learning is one of the most commonly gamified contexts, with gamification commonly used to increase the fun and make learning more engaging. In a gamification-learning environment, learners may feel motivated and pulled back into the learning environment. The gamification strategy used in the online learning environment shows a positive influence to support learner's self-directed learning [35]. A literature review of forty related articles from 2016–2021 concludes that the use of gamification plays a significant role in improving student learning outcomes, imposing effects on students' engagement, motivation, interest, enjoyment, satisfaction, and innovation in learning activities [36].

Gamification has also been applied in disaster management and education [37]. Implementing gamification in DE can complete the solution to fulfilling the disaster planning process for residents. Gamified mobile application employed for flood emergency planning shows that gamification can increase user effectiveness in terms of time spent on information and knowledge about disaster risk and DP [38]. Gamified applications related to disasters are efficient modes for raising community disaster awareness. The possibility of using gamified applications to increase community awareness through virtual platforms is emphasized, with relatively less space, cost, and time-consuming environments [39]. Further, a study was conducted to evaluate the effectiveness of EP training courses through gamification in a virtual reality environment on students' knowledge levels. The results show that students taking part in gamification courses demonstrated better related knowledge than other students who received educational lectures and watched movies [40].

In Japan, DE for foreign adults, including EE, is more likely ignored because it is not compulsory and often results in serious topics, despite knowing the importance. This situation results in the research need for RN4. Although decision-making cannot be made at the policy level, keeping individuals motivated can minimize the negative impact of noncompulsory disaster courses. Under this premise, gamification is introduced into the learning model.

Gamification is expected to make EE more engaging and encourage active participation. It is another motivation source for learning in the model, which is expected to meet the research need for RN4.

In this section, a conceptual description of gamification is provided, including its definition and purpose. In the development stage, a tangible system based on this learning model is designed and developed. The selection and usage strategies of game elements and mechanics are introduced in detail.

3.3.3 Earthquake Awareness

The extent of common knowledge about disaster risks, the factors that lead to disasters, and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards is referred to as public disaster awareness (from UNDRR). Earthquake awareness, as a subset of disaster awareness, can easily replace the scope of a disaster with the earthquake in the definition of contextualization.

Public earthquake awareness can be showcased from individual and institutional levels. This study focused on individual earthquake awareness fostering. Earthquake awareness, including the psychological need for earthquake risk aversion, is a key factor in effective earthquake risk reduction. It may affect the attitudes and behaviors toward EE and promote better learning engagement. Awareness and perception of risk are among the most crucial steps in the process of taking precautions at an individual level for various hazards [41] [42].

In terms of earthquake disaster prevention, EE to raise awareness of earthquake disasters is a critical issue. For foreigners intending to visit Japan, it is also an important prerequisite for improving the EE situation to be equipped with earthquake awareness. Solid earthquake awareness imposes a long-term impact on stimulating participation in EE, allowing the target objects to be motivated for a long period and raising self-directed learning levels. Accordingly, helping foster earthquake awareness is one of the research goals.

As shown in Figure 4, the elements "FOE" and "Learning" work on earthquake awareness. These two elements are called information exposure and knowledge exposure, respectively. The formative process of earthquake awareness is shown in Figure 5.

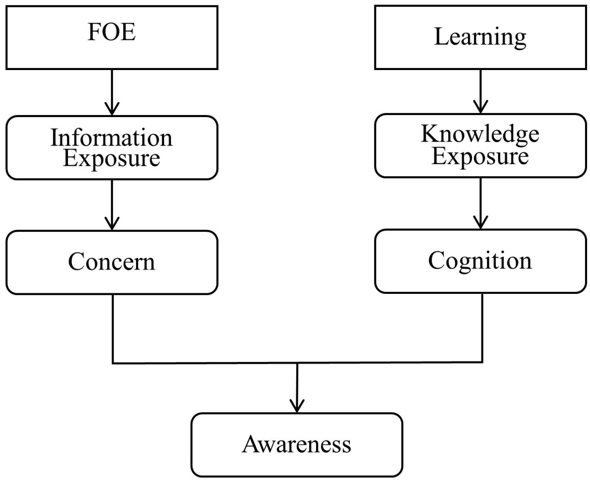

Figure 5: Formative process of earthquake awareness

Figure 5 shows that there are two branches. One is from ‘FOE,’ that is, the element ‘FOE’ in the learning model in Figure 4, called information exposure. Another is from ‘Learning,’ that is, the element ‘Learning’ in the learning model, called knowledge exposure.

Under the information exposure branch, the target group plans to visit Japan, so earthquakes occurring in Japan are related to their self-safety, triggering their concerns.

Under the knowledge exposure branch, the target group learns about earthquake knowledge. The more they learn, the better cognition to earthquakes they have.

In these two branches, earthquake and knowledge exposures appear repeatedly, which gradually improves the cognition level of earthquakes and induces a psychological tendency to avoid disasters, such as earthquake awareness.

3.3.4 Motivation

In this learning model, the elements motivation is a type of driving force to encourage better learning performance.

Several studies and literature show that the role of motivation in learning behavior is beyond doubt. EE, as a special sub-discipline in the educational field, also needs motivation to propel learning performance. The element "Motivation" in this model, in brief, refers to the enthusiasm and initiative to participate in EE. In this study, motivation comes from earthquake awareness and gamification (Figure 4).

As mentioned above, earthquake awareness is a type of crisis awareness, which is the level of cognition to earthquakes and ensuing hazards, as well as the resulting psychological needs for earthquake risk aversion. This need belongs to the safety need, which is a basic need of human beings [43]. Needs are the root of motivation. The target group is planning to go to Japan, so correlation generates between the earthquake situation in Japan and the target group. According to this correlation, the more one's understanding of earthquakes and hazards, the higher one's expectations for earthquake risk avoidance and thus the need for ensuring one's safety. The safety need prompts the force to seek methods and approaches to avoid risks, resulting in motivation.

Gamification is another source of motivation. How gamification leads to noticeable benefits is still unclear. Some research attempted to explain this from a theoretical basis. Besides the most common SDT, a study shows many other motivation theories, such as Achievement Goal Theory, Situational Relevance Theory, the ARCS motivational model, and Flow Theory, have been used to explore and explain how gamification works [44].

A study examined the effectiveness of gamification. The results indicate that gamification does work on psychological outcomes, including motivation, and behavioral outcomes, even though some caveats and mixed conflicting results exist [45]. A study illustrates the usefulness of self-determination theory and basic psychological needs as a theoretical framework to understand, research, and design the motivational power of gamification [46].

Although it has been more than 10 years since its inception, research explaining how gamification maintains learning motivation remains dominant from a more profound and broader theoretical basis. Gamification matured in theory-driven empirical studies [47]. Currently, a relatively mature theoretical basis already exists that establishes a theoretical framework for the design and application of gamification.

In short, the role of gamification in learning motivation is acceptable, despite some mixed or conflicting results. To some extent, gamification potentially affects users' psychological tendencies and motivates them to specific behavior.

Motivation helps a positive attitude toward learning (EE) and propels better learning performance.

3.3.5 Learning

This element refers to a state in which the target group maintains continuous participation in the EE from an abstract concept perspective. It covers learning behavior and learning results in concrete implementation and experimental evaluation. In this model, "Learning" is one of the research goals. That is, to improve earthquake survival ability, the target group is expected to learn actively and master adequate earthquake survival knowledge.

As shown in Figure 4, there are two routes leading to "Learning." One is driven by FOE. The second is propelled by "motivation." Motivation is what causes behavior. The motivation from the safety need urges to seek risk aversion, which is participating in EE in this study, that is, learning.

Simultaneously, learning can reversely improve earthquake awareness and form a virtuous circle, which coincides with the training process of earthquake awareness discussed in section 3.1.3.

The learning model is expected to work. Figure 6 shows how the learning model works. According to the learning model (Figure 4), there are two routes to "Learning." One route is direct from FOE to Learning. It is realized by learning materials (LM) carried on the notification (that is FOE). This learning behavior is triggered by notification directly, so it is defined as notification-activated learning (NL). Another case is that a learner may ignore the notification. However, he/she may learn autonomously in a short period after receiving the notification. In such case, FOE works as a reminder and trigger learners' autonomous learning (AL) behavior. Another route is from "Motivation" to "Learning." It triggers autonomous learning in a long period in EE, and the frequency depends on learners' EA and motivation level.

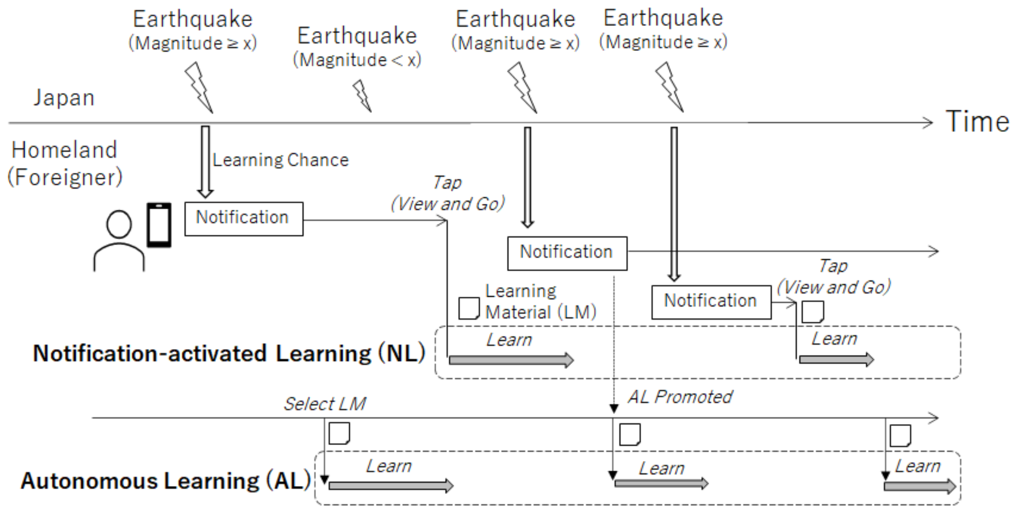

Figure 6: How learning model works

3.4 Research Questions

Research questions (RQs) are used to comprehensively evaluate the research results. All RQs are answered according to the research results, and then, the conclusion is used to verify if the research achieves the established research goals. The research question design must cover all the research goals.

The purpose of the research topic is to improve the situation of EE for the target group. The improvement of the EE situation for the target group can be assessed in two aspects, as mentioned two research goals: RG1. help the target group to build earthquake awareness in advance; and RG2. help the target group to master core earthquake survival knowledge in advance. The improvement can be measured in two dimensions: the level of participation and knowledge acquisition.

Based on the research goals and needs, four RQs are set, which measure the achievement of the research goals.

RQ 1. To what extent does FOE contribute to raising earthquake awareness?

RQ 2. To what extent does FOE contribute consequently to improving learning (earthquake knowledge acquisition)?

RQ 3. To what extent does G (Gamification) contribute to keeping motivation?

RQ 4. Which is more suitable for the targeted learning, FOE or FOE+G (or the control group)?

4 Mobile Application Development

4.1 Development Overview

A rapid prototype is adopted as the process model. The system is a prototype for research, rather than for business, so the software process includes only rapid requirements analysis, design, implementation, and testing.

The system is designed in the form of a cross-platform application with an appendant small server. The development processes of the application and server are synchronous.

4.2 Architecture Design

The system architecture is designed based on the layer mode.

A mobile system is designed and developed on the basis of the "FOE+G" learning model proposed in the design phase. This prototype system exhibits a central part as an application, with an attached server. The server mainly performs functions such as retrieving seismic information from the JMA, pushing earthquake messages to the application via WebSocket, retaining seismic information, managing users, and sending notifications to Apple's Push Notification service (APNs) or Google's Firebase Cloud Messaging (FCM). The application mainly implements seismic information subscription to the server, information display and reviewing, notification processing, gamification, learning materials, and multilingual support. The system architecture is presented in Figure 7.

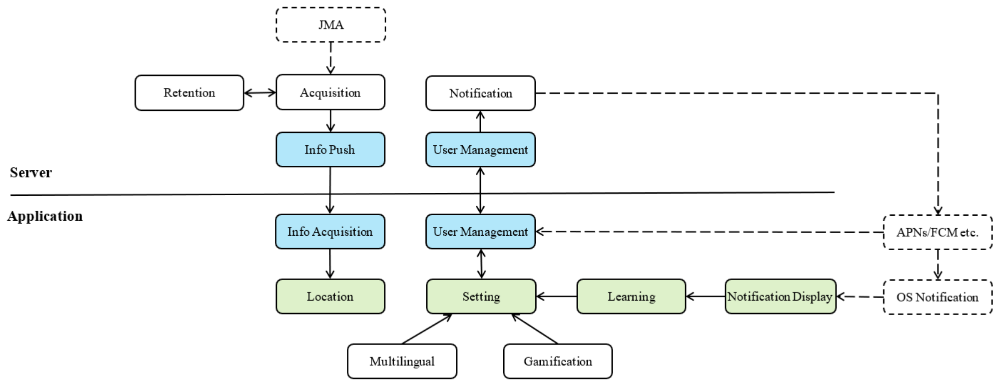

Figure 7: System architecture

The dashed round rectangles represent external functions, and the dashed lines represent the interaction between the system and external functions. Rectangles marked in light blue indicate the interaction layer modules between the server and the application. Rectangles in light green indicate the UI layer modules in the application. The remaining rectangles belong to the lower-level processing modules.

4.3 Application Introduction

The application was developed on the basis of the Flutter [8] and Dart [9] development language, and it is cross-platform to be available for iOS and Android operating systems.

Information Acquisition

The application supports the WebSocket protocol, which enables users to subscribe to the server push notifications. When the application launches, it makes a subscription to the server. Then, the application listens to the server for new seismic messages, whether they are active or in the background.

[8] https://flutter.dev/
[9] https://dart.dev/

Location

It supports displaying and preserving the seismic information from “Information Acquisition module.” No more than three locations are allowed to be present. Each place presents a card with the location name and the number of total earthquakes, as well as the number of earthquakes demonstrating a magnitude equal to or greater than 3. Figure 8 shows how this module works.

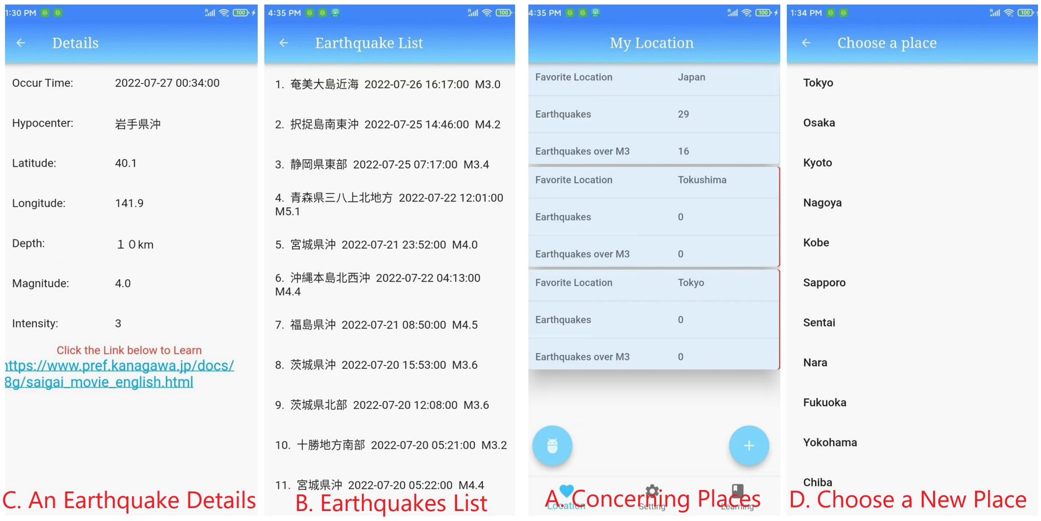

Figure 8: Information display and retention in location module

On the “My Location” page (Figure 8-A), the first one in the list defaults to Japan, implying that users can manage up to two locations. Users can remove a place from the list by swiping to the left, or add a new one by clicking the round button at the bottom right, which navigates to the page “Choose a Place” (Figure 8-D).

Clicking the round button at the bottom left navigates to the earthquake message intention page titled “Earthquake List” (Figure 8-B), and click any item to view the details, as shown on the page titled “Details” (Figure 8-C).

Setting

English and Simplified Chinese are available to set. Setting the threshold (by seismic magnitude) to trigger a notification is supported. Furthermore, user personal information is shown, including username, rewards, and study. User information and settings are synchronized between the “Setting” module and the “User Management module.” The “Setting” page and subpages are shown in Figure 9.

The first screenshot in Figure 9 is the “Setting” page (Figure 9-A); others are subpages navigated by clicking items orderly on the “Setting”, shown as labels B-F.

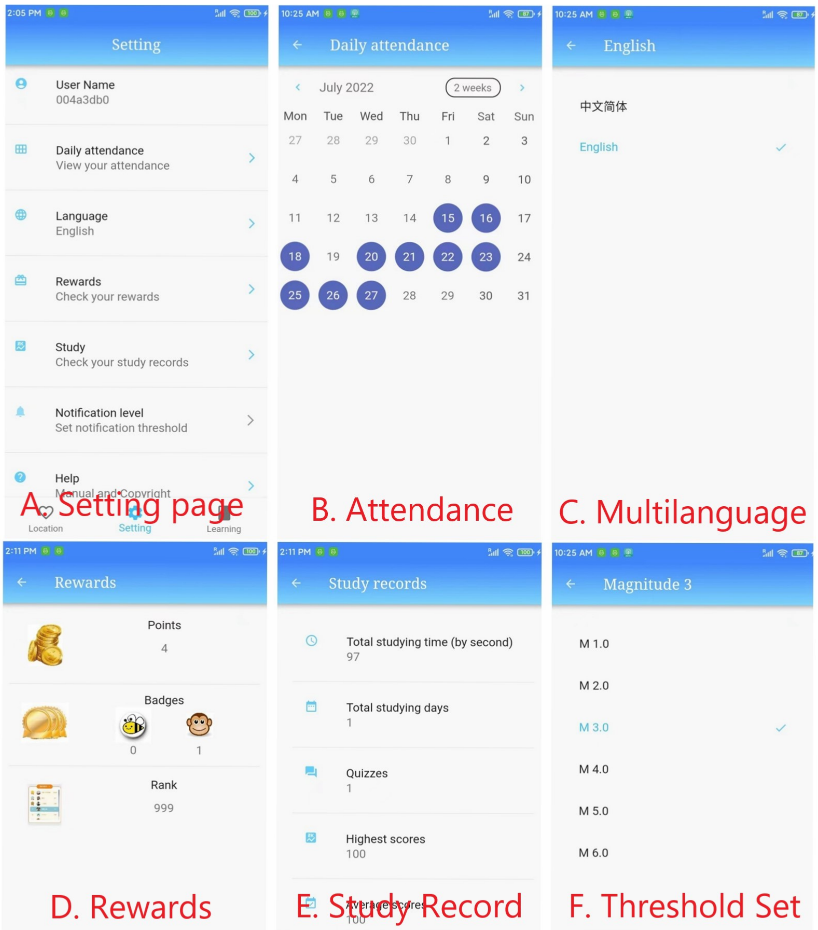

Figure 9: Screenshots for settings and subpages

Learning Materials

The application provides rich applied learning materials in both contents and forms, including scenario earthquake knowledge (named “Text” type, in Figure 10-A), video links (“VLink” type, in Figure 10-B), learning links (“Link” type, in Figure 10-C), pictures (“Pic” type, in Figure 10-D), and quizzes (“Quiz” type, in Figure 10-E), enabling learning anytime and anywhere. All learning materials are from reliable sources, and are restructured to suit user preferences.

Learners can click the button “Learning” and access the learning materials page where users can learn five types of earthquake knowledge. The five types of learning materials available in the application are shown in Figure 10. Learning behaviors for each learner are counted and recorded. Learners can check their learning statistics in the “Setting-Study Record.” During the experiment, detailed learning information, including timestamps, duration, type of learning materials, and more, were temporarily posted to the server to help evaluate learning behaviors and results.

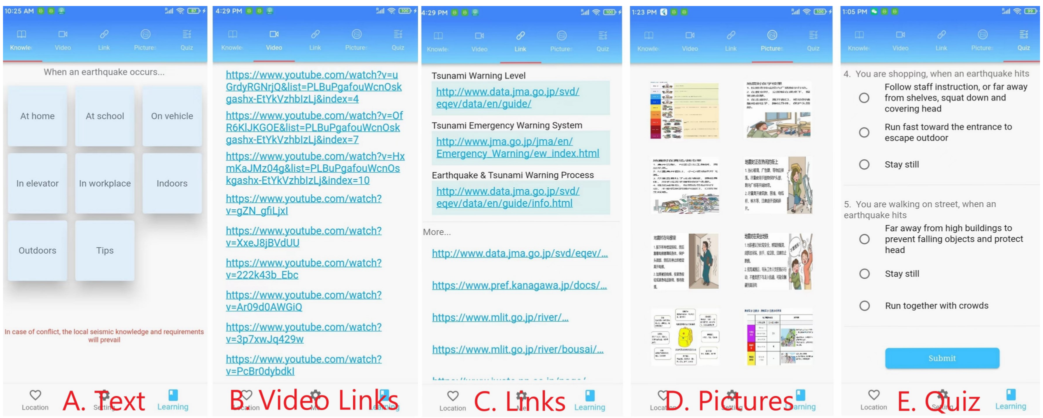

Figure 10: Five types of learning material

Notification Display

This module takes charge of responding to the user’s tap when the OS pops up a notification and displays it in the application.

Notification is the instance of FOE in the application. Even when the application exits, users can be aware of frequent earthquakes in Japan through notifications. Besides earthquake information, each notification presents a tip of a random type of earthquake knowledge. Therefore, user attention is drawn to earthquake notifications, which also present learning opportunities. In such a situation, high levels of attention enable the effective acquisition of knowledge, that is, learning. Consequently, this is how notifications contribute to earthquake education awareness and participation.

Figure 11 shows how a notification works. The first screenshot shows that the OS pops a notification (Figure 11-A), and the second shows the response page after tapping on the notification (Figure 11-B). Besides earthquake details, a URL to the learning tip is attached. Clicking the URL will navigate to the corresponding page (Figure 11-C). Also, users are reminded to navigate to "Learning" for more learning materials.

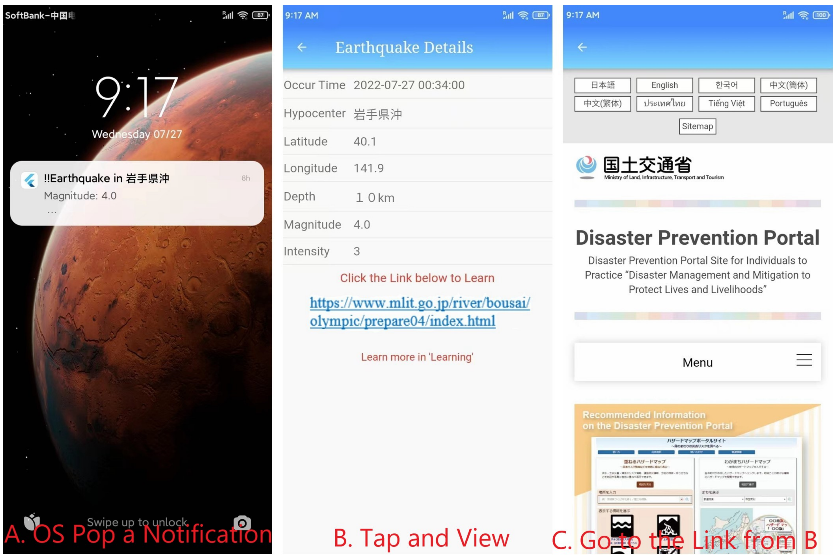

Figure 11: Notification working mode

User Management

This module processes the synchronous local and server storage of personal information. When a user's status, such as learning status and rewards, is updated, or the notification threshold is reset, and the new values are locally written and synchronously posted on the server.

Furthermore, this module is responsible for retrieving and updating the device's unique identity from APN/FCM and posting the identifier to the server to locate the target application and send notifications.

Gamification

Currently, various game elements and mechanics are applied. Points, badges, leaderboards, progress bar, avatar, virtual currencies, level-up, and so forth. Among them, points, badges, and leaderboards (so-called PBL) are widely accepted and commonly used game elements. All elements have corresponding game mechanics behind them, and some are overlapped. Commonly used game mechanics include rewards (like points, badges, and virtual currency), competition (like leaderboards), upgrades (like level-up), visibility (like progress bar, avatar), and so on.

Table 2 shows gamification used in this App, including game elements and mechanisms. Point and badge are the most common game elements. Daily attendance recently became popular, encouraging people to conduct specific missions daily. This application, for example, is designed for a particular page to be accessed once a day, which may remind users to use the application and contributes to customer adherence to the application. These types of game elements may facilitate learning directly or indirectly.

Table 2: Game elements and mechanisms adopted in the application

Game elements	Game mechanisms
Point	Rewards, feedback
Badges	Rewards, feedback
Daily attendance	Challenge, achievement, chance

This study focuses on motivating the learning of earthquake survival knowledge, so the gamification rule design has more emphasis on learning behaviors.

The rules for gaining points are as follows: 1. Launching the App gains one point once a day; 2. Viewing a notification gains one point; 3. Learning the tip on a notification gains one point; 4. Learning for at least 1 min gains one point once a day for each type of learning material; 5. Daily attendance gains one point per day; 6. Keeping daily attendance up to specified days gains a box with random points, no more than the number of consecutive attendance days; 7. Full marks in a quiz gains a point.

Two types of badges are found in this game: 1. Bee badge, representing diligence; 2. Monkey badge, representing intelligence. The rules for gaining badges are as follows: 1. Full marks in a quiz earn a monkey badge; 2. Daily attendance up to specified days (5, 10, 15, 20, 25, and 28) gains a bee badge.

Figure 12 shows partly the gamification used in the application. The first screenshot indicates gaining a point after learning the Text material for at least 1 minute (Figure 12-A). The second screenshot shows gaining a point by clicking the Link material (Figure 12-B). The third screenshot shows earning a Monkey Badge when users get full marks on a quiz (Figure 12-C), and the fourth screenshot shows the daily attendance (Figure 12-D).

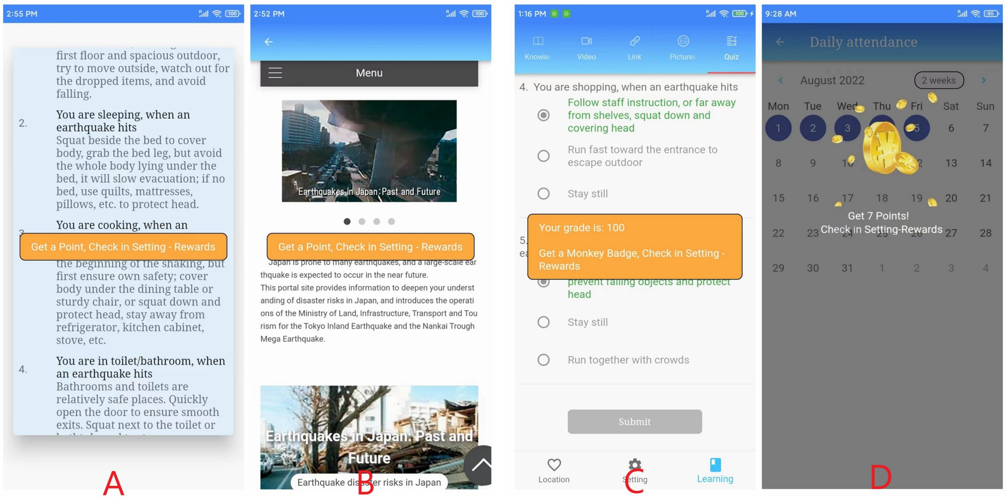

Figure 12: Samples of gamification in the application

Multilingual

Multilingual support is required because the target group is foreign users. According to a survey, the Japanese language may be a barrier for foreigners to access sufficient disaster information [48]. Therefore, multilingual support should be a tool to work to serve multicultural students [49]. The application currently supports simplified Chinese and English. The default language of the application initially follows the device language. If this language is not supported currently in the App, English is the default language in th App. Languages can be shifted manually on the “Setting Language” page shown in Figure 9.

4.4 Server Introduction

In addition, a simple server has been developed to support the application, and it is based on the Spring Boot framework, which is implemented using the Java development language. The current version of the server supports 200 concurrent accesses and keeps improving.

As shown in Figure 7, the server supports functions as follows.

Seismic Info Acquiring: This module is in charge of retrieving earthquake information from JMA. It accesses the URL released by JMA regularly to check the new information, once a minute. The newly available information will be transferred to the retention module and the push module.

Seismic Info Retention: This module retains earthquake information within a certain period.

Seismic Info Push: After the application subscribes to the server, the server sends earthquake information to the application through the WebSocket protocol.

User Management: The user management module supports personal information and setting preservation. In the user management module, to trigger notifications to APNs/FCM, a unique device identifier and notification threshold are combined.

Notification: Send notifications to eligible users forwarded by APNs/FCM.

5 Experimental Evaluation

An experiment was conducted using the prototype application to determine whether the study achieved the expected goal, i.e., to answer the following questions:

RQ 1. To what extent does FOE contribute to raising earthquake awareness?

To answer this question, FOE and FOE+G, the experimental groups, were compared with a control group. The expected result was that the participants in FOE and FOE+G raise more earthquake awareness and learn more frequently than those of the control group.

RQ 2. To what extent does FOE contribute to improving learning (earthquake knowledge acquisition)?

To answer this question, FOE and FOE+G were compared with the control group. Although some uncontrollable factors may influence learning activities and outcomes, the expected result is that the participants in FOE and FOE+G acquire (and memorize) more earthquake knowledge than those of the control group.

RQ 3. To what extent does gamification (G) contribute to retaining motivation?

To answer this question, FOE+G was compared with FOE and the control group. The expected result is that FOE+G participants learn more frequently than those of FOE and the control group.

RQ 4. Which is more suitable for the targeted learning, FOE or FOE+G (or the control group)?

To answer this question, the experimental and the control groups were evaluated. The expected result is that both FOE and FOE+G are satisfactory, but FOE+G is slightly superior.

5.1 Experiment Design

The experiment stage includes three steps, experimental preparation, experiment implementation, and post-experiment surveys. The entire experimental process is shown in Figure 13, and detailed descriptions are given in the following subsections.

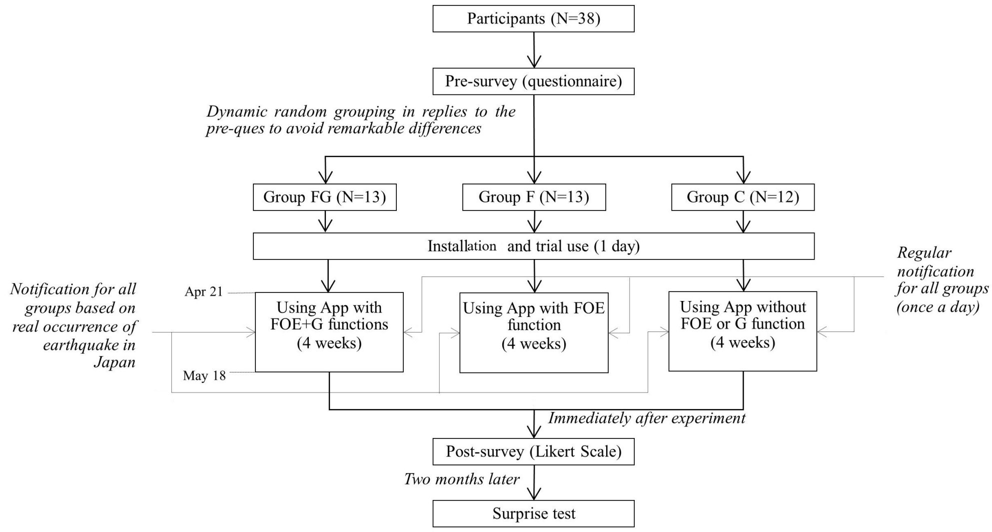

Figure 13: Experiment process

5.1.1 Experimental Preparations

Here, the preparatory work of recruiting experimental subjects, pre-survey (distributing questionnaires, collecting and analyzing questionnaires), and grouping based on questionnaire results are completed.

(1) Participants

Given the large population of possible learners, thirty-eight participants intending to come to Japan were recruited in China. The purpose of the experiment was explained to the participants before the experiment. This experiment was anonymous, including all questionnaires, did not involve personally sensitive information, and participants did not need to worry about personal information security issues. It was promised that all questionnaire and experimental data would only be used for the discussion and analysis in this experiment and would not be leaked. Every participant agreed on and accepted the practical terms (for example, the App installation into their smartphone and a 4-week experimental period).

(2) Pre-survey

A questionnaire survey was designed and delivered to the subjects to understand the subjects' basic information, including age and gender distribution, earthquake experience, earthquake education experience, attitude toward earthquake education, and earthquake knowledge mastery, as well as preferred education mode. The complete questionnaire is provided in Appendix A.

The results of the anonymous prequestionnaire revealed that the age distribution was 33 participants in the age group 18-25, 4 participants in the age group 26-30, and 1 participant in the age group 31-40. The results also revealed the following participant features:

· Thirty participants never experienced a large earthquake.

· Thirty-six participants had limited knowledge of earthquakes.

· Twelve participants knew nothing about surviving earthquakes in Japan, and twenty-six knew only a little.

Based on these features, most participants fit the targeted learners because they have not acquired adequate knowledge and skills to survive earthquakes.

(3) Grouping

Simple randomization was not applicable for grouping because of the small size. A dynamic randomization method was used for grouping. Strong earthquake experience and attitudes toward earthquake education were important factors that could affect participants' behavior. Therefore, participants who had experienced strong earthquakes or held negative attitudes toward earthquake education, as two subgroups, were randomly assigned to three groups based on the statistical results of the prequestionnaire, and the remaining participants, as the last subgroup, were randomly assigned to these three groups. For small samples, dynamic random grouping reduced group differences to ensure that the experimental groups have better homogeneity based on potentially influencing factors, thereby making the experimental results more statistically significant.

According to the abovementioned principle, participants were divided into the following groups while minimizing the participant features' differences.

· **Group FG (N = 13):** Participants installed the application with earthquake notifications of FOE (F) and Gamification (G) functions. These participants received not only an earthquake notification every time a large earthquake occurred (Magnitude greater than 3.0 in this experiment) but also a daily tip notification. Furthermore, these participants received points, badges, and other rewards when the gamification conditions were satisfied–experimental group.

· **Group F (N = 13):** Participants installed the application in the F function-experimental group. These participants received not only an earthquake notification every time a large earthquake occurred (Magnitude greater than 3.0 in this experiment) but also a daily tip notification–experimental group.

· **Group C (N = 12):** Participants installed the application without any F or G function. These participants received a daily tip notification once per day–control group.

A daily tip function was implemented specifically for the experiment as a baseline. Participants received a daily tip notification (DTN) as a pop-up message once daily. If they clicked on the notification, the daily tip (the main body) would be displayed. The daily tip was randomly selected from the knowledge database to avoid repetition in type and content. The daily tip function worked almost the same as the earthquake notifications of FOE except for the time of delivery. Figure 14 shows a snapshot of daily tip notification.

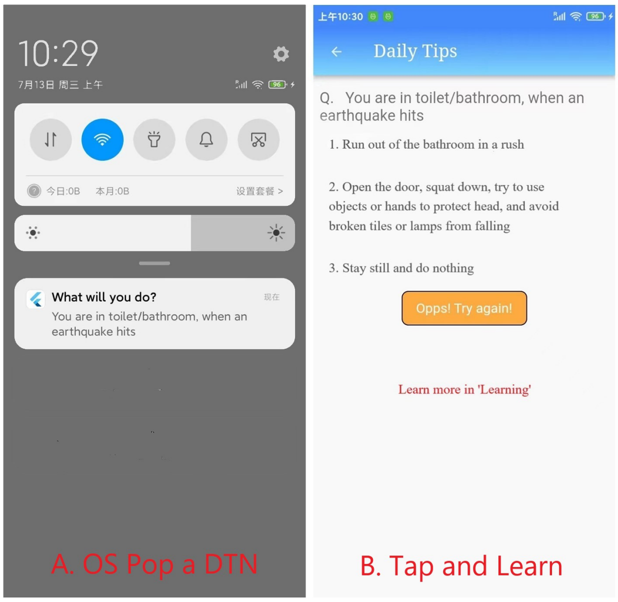

Figure 14: Snapshot of daily tip notification

The grouping of all participants was transparent in the sense that they had no idea they were in one of the three groups and would be using different applications.

5.1.2 Experiment Implementation

Procedure: Participants were provided with the app manual (different among groups) and a short trial period before beginning the experimental period. All participants entered the 4-week experimental period simultaneously, from April 21 to May 18, 2022. During the experimental period, participants were not forced to use the application. They used the App totally up to themselves.

Participants were classified according to their responses to the application.

· **Non_User:** Participants that did not use the application during the experimental period.

· **User:** Participants that used the application during the experimental period at least once. The term "using the application" referred to any operation performed on the application, such as viewing notifications, learning any type of material by tapping the "Learning" icon in App UI, or just non-learning-related operations, such as adding or removing a concerning place, reviewing the earthquake information list, and checking rewards.

· **Learner:** Participants that had viewed a learning material at least once, and as mentioned in section 3.3.5, two types of learning behavior were defined for learners:

1. Notification-activated Learning (NL): When a learner viewed a learning material by tapping a learning tip carried on a notification (earthquake notification or daily tip notification).

2. Autonomous Learning (AL): When a learner viewed a learning material by autonomously (directly) selecting it from the menu of the app. NL shares almost the same knowledge database as AL. NL is based on so-called tips, which are small pieces of knowledge in the form of different types. AL also counted the number of learning times based on learning material type shifting to unify AL and NL. Depending on the learning material types, a short period of AL may be one time of effective learning.

Besides, notification viewing (NV) means participants tap and view a notification, which may trigger ensuing learning or not. So, NL is a subset of NV.

In addition, the following experimental data sets were collected and recorded temporarily on the server.

· **Earth_Notif_Times:** The total number of times earthquake notifications are pushed to groups FG and F each day.

· **Earth_Notif_Tapping_Times:** The total number of times of tapping earthquake notifications each day (for each of FG and F).

· **Daily_Tip_Notif_Tapping_Times:** The total number of times daily tip notifications were tapped each day (for each group).

· **Notif_Learning_Times:** The total number of times each group observed NL (FG, F, and C) per day.

· **Auton_Learning_Times:** The total number of AL observed per day for each group (FG, F, and C), counting when shifting learning material types.

· **Auton_Learning_Duration:** The total duration (by second) of AL in each group, from the start (when learning material is presented) to the end (when learning material is closed). Note that because of the constraints of the app implementation, the duration of NL was not collected.

· **Learning_Days:** The total number of learning days in each group. This dataset is defined as a day when any participant has viewed any type of learning material. This data is used to evaluate the motivated period aimed at the entire group.

· **Learner_Days:** Learner_Days refers to the total number of learning days for all participants. Unlike Learning_Days, which primarily reflects the motivation period of the entire group, Learner_Days reflects the motivation level of the entire group.

· **Resume_Times:** The total number of times each group resumed the application (by participants). "Resume" indicates that this dataset does not contain the first launch of the application.

· **N_Badges:** The number of each type of badge gained while using the application (group FG only), including two subtypes: N_Badge_Mon (Monkey badge) and N_Badge_Bee (Bee badge).

· **N_Attend:** The number of days of daily attendance (group FG only).

· **N_Points:** The number of points gained while using the application (group FG only).

Participants do not need to register or log in when using the application, which corresponds to the abovementioned anonymous experiment. When the application is launched for the first time, a random string containing the group identifier is automatically generated for participants to distinguish and record each participant's group identifier and their behavior in using the application. This random string is the unique user ID for participants in the experiment. During the experiment, all user behavior data, including time stamps, were temporarily recorded on the server and differentiated by the user ID.

5.1.3 Post-surveys

(1) Post-questionnaire

After the experimental period, an online questionnaire was distributed to all participants to evaluate the application and collect user feedback. The questionnaire was designed using a five-point Likert Scale. The survey remained anonymous, and participants only needed to fill out the unique ID assigned to them in the application.

The questionnaire survey was divided into three parts that corresponded to three groups. The three groups included the same basic questions, such as the experience of using the app. In addition, for groups F and FG, participants' experiences and perceptions of notification (FOE) were included. For group FG, participants' experiences and perceptions of gamification (G) were also investigated. The complete questionnaire is provided in Appendix B.

(2) Online surprise test

Two months later, without notice, an online test was conducted to examine the situation of knowledge retention among the groups. A 25-question multiple-choice test was distributed online to all participants. Questions were asked about the correct behavior of earthquakes in various scenarios, handling after shaking, preparations before earthquakes, and so forth. The participants were asked to indicate whether they used the app for learning during the experiment. The complete test questions are provided in Appendix C.

5.2 Data Analysis and Results

Discussions and conclusions are based on the experimental data. The participant datasets collected during the experiment, the questionnaire data after the experiment, and the test data to test the retention of knowledge after the experiment, are mainly processed. Given the limitations of the small sample size, the performance of groups and participants from multi-aspects can be comprehensively evaluated using various experimental data and user feedback.

5.2.1 Experimental Data

Participant behavioral data collected for each group during the experiment included the following:

1. Activity level
2. Earthquake notification frequency for groups FG and F
3. Daily tip notifications for all groups
4. Learning frequency of autonomous learning
5. Learning duration
6. Stickiness to the application
7. Gamification for group FG
8. Use of different types of learning materials

All types of data would be presented, analyzed, and interpreted successively in the subsequent part. This experiment used parametric statistics to compare calculated mean values while assuming a normal population and homoscedasticity.

Participants in each group were indexed using capital letters (A-M). In the following data analysis, same letters in the same group refer to the same participant.

(1) Activity level

Table 3 shows the distributions of Non_User, User, and Learner. The collected data revealed that nine participants belonged to the Non_User: two, one, and six in groups FG, F, and C, respectively. Group C had more participants belonging to Non_User than the other groups, indicating lower participation. Twenty-nine participants belonged to User: eleven (84.62%), twelve (92.31%), and six (50.0%) in groups FG, F, and C, respectively. Twenty-one participants belonged to Learner: eight (84.62%), nine (92.31%), and four (33.33%) in groups FG, F, and C, respectively. The L_Rate values of groups FG and F were approximately twice that of group C.

Pearson Chi-Square tests revealed a calculated chi-squared statistic of 6.933 with a p-value of 0.031 (df=2), which suggested a significant difference of "User" among the 3 groups. And there was no significant difference of "Learner" among the three groups through a calculated chi-squared statistic of 3.567 with a p-value of 0.168 (df=2).

Table 3: Participation levels in three groups

Group	Non_User	User	U_Rate*	Learner	L_Rate**
FG	2	11	84.62%	8	61.54%
F	1	12	92.31%	9	69.23%
C	6	6	50.00%	4	33.33%

* User percent to total participants
** Learner percent to total participants

(2) Earthquake notification frequency

JMA reported 143 times of sensible earthquakes occurring in Japan between 21st April and 18th May, 99 of which were eligible earthquakes (magnitude >= 3.0). In total, 98 (Earth_Notif_Times) earthquake notifications were delivered to groups FG and F, nearly matching the number of eligible earthquakes reported. No earthquake notifications were delivered on 15th May. Groups FG and F received 0–8 pieces of earthquake notifications per day in addition to one daily tip notification. The mean number of times of earthquake notifications was 3.5 per day.

Figures 15 and 16 show the transition of the earthquake notification frequency with the frequencies of notification viewing and notification-activated learning for groups FG and F, respectively. In Figures 15–21, the first day (Day 1) and the last day (Day 28) correspond to April 21st and May 18th, respectively. For group FG, small squares represent the total number of earthquake notification that was viewed only, whereas small filled squares with a line represent earthquake notification that were viewed and triggered learning behavior (Figure 15).

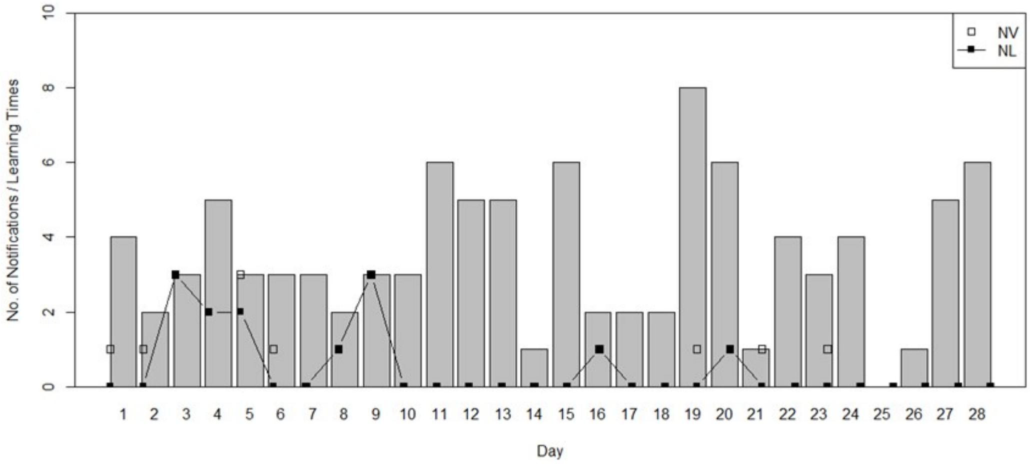

Figure 15: Viewing and learning from earthquake notifications in group FG

Based on data statistics, participant FG-G has the following characteristics: He/She had the most learning days (9) including autonomous and notification-activated learning. He kept a low and relatively even learning frequency of 1–2 times per day. He had the most NV and NL frequencies total in EN and DTN (14, 9).

For group F, small circles represent the total number of earthquake notification that was viewed only, and small filled circles with line represent earthquake notification that were viewed and triggered learning behavior (Figure 16).

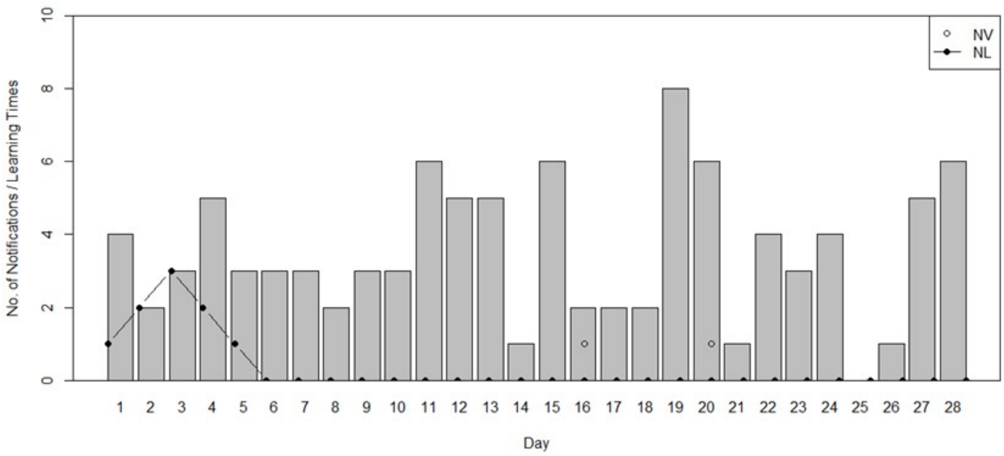

Figure 16: Viewing and learning from earthquake notifications in group F

According to Figures 15 and 16, both groups FG and F did not view notifications or learn from learning materials in the half latter period (after Day 15). Both groups learned during the initial few days, but group FG learned a few times during the middle period (between Day 8 and Day 20).

(3) Daily tip notification viewing and learning

Figures 17, 18, and 19 show the frequency of viewing and learning of daily tip notifications for groups FG, F, and C. The figures show that all groups have low notification viewing and notification-activated learning frequencies (FG: 4 and 3, F: 3 and 2, C: 6 and 5), resulting in little effect on evaluating FOE (earthquake notification).

For group FG, small squares represent the total number of DTNs that were viewed only, and small filled squares with lines represent DTNs that were viewed and triggered learning behavior (Figure 17).

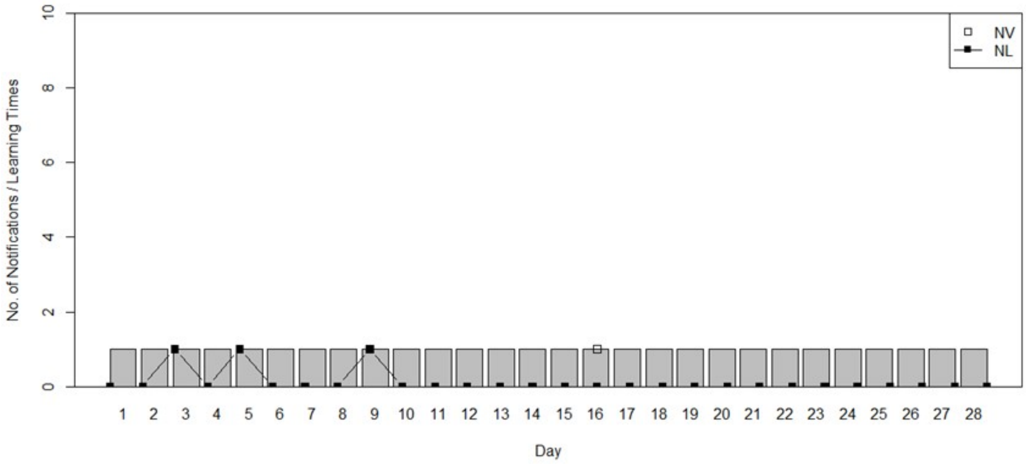

Figure 17: Viewing and learning from DTN in group FG

For group F, small circles represent the total number of DTN that was viewed only, and small filled circles with lines represent DTN that was viewed and triggered learning behavior (Figure 18).

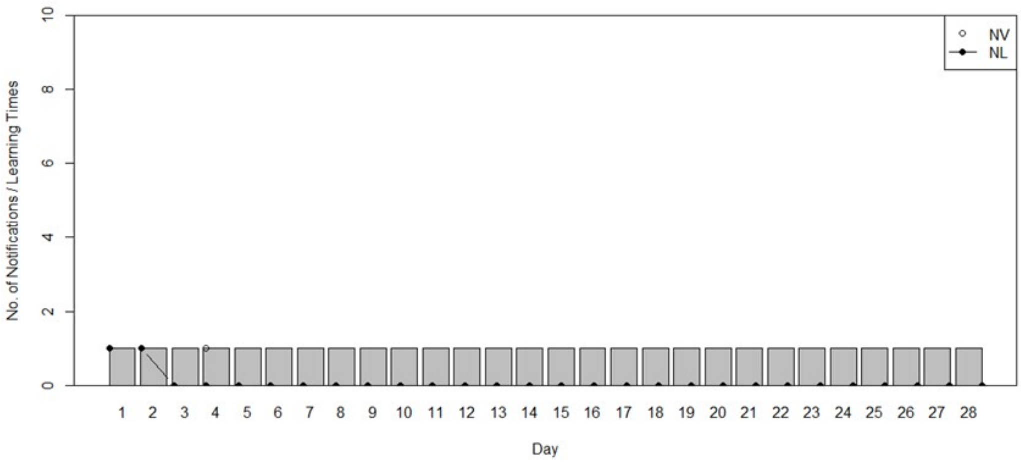

Figure 18: Viewing and learning from DTN in group F

For group C, small triangles represent the total number of DTNs that were viewed only, and small filled triangles with lines represent DTNs that were viewed and triggered learning behavior (Figure 19).

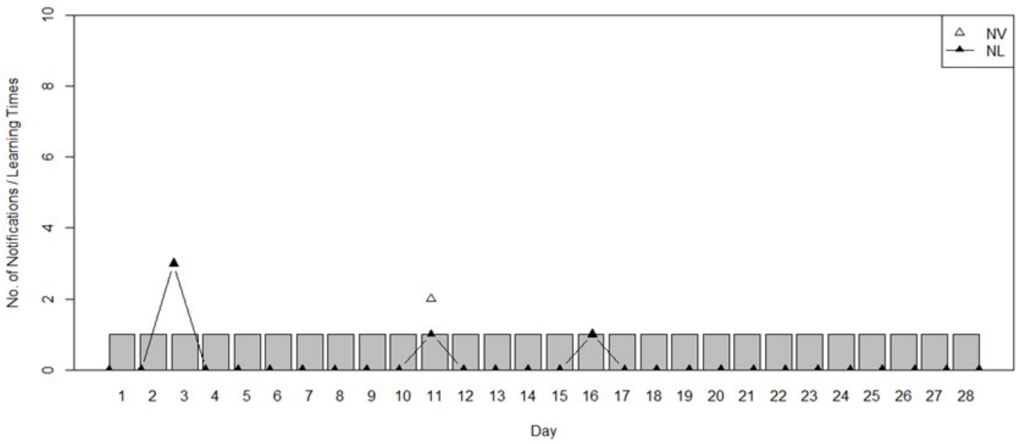

Figure 19: Viewing and learning from DTN in group C

(4) Learning frequency

(4-1) Notification-activated Learning (NL) frequency

Table 4 shows the Notif_Learning_Time, its mean value calculated by dividing the number of participants (Group_Mean), and its mean value calculated by dividing the number of Learners (Learner_Mean) in each group. Regarding NL, participants in groups FG, F, and C learned 16, 11, and 5 times, respectively. These values include learning from earthquake notifications and daily tip notifications. The three groups had low notification-activated learning frequencies and mean values.

Table 4: NL frequency and mean values for three groups

Group	Notif_Learning_Times	Group_Mean (SD)	Learner_Mean (SD)
FG	16	1.23 (2.49)	2.0 (2.92)
F	11	0.85 (1.29)	1.22 (1.39)
C	5	0.42 (0.43)	1.25 (0.64)

Table 5 shows the Notif_Learning_Times of each participant for the experimental period. The maximum Notif_Learning_Times were 9, 4, and 2 in groups FG, F, and C, respectively. Table 4 shows that notification was in low frequent use.

For example, participant FG–G viewed a piece of learning material through notification nearly once every three-day. Participants F–F viewed a piece of learning material only once a week. Participants C–C viewed a piece of learning material only twice.

For the whole groups, a one-way ANOVA was performed. The results showed no significant differences in NL frequency in the three groups, $F(2, 35) = 0.653, p = 0.527, \eta^2 = 0.036$. For the learners in each group, a one-way ANOVA was conducted. The results showed no significant differences in NL in Learner part of each group, $F(2, 18) = 0.292, p = 0.750, \eta^2 = 0.031$.

Table 5: Notif_Learning_Times of each participant

Group	A	B	C	D	E	F	G	H	I	J	K	L	M
FG	3	3	0	1	0	0	9	0	0	0	0	0	0
F	0	0	3	0	0	4	0	1	3	0	0	0	0
C	1	1	2	1	0	0	0	0	0	0	0	0	

(4-2) Autonomous Learning (AL) frequency

Table 6 shows the Auton_Learning_Time, its mean value calculated by dividing the number of participants (Group_Mean), and its mean value calculated by dividing the number of Learners (Learner_Mean) in each group. Regarding AL, participants in groups FG, F, and C learned 159, 195, and 59 times, respectively. Some of them had very short durations, only 1–2 seconds, and were judged as invalid learning. However, invalid learning was also counted because it was the participant' s behavior.

Table 6: AL frequency and mean values for three groups

Group	Auton_Learning_Times	Group_Mean (SD)	Learner_Mean (SD)
FG	159	12.23 (13.09)	19.875 (11.26)
F	195	15.00 (14.23)	21.67 (15.51)
C	59	4.92 (9.14)	14.75 (10.28)

Table 7 shows the Auton_Learning_Times of each participant during the experimental period. The maximum Auton_Learning_Times were 40, 40, and 29 in groups FG, F, and C, respectively. The following facts were found while focusing on the participants who had the maximum time in each group. Participants FG–D viewed learning materials intensively for one week from 27th April to 3rd May. Participants F–H viewed learning materials approximately once a week. Participants C–C had maximum times for NL and AL.

For the whole groups, a one-way ANOVA was performed. The results showed no significant differences in AL frequency in the three groups, $F(2, 35) = 1.847, p = 0.173, \eta^2 = 0.095$. For the learners in each group, a one-way ANOVA was conducted. The results showed no significant differences in AL in Learner part of each group, $F(2, 18) = 0.367, p = 0.698, \eta^2 = 0.039''$.

Table 7: Auton_Learning_Times of each participant

Group	A	B	C	D	E	F	G	H	I	J	K	L	M
FG	24	25	10	40	21	2	10	27	0	0	0	0	0
F	17	10	39	6	2	39	14	40	28	0	0	0	0
C	4	6	29	20	0	0	0	0	0	0	0	0	

(4-3) Total learning frequency (NL + AL)

Table 8 shows the total learning times, i.e., the combination of Notification-activated Learning and Auton_Learning_Time, its mean value calculated by dividing the number of participants in each group (Group_Mean), and its mean value calculated by dividing the number of Learners in each group (Learner_Mean). Regarding the total learning times, participants of groups FG, F, and C learned 175, 206, and 64 times, respectively. Table 8 shows that the mean values of "Group_Mean" in groups FG and F are approximately the same, but more than 2.5 times and nearly 3 times that of group C, respectively. Groups FG and F had a higher learning frequency overall. "Learner_Mean" shows approximate mean learning frequencies for learners in all three groups.

For the whole groups, a one-way ANOVA was performed. The results showed no significant differences in the total learning frequency (AL+NL) in the three groups, $F(2, 35) = 1.818, p = 0.177, \eta^2 = 0.094$. For the learners in each group, a one-way ANOVA was conducted. The results showed no significant differences in the total learning frequency (AL+NL) in Learner part of each group, $F(2, 18) = 0.342, p = 0.715, \eta^2 = 0.037$.

Table 8: Total learning frequency and mean values for three groups

Group	**Learning_Times**	**Group_Mean (SD)**	**Learner_Mean (SD)**
FG	175	13.46 (13.79)	21.88 (11.19)
F	206	15.85 (16.68)	22.89 (15.51)
C	64	5.33 (9.72)	16.0 (10.63)

Figure 20 shows the total learning frequency for the three groups. On the third day of the experiment (23rd April), all three groups had a maximum learning frequency. Besides the notification of earthquakes in Japan, an earthquake (Magnitude 3.9) occurred in a place in China. M3.9 was relatively rare in China, and its epicenter was the same as that of the M6.9 earthquake on 8th Jan. M6.9 was the strongest earthquake in China in 2022. Related to the M6.9 on Jan 8th, M3.9 on Apr 23rd generated much media attention. That is, local earthquake information exposure had a superimposed effect. In addition, Apr 23rd was the first Saturday of the experiment. Another factor that might have contributed to the hill on Apr 23rd is less busy on weekends or holidays.

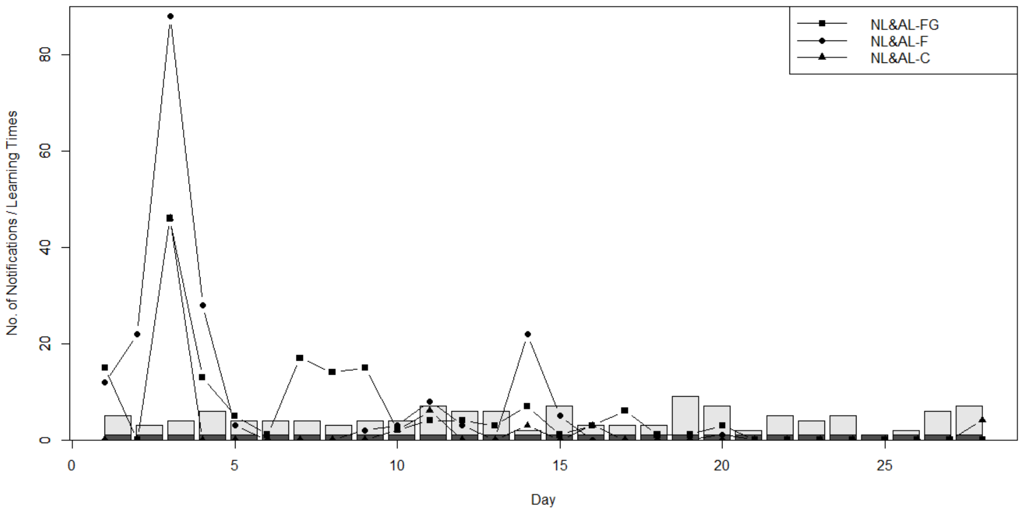

Figure 20: Total learning frequency of three groups

Table 9 shows that the results of the Pearson Correlation Coefficient have no linear correlation between EN and AL/NL in groups FG and F.

Table 9: Pearson correlation coefficient between EN and Learning

Group	**Datasets**	**Pearson correlation coefficient**
FG	Cor(EN, AL_FG)	-0.068
	Cor(EN, NL_FG)	-0.031
F	Cor(EN, AL_F)	-0.052
	Cor(EN, NL_F)	-0.037

EN: Number of earthquake notifications

AL: Number of autonomous learning

NL: Number of notification-activated learning

Figure 21 shows the date distribution of Learning_Days, and the vertical axes represent the number of activity learners daily for each group. Compared to groups F and C, group FG has a longer period kept in motivation and more activity learners per day (Figure 21).

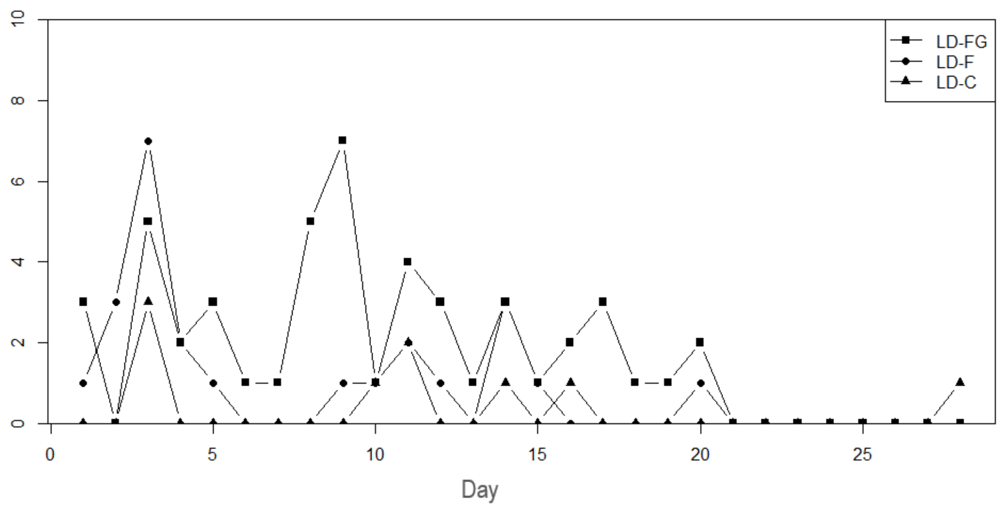

Figure 21: Learning days and active learners distribution for three groups

The learning behavior of group F was intense for the first 5 days, but then declined rapidly, and the number of daily active users showed the same downward trend. Group C also had relatively concentrated learning in the first 5 days, but both the learning frequency and per day active learners were low.

In addition, from 29th Apr to 5th May, all three groups had a small increase in active learners (Figure 21), possibly because this period was a 3-day International Workers' Day in China, as mentioned earlier, weekends and holidays were an influencing factor on learning behavior.

Figure 21 shows that the Learning_Days counted to date are 19, 12, and 6 in groups FG, F, and C. Learner_Days are 49, 24, and 7 in groups FG, F, and C, respectively. Table 10 shows the Learning_Days and Learner_Days, as well as their mean values for the entire group (Group_Mean) and the Learner part (Learner_Mean). Group FG has better performance in both Group_Mean and Learner_Mean. In Group_Mean, the value of group FG is approximately 1.5 and 3 times that of groups F and C, respectively. In Learner_Mean, the value in group FG is approximately 1.5 times that of groups F and C.

For the whole groups, a one-way ANOVA was performed to estimate the difference in "Learner_Days" among the three groups. The results showed a significant differences in "Learner_Days" of each participant in the three groups, $F(2, 35) = 4.508, p = 0.018, \eta^2 = 0.205$. Post-hoc comparisons using Tukey's HSD test revealed that group FG was significantly different from group C, p = 0.015, and there were no significant differences between groups FG and F (p = 0.148), and groups F and C (p = 0.537).

For the learners in each group, a one-way ANOVA was conducted to estimate the difference in "Learner_Days" among the three groups. The results showed a significant differences in "Learner_Days" of each learner in the three groups, $F(2, 18) = 7.255, p = 0.005, \eta^2 = 0.446$. Post-hoc comparisons using Tukey's HSD test revealed that group FG was significantly different from group F (p=0.009) and group C (p=0.02), and there was no significant difference between groups F and C (p=0.942).

Table 10: Learning_Days and the sum of Learner_Days

Group	**Learning_Days**	**Learner_Days**	**Group_Mean (SD)**	**Learner_Mean (SD)**
FG	19	49	3.77 (3.85)	6.13 (2.99)
F	12	24	1.85 (1.72)	2.67 (1.41)
C	6	9	0.75 (1.14)	2.25 (0.5)

(5) Learning duration

Table 11 shows the total duration (by second) of AL (autonomous learning) of each participant for the experiment period. The summation of the row values indicates the Auton_Learning_Duration in each group. Participants FG–B, F–C, and C–C have the maximum duration in groups FG, F, and C, respectively. FG–B and F–C do not have a maximum learning frequency or notification use frequency, but C–C does.

For the whole groups, a one-way ANOVA was conducted. The results showed no significant differences in total learning duration of each participant in the three groups, $F(2, 35) = 0.902, p = 0.415, \eta^2 = 0.049$. For the learners in each group, a one-way ANOVA was conducted. The results showed no significant differences in total learning duration of each learner in the three groups, $F(2, 18) = 0.036, p = 0.964, \eta^2 = 0.004$.

Table 11: Learning duration for participants in three groups

Group	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
FG	158	585	42	331	117	31	217	136	0	0	0	0	0
F	28	154	508	377	39	155	44	273	169	0	0	0	0
C	60	9	325	294	0	0	0	0	0	0	0	0	

Table 12 shows the Auton_Learning_Duration (Group_Total), its mean value calculated by dividing the number of participants in each group (Group_Mean), and its mean value calculated by dividing the number of Learners in each group (Learner_Mean). The values of Group_Mean in groups FG and F are similar and more than twice that of group C. The values of Learner_Mean in the three groups are similar, indicating that learners in the three groups have similar mean learning duration.

Table 12: Mean values of learning duration in three groups

Group	**Group_Total**	**Group_Mean (SD)**	**Learner_Mean (SD)**
FG	1,617	124.38 (172.63)	202.13 (182.02)
F	1,747	134.38 (163.43)	194.11 (164.37)
C	688	57.33 (119.20)	172.0 (160.63)

(6) Stickiness

For each group, the number of application resuming times was recorded. Resuming action means repeatedly activating the application throughout its lifecycle, excluding the first launch. A repeat is referred to as one time of resuming. Resuming reflected how frequently users woke up to the application, which is an aspect of customers' stickiness with the application. The Resuming_Times for groups and values in brackets indicate the number of participants who resumed the application during the experiment (Table 13). Here a point must be clarified that resuming behavior is not equal to learning behavior, so the participants did not match the Learner part in each group. Group FG has the maximum resuming times and users, as well as the highest stickiness with the App among all groups.

Table 13: Application resuming frequency in three groups

Group	**FG**	**F**	**C**
Resume_Time	156 (10)	70 (6)	20 (4)

(7) Statistics on gamification

Table 14 shows the use of gamification for group FG, with the number in brackets corresponding to the number of users. Game element point is the most popular in terms of the number of users.

Table 14: Statistics of game elements usage in group FG

Group	**N_Attend**	**N_Points**	**N_Badge_Mon**	**N_Badge_Bee**
FG	42 (8)	180 (11)	24 (6)	1 (1)

Table 15 shows the use of each game element for each participant in group FG. The number of days that each participant used each type of element is also shown in brackets in Table 15. From Table 15, some facts were revealed. FG-G had the most gamification days, points, and attendance times. FG-D got the most badges, mainly by finishing quizzes. FG-B got a Bee badge which indicated these participants had at least a 5-day continuous attendance.

Table 15: Game elements usage of each participant in group FG

Element	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Point	21 (9)	36 (11)	5 (3)	31 (16)	11 (6)	2 (1)	57 (22)	14 (7)	1 (1)	1 (1)	1 (1)
Badge	3 (3)	7 (6)	0	9 (8)	0	0	2 (2)	4 (4)	0	0	0
Attend	4	12	1	3	1	1	18	2	0	0	0

(8) Learning materials using

The application provides five types of learning materials, including earthquake knowledge (Text), picture (Pic), links to external learning materials (Link), links to external videos (VLink), and quizzes (Quiz). The frequency and duration of use for each type of learning material were recorded, which may help analyze user preferences for learning materials and adjust weights accordingly. As previously mentioned, 159, 195, and 59 times of autonomous learning on the basis of different types of learning materials were recorded for groups FG, F, and C, respectively. The number of times and duration for types of learning materials are shown in Tables 16 and 17, respectively. In the three groups, Text occupied the maximum number of using times. Quiz is another popular learning material type, occupying the maximum duration in groups F and C. The numbers in brackets are the percentage of the corresponding type to the number of total times in each group.

Table 16: Learning frequency of materials

Group	Total	Text	VLink	Link	Pic	Quiz
FG	159	71 (44.65%)	19 (11.95%)	17 (10.69%)	21 (13.21%)	31 (19.50%)
F	195	67 (34.36%)	30 (15.38%)	14 (7.18%)	18 (9.23%)	66 (33.85%)
C	57	25 (43.86%)	6 (10.53%)	4 (7.02%)	8 (14.04%)	14 (24.56%)

Table 17: Learning duration of materials

Group	Total	Text	VLink	Link	Pic	Quiz
FG	1,617	811 (50.15%)	67 (4.14%)	14 (.87%)	46 (2.84%)	679 (41.99%)
F	1,747	644 (36.86%)	40 (2.29%)	21 (1.20%)	387 (22.15%)	655 (37.49%)
C	6,88	144 (20.93%)	6 (.87%)	7 (1.02%)	165 (23.98%)	366 (53.20%)

5.2.2 Application Feedback

The Likert Scale questionnaire received 29 responses, 6 in group C, 12 in group F, and 11 in group FG. Some of these respondents had not learned about the system during the experiment. However, all participants had a short trial before the experiment, so all answers could be considered valid.

(1) Overall feedback on applications

The Likert Scale had five survey questions to evaluate the three Apps, covering usage, ease of use, ease of learning, and user satisfaction. Questions, corresponding mean scores, and p-values are shown in Table 18. The numbers of participants who answered the questionnaire were 11, 12, and, 6 in group FG, F, and C, respectively. For the mean values of 5 questions in three groups, a one-way ANOVA was performed. The results of the ANOVA showed no statistically significant difference. Except for Q3, the mean values were more than 3.50, and no large differences in the three groups. Group C received a mean score of 3.00 for Q3, indicating that group C holds a neutral attitude toward the app's ability to enhance its earthquake awareness.

Table 18: Results of the Likert Scale on the App

Question	FG (SD)	F (SD)	C (SD)	p-value
Q1. The App is easy to use	3.91 (1.14)	4.00 (0.74)	3.83 (0.41)	0.924
Q2. The App has rich learning materials	3.64 (1.12)	3.58 (0.79)	3.67 (0.52)	0.980
Q3. The App helps enhance earthquake awareness	3.91 (0.94)	3.75 (0.75)	3.00 (0.89)	0.120
Q4. The App helps master earthquake knowledge	3.82 (0.75)	3.83 (0.72)	3.67 (0.52)	0.882
Q5. Overall, the App is satisfactory	3.82 (1.25)	3.58 (0.90)	3.50 (0.84)	0.795

(2) Feedback on FOE

The Likert Scale had four survey questions for groups FG and F to evaluate the user experience of using notification (FOE) in the application. The questions and their corresponding mean scores are listed in Table 19. For the mean values of 4 questions in two groups, Student's t-test was performed. The results of the t-test showed no statistically significant difference. Groups FG and F had similar mean values on Q1,2,3, which indicated FG and F held relatively positive attitudes to the roles of FOE. However, FG and F both got relatively low mean values on Q4, which showed FG and F held a neutral or even negative attitude to frequent FOE. For all questions, the mean values of group FG were higher than those of group F maybe because of the role of gamification.

Table 19: Results of the Likert Scale on FOE

Question	FG (SD)	F (SD)	p-values
Q1. Do you agree that notifications help enhance your earthquake awareness?	4.09 (1.04)	3.75 (0.75)	0.376
Q2. Do you agree that tips on notifications help you master earthquake knowledge?	4.18 (1.17)	3.92 (0.67)	0.506
Q3. Do you agree that notifications prompt you to learn earthquake knowledge?	4.00 (1.18)	3.75 (0.75)	0.548
Q4. Do you agree that frequent notifications are acceptable?	3.18 (1.25)	2.92 (1.08)	0.591

3) Feedback on gamification

The Likert Scale had four survey questions for group FG to evaluate user experience toward the use of gamification (G) in the application. The questions and their corresponding mean scores are shown in Table 20. Group FG maintains a relatively positive attitude toward gamification in terms of knowledge acquisition and stickiness.

Table 20: Results of the Likert Scale on gamification

Question	FG (SD)
Q1. Do you agree that gaining points prompts you to learn earthquake knowledge?	4.09 (1.14)
Q2. Do you agree that gaining badges prompts you to learn earthquake knowledge?	4.09 (1.14)
Q3. Do you agree that daily attendance prompts you to learn earthquake knowledge?	4.18 (0.87)
Q4. Do you agree that gamification is useful?	4.18 (1.08)

5.2.3 Knowledge Retention Situation

Two months after the experiment, an online test was delivered to each group to examine the participants' knowledge retention situation. The test assessment included 25 multichoice questions (single-correct or multi-correct choices) on basic earthquake survival knowledge, and the maximum score was 100. This test was also anonymous, and participants were required to fill out their unique ID assigned in the experiment. In total, 36 valid responses were received, 12 belonging to group FG, 13 to F, and 11 to C. The responses were classified as “Learner” and “Non_Learner,” according to their learning behavior in the experiment. “Learner” represents participants who have learned earthquake knowledge using this application in a previous experiment. “Non_Learner” represents participants who have not learned earthquake knowledge using this application. Here, “Learner” has the same definition as the one above. “Non_Learner” includes “Non_User” and the part in the User except Learner. The results are shown in Table 21.

For the whole groups, a one-way ANOVA was performed. The results showed no significant differences in scores of surprise test in the three groups, $F(2, 33) = 1.462, p = 0.246, \eta^2 = 0.081$. For the learners in each group, a one-way ANOVA was conducted. The results showed no significant differences in scores of learners in the three groups, $F(2, 17) = 0.669, p = 0.525, \eta^2 = 0.073$. For the non-learners in each group, a one-way ANOVA was performed. The results showed no significant differences in scores of non_learner in the three groups, $F(2, 13) = 0.027, p = 0.973, \eta^2 = 0.004$.

However, higher mean values of Group_Mean and Learner_Mean in Groups FG and F than that in group C showed that FOE and FOE+G helped learning to some extent.

Table 21: Results of knowledge retention test

Group	Non_Learner	Non_Learner_Mean (SD)	Learner	Learner_Mean (SD)	Group_Mean (SD)
FG	5	62.4 (7.42)	7	84.0 (6.05)	75.0 (12.56)
F	4	64.0 (11.31)	9	84.44 (10.23)	78.15(14.17)
C	7	63.43 (9.66)	4	78.0 (10)	68.73 (12.04)

5.3 Discussions

Research questions were discussed and concluded on the basis of the experimental and survey results from multi-dimensions.

RQ 1. To what extent does FOE contribute to raising earthquake awareness?

Discussion: Apps for groups FG and F support the FOE function. To evaluate the role of FOE in raising earthquake awareness (EA), FG and F were compared with the control group C, which is assessed using the following three aspects: 1. Participation level; 2. Learning behavior; 3. Post-survey results.

1. Participation level

Table 3 shows that groups FG (U_Rate: 84.62%, L_Rate: 61.54%) and F (U_Rate: 92.31%, L_Rate: 69.23%) have significantly higher levels of participation from both Users and Learners than group C (U_Rate: 50.00%, L_Rate: 33.33%). The U_Rate and L_Rate values of groups FG and F are approximately 1.7 and 2 times that of group C, respectively. These results indicate that earthquake notifications (ENs) motivated participants to use the app and learn more than daily tip notifications (DTNs). DTNs may lose participants' EA because of their regular monotonous delivery, whereas ENs may awaken their EA because of their irregular delivery. If numerous ENs were delivered, participants may have felt disgusted. To raise and maintain the participant level, a moderate frequency of ENs will be required.

There was a significant difference in the participation level among the three groups, and no significant difference between groups FG and F. The results indicated that FOE increased the participation level significantly, however, gamification did not affect the participant level in this experiment significantly.

2. Learning behavior

FOE, that is, the delivery of ENs, was expected to raise EA and consequently increase learning times; it was ideal that every delivery made participants learn. However, the experimental results (Figures 15 and 16) indicated that the delivery did not promote participants to learn; viewing ENs was also not promoted. Notification-activated learning (NL) was uncommon as expected (Table 5), and autonomous learning (AL) was also uncommon as expected (Table 7). However, it was possible that ENs were not viewed but promoted participants to do AL unconsciously because ENs popped up and let participants know about the occurrences of earthquakes in Japan, thus increasing earthquake awareness. In addition, ENs might have raised EA and motivated participants to activate the app later regardless of the contents of the received ENs. This possibility should be evaluated to provide more learning opportunities in terms of busy users and unpredictable delivery time, as well as the frequency of ENs. Comparison with DTNs (Figures 17,18, and 19) indicates that the delivery of ENs was more effective in promoting learning.

However, participants in groups FG and F did not maintain a high frequency of learning throughout the experimental period, though ENs were delivered 3.5 times every day on average. Groups FG and F hold a relatively positive attitude that notification increased their earthquake awareness (Table 18), but they did not require frequent delivery. The FOE must determine how frequently ENs should be delivered.

3. Post-survey results

Post-survey results are important in terms of directly knowing the participants' feelings. Although there were no significant differences in the results shown in Table 18, groups FG and F accepted the app more positively than group C. Especially, for Q3 about the app (i.e., EA possibly for Groups FG and F), the mean values of groups FG and F were greater than 0.75 than those of group C. This is favorable in that FOE can raise the EA. The results shown in Table 19 also indicate that ENs were accepted and could promote EA and successive learning.

Conclusion: FOE has relatively significant effects on raising foreigners' earthquake awareness.

RQ 2. To what extent does FOE contribute consequently to improving learning (earthquake knowledge acquisition)?

Discussion: Three aspects are considered in evaluating the improvement of learning: 1. Learning behavior; 2. Post-survey results; 3. Knowledge retention test results.

1. Learning behavior

The frequencies of NL, AL, and NL+AL were studied. Given the importance of NL+AL in the RQ1 discussion, groups FG and F learned more frequently than group C (Table 8 and Figure 20). Table 8 shows that the values of Group_Mean of groups FG (13.46) and F (15.85) are approximately 2.5 and 3 times higher than that of group C (5.33), respectively. Although significant differences were not found in the statistical analysis, the remarkable difference indicates that FOE (ENs) encouraged participants to learn regardless of NL or AL. In terms of Learner_Mean, which reflects the average level of learning engagement in terms of learners in a group, the values of group FG (21.88) and F (22.89) were also higher than that of group C (16.0).

In terms of learning duration, the values of Group_Mean of groups FG (124.38) and F (134.38) were significantly higher than those of group C (57.33), respectively (Table 12). Learner_Mean values in groups FG (202.13) and F (194.11) were moderately higher than those of group C (172.0), increasing by approximately 17.52% and 12.85% respectively. The frequency of NL+AL may have proportionally affected learning duration. Here, a question arose whether it was reasonable for some learners to have a very short mean learning duration (Tables 7, 11, and 12). For example, FG–A spent 158 s on AL and learned 24 AL times, indicating that he/she used 6.58 s for each AL. Tables 7, 11, 12, 16, and 17 were combined for comprehensive analysis, and partial invalid learning, i.e., a duration of 1–2 s only, was found. The following reasons could have contributed to invalid learning behavior: 1. Inability to access or video links; 2. Recurring knowledge points (due to small knowledge database); 3. Give up quickly because of other reasons. According to the different types of learning times and durations (Tables 16 and 17), links and vlinks account for approximately 20% of the total learning times and approximately 5% (FG), 3.5% (F), and 2% (C) of the total learning duration. These two types of learning materials contribute to most of the invalid learning behavior because some links are inaccessible in the experimental area, which is a limitation of the experiment. Given the removal of these invalid learning behaviors and recalculating the use of text, picture, and quiz according to Tables 16 and 17, the results of the mean learning duration of each AL were approximately 12.49 s for group FG, 11.17 s for group F, and 14.36 for group C. This mean duration of each time is acceptable considering the small block organization of learning content.

2. Post-survey results

The results of Q4 in Table 18 also show that users in the three groups have a relatively positive attitude toward the application's ability to help them master basic earthquake knowledge (FG: 3.82, F: 3.83, C: 3.67), with the values of groups FG and F slightly higher than that of group C. The results of Q2 and Q3 show that groups FG and F hold relatively positive attitudes toward FOE's ability to help them learn, with 4.18 and 4.00 for group FG, and 3.92 and 3.75 for group F, respectively (Table 19). These favorable results indicate that the learning styles using the app can be accepted with or without FOE.

3. Knowledge retention test results

Table 21 shows that the three groups had no significant difference in knowledge retention when focusing on "Non_Learner." However, the mean scores of "Learner" in each group were significantly higher than that of "Non_Learner." This indicates that learning via the application was effective in all groups. In addition, the mean scores of "Learner" in groups FG and F were higher than that in group C, indicating that groups FG and F had better knowledge retention than group C, and FOE and G contributed to better knowledge retention (acquisition and memory). There was no significant difference in the mean scores of "Learner" between groups FG and F. The mean scores of the total responses in groups FG and F were higher than those in group C, indicating that groups FG and F benefit from FOE or G and achieve better learning results than group C.

Conclusion: FOE significantly improves learning participation, and helps knowledge acquisition and retention effectively to some extent.

RQ 3. To what extent does G (Gamification) contribute to keeping motivation?

Discussion: Figure 21 shows that group FG has a higher value of Learning_Day than groups F and C, with values of 19, 12, and 6 days, indicating that group FG has a longer motivation period than groups F and C. The vertical axis in Figure 21 represents the number of activity learners per day. The values show that group FG has more activity learners than groups F and C on most days, indicating that group FG had a higher number of learners who are motivated than those of groups F and C on most days during the experiment, shown in Table 10.

Group FG had a gradually decreasing learning frequency when Figures 20 and 21 were combined. Its learning behavior lasted more days, and it had more active learners per day; however, having more active learners did not contribute to a higher learning frequency. Statistics show that during the first 5 days, group FG had a relatively high learning frequency. In the following period, more learners maintained a low learning frequency each day, only 1–2 times, which could be attributed to gamification. Statistics show that active learners gained points more frequently, participated in daily attendance, and had more App resuming behavior. Gamification has extended FG's motivational period to a certain extent. In addition, the mean learning duration in terms of Learners in group FG (202.13) is slightly longer than that in groups F (194.11) and C (172) (Table 12), indicating that the use of gamification benefits individual learning performance in group FG.

Table 13 shows that group FG has significant differences in application resuming, indicating that gamification helps motivate users in the long term and increases user stickiness with the application. The usage of game elements and statistics of each participant are shown in Table 14 and Table 15. The post-survey results in Table 20 also show that users maintained a positive attitude toward game elements as a means of promoting learning. However, motivation and stickiness have not improved learning behavior significantly. According to the post-survey results, it could be attributed to the fact that some learning materials were inaccessible in the experimental area.

Conclusion: Gamification (G) has effects on improving individuals' participation and learning performance within the group and maintaining learning motivation to certain extent.

RQ 4. Which is more suitable for the targeted learning, FOE or FOE+G (or the control group)?

Discussion: Comprehensive comparisons and analyses of all types of experimental data listed above, as well as discussions and conclusions on FOE and G, indicate that FOE works on participation, learning engagement, as well as knowledge acquisition and retention in terms of the entire group. This can be reflected in different types of group mean values (Group_Mean). Groups FG and F with the FOE function outperform group C in all aspects. However, the results of Q4 in Table 19 show that participants in groups FG and F did not hold a positive attitude toward frequent notifications, with 3.18 for group FG and 2.92 for group F. More than half of the participants considered only one piece per day acceptable. Even though notifications affect user learning attitudes and behaviors, the frequencies of notification clicking and learning are not as expected (Figures 15, 16, 17, 18, and 19). High FOE can activate learning behavior but may demotivate or bother participants.

Gamification is used to make earthquake education more engaging to partially offset the negative effects of FOE.

Gamification helps to keep participants motivated for a long time, increases the level of individuals' participation and learning performance within the group, and maintains learning motivation, as shown in Table 10 and Figure 21. However, it does not contribute much to the participation of the entire group. This is consistent with the result of a study that game design elements do not motivate the initiation of new user sessions, but can prolong an already started session [50].

Conclusion: Groups FG and F outperform Group C, implying that FOE and FOE+G both worked. In terms of improvement potential, FOE+G is a stroke above FOE.

5.4 Other Findings

The experimental data collected revealed user preferences for the types of learning materials. The learning times and duration for each type of learning material, as well as the corresponding percentage, are shown in Tables 14 and 15. The types "Text" and "Quiz" are the most popular in the three groups. However, the types "Vlink" and "Link" are rarely used. A subsequent survey found that the main reasons included “avoiding unknown URLs because of security,” “inaccessible,” “loading the URL very slowly,” “watching video is time-consuming,” and “watching video is costly in case of no Wi-Fi.” These data and surveys assist in customizing learning materials for different target groups and adjusting the weight of types of learning materials to better user experience.

5.5 Limitations

The experiment had the following limitations that may influence its reliability and validity.

1. The participants were limited to Chinese, and the app’s effects revealed from the experimental results cannot be applied to all foreigners. The app should be re-designed on the basis of participants’ learning styles, region, culture, and other circumstances.

2. It was not prohibited for participants to disable the app or make any notification settings (customizable at the OS level). Therefore, some participants may never view notifications from the beginning of the experiment. In addition, the app sometimes could not receive notifications because of uncontrollable technical issues, such as information security (blocking) at the border.

3. Notifications (ENs and DTNs) may have caused participant frustration and a negative attitude toward the experiment. The negative attitude may have caused some participants to be demotivated and clear notifications directly, or even disable notifications through OS settings. Gamification can partly neutralize users’ negative attitudes, thereby prolonging the motivation period.

4. The prototype application used in the experiment had a fixed small-size knowledge database, which leads to tips that are easily repeated. The repetition of the same tips (knowledge) may have made participants lose interest gradually.

6 Conclusion and Future Work

In this study, EE targeting foreigners planning to visit Japan was implemented.

Given the earthquake situation in Japan, to increase their chances of surviving a possible strong earthquake and ensuing tsunami, foreigners must be equipped with adequate earthquake survival knowledge and skills.

Japan attaches great importance to the implementation of comprehensive EE for foreigners living in Japan. Foreigners exhibit many opportunities to be exposed to various earthquake knowledge and lectures in Japan. However, the EE situation of foreigners in Japan is not as satisfactory as that of the Japanese. Different factors contributed to this situation, though the importance and necessity of EE are widely recognized.

Based on the current situation, the implementation of EE in this study has been started forward on the timeline before arriving in Japan. Next, implementing EE before arriving in Japan gains more learning time and opportunities, which contributes to the following: 1. avoiding neglecting EE due to being busy and not having enough time after arriving in Japan; 2. knowing the specific earthquake situation in Japan in advance and helps build earthquake crisis awareness in advance, which not only motivates foreigners to engage in EE currently but also imposes a long-term positive influence on users' psychological tendency for EE; 3. mastering the core earthquake survival knowledge in advance, which enhances survivability, helps build confidence to face unexpected strong earthquakes, and eliminate the negative impact on visiting Japan that may be caused by frequent earthquakes.

Therefore, this study proposes two research goals: RG1. help the target group to build earthquake awareness in advance; RG2. help the target group to master core earthquake survival knowledge in advance. The research target is foreigners who are interested but have not yet arrived in Japan. To provide remote EE to the research objects, ICT was required. Highly developed ICT, increasingly popular networks, and affordable smart mobile devices are the cornerstone and boost of this study.

To achieve these research goals, a learning model called "FOE+G" was proposed. The FOE is the frequency of earthquakes in Japan, and G is gamification. Based on this learning model, an ICT system was designed and developed to implement EE for the target group. To enable the system to be available widely, the system is designed and developed as a cross-platform application and currently supports iOS and Android mobile operating systems. In this system, the main form of FOE to be presented are notifications. When an earthquake occurs in Japan, a notification will be pushed with the details of the earthquake to the user's cell phone, as well as an earthquake knowledge tip or a URL navigating to an earthquake knowledge learning page. That is, a FOE is an arousal event that draws user attention, thereby increasing earthquake crisis awareness. Also, it is a learning opportunity to learn efficiently under a high level of attention. In addition, G is used to increase the fun of EE, increase users' stickiness to the application, and improve the participation level and learning performance.

To quantify the contribution of FOE and G to the achievement of the research goals, four RQs were posed in the research:

RQ 1. To what extent does FOE contribute to raising earthquake awareness?

RQ 2. To what extent does FOE contribute consequently to improving learning (earthquake knowledge acquisition)?

RQ 3. To what extent does G (Gamification) contribute to keeping motivation?

RQ 4. Which is more suitable for the targeted learning, FOE or FOE+G (or the control group)?

An experiment verifies that the system achieves the expected research goals.

FOE exhibits a significant impact on raising the earthquake crisis awareness of foreigners. Simultaneously, participation in EE was significantly improved, and to a certain extent, learning behavior and performance were improved.

Helping users establish earthquake crisis awareness is an important prerequisite for improving EE. Demonstrating a good sense of an earthquake crisis can result in a long-term influence on motivating users to participate in EE. The FOE converts earthquake occurrences into wake-up events in the form of notifications, influencing users' cognition of real earthquake hazards in Japan, as well as the resulting risk-aversion psychology, that is, earthquake crisis awareness. Earthquake crisis awareness motivates users to exhibit behaviors that can reduce earthquake hazards, such as participating in EE and mastering survival knowledge and skills to offset the negative psychological effects of earthquakes. Therefore, FOE helped build earthquake awareness while contributing to greater participation in EE and learning behaviors.

Gamification (G) rarely increases earthquake awareness and overall engagement. However, it demonstrates a certain impact on improving individual learning performance and maintaining learning motivation. Well-designed game elements and mechanics make EE more attractive. In addition, gamification changes people's behavior and habits, affecting people's psychology. It aids in generating intrinsic motivation, which is necessary to maintain long-term motivation to participate in EE.

In conclusion, the system based on the "FOE+G" learning model achieved the expected research goals. To receive earthquake education in advance in home country gains sufficient time as learning opportunities, which largely solves the problem of easy neglect of EE due to busyness after arriving in Japan. Users who are well-equipped with earthquake awareness and knowledge can enhance their confidence in dealing with earthquakes and increase their chances of earthquake survival.

In addition, there is some future work. The research group is foreigners, so addressing the language barrier is necessary. At present, the system only supports English and Simplified Chinese, and languages with a large proportion of foreigners in Japan, such as Korean and Vietnamese, etc., are all in the plan list. Different cultural backgrounds or customs in different countries have a certain impact on users' learning preferences. The contents and formats of earthquake education provided should vary. The follow-up needs to understand more user preferences, so as to have different emphases on educational contents and forms.

Finally, gamification plays a role in education, but it is also closely related to different cultural backgrounds and customs. When designing and applying gamification, it is necessary to consider the preferences of different target groups to work better in promoting participation in earthquake education and maintain long-term incentives. Likewise, the well-designed UI is user-friendly. The UI of the application needs to be partly redesigned to improve user experience.

Besides, the experiment also exposed some problems. At present, the App uses a fixed small knowledge base with less content. Subsequent improvements are needed to support updating the new knowledge base from the server. Participants did not harbor a positive attitude towards frequent notifications, most of the feedback from the post-questionnaire was once a day. In addition to the customizing notification trigger threshold that has been implemented, further improvements are needed in the future. Consider using intensity rather than magnitude as a trigger threshold, as well as support for aggregated notifications. The aggregated notification is a collection of all the earthquake information of the previous day delivered regularly once a day. Users can also customize the time point to receive aggregated notifications.

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Publications

Journal

1. "A Mobile Application for Earthquake Education Targeting Foreigners Intending to Visit Japan" Liu, M., Mitsuhara, H., and Shishibori, M. International Journal of Interactive Mobile Technologies (iJIM), Vol.16, No.24, pp.170–190, Dec. 2022, Published.

Conference

1. "Make it Fun: The Application of Gamification in Earthquake Education for Foreigners" Liu, M., Mitsuhara, H., and Shishibori, M. Proc. of the 28th International Conference on Computers in Education (ICCE2020), Vol.2, pp.240–245, Nov. 2020, Published.

2. "Exploring the Application of ICT base Disaster Education System for Foreigners in Japan" Liu, M., Mitsuhara, H., and Shishibori, M. Proc. of the 27th International Conference on Computers in Education (ICCE2019), pp.217–224, Dec. 2019, Published.

A Pre-questionnaire

1. Age
   a. Under 18 b. 18 – 25 c. 25 – 30 d. Over 30
2. Gender
   a. Male b. Female
3. Have you ever experienced strong earthquakes?
   a. Yes b. No
4. Do you know something about earthquake and surviving earthquake?
   a. Not at all b. A little c. Very well
5. Do you know the earthquake situation in Japan?
   a. Not at all b. A little c. Very well
6. Have you ever attended earthquake education?
   a. No b. Only once c. Twice d. More than twice
7. Have you ever participated in earthquake evacuation drills?
   a. No b. Only once c. Twice d. More than twice
8. Would you like to attend earthquake evacuation drills?
   a. Yes b. No
9. Would you like to attend earthquake education?
   a. Yes b. No
10. Choose the learning methods you prefer, multichoice.
    a. Offline face to face
    b. Learning through software
    c. One-time intensive learning
    d. Decentralized learning, using time fragments
11. Choose items you want to learn, multichoice.
    a. Seismic features
    b. Earthquake hazards
    c. Prepare in advance for eartquakes
    d. What to do in case of an earthquake

e. What to do after an earthquake

f. Earthquake and Tsunami Evacuation Drills

g. Post-earthquake psychological counseling

12. Write down others you want to learn.

B Post-questionnaire

1. The App is easy to use

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

2. App has rich learning materials

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

3. I enhanced my earthquake awareness by the App

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

4. I have mastered basic knowledge of surviving earthquakes by using the App

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

5. I like this learning mode on the APP

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

For groups FG and F only

6. Earthquake notifications enhance my earthquake awareness

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

7. Tip on the notification promotes me to learn earthquake knowledge

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

8. Earthquake notifications promote me to learn earthquake knowledge

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

9. Frequent notifications will be acceptable

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

For group G only

10. Do you agree that gaining points prompts you to learn earthquake knowledge?

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

11. Do you agree that gaining badges prompts you to learn earthquake knowledge?

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

12. Do you agree that daily attendance reminds you to learn earthquake knowledge?

   1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

13. Do you agree that gamification is useful?

    1. Strongly disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly agree

C Surprise Test

1. You are at home, a strong earthquake happens

a. I am living in high floor, and run downstairs immediately

b. Drop down beside the window and wait for rescue

c. Cover under table, in case of no table, drop down and protect head using handy items

d. I am living low floor, just jump out of the window directly

2. You are in classroom, a strong earthquake happens

a. Escape outside along stairs quickly and orderly

b. Jump outside by window

c. Squat down against the wall in corrido

d. Cover under desk and hold on desk legs

3. You are in the elevator, a strong earthquake happens (multi choices)

a. Force to open elevator door in case of the door can't be opened

b. Push all floors and escape downstairs when elevator stops and opens, in case of stuck, push the 'emergency' button and wait for rescue

c. If the door is stuck, push the 'emergency' and wait for rescue

d. Try to climb up to the top to escape in case of the elevator can't be opened.

4. You are walking on street, a strong earthquake happens

a. Squat down immediately, protect head by handy objects

b. Squat down against wall or pole, protect head and avoid broken glass pieces billboards, etc.

c. Observe and quickly move to a nearby open place, stop and squat in case of strong shaking, move again when the shaking is slowed down, protect head and watch out falling objects.

d. Just follow the crowds

5. You are in movie theatre, a strong earthquake happens

a. Rush to the exit immediately to escape outside

b. Squat down between seat, and protect head by handy object, watch out falling items, avoid large light above

c. In a panic and do not know what to do

d. Exit by elevator immediately

6. You are in library, a strong earthquake happens

a. Rush to the exit and escape by elevator

b. Squat down against bookshelf, protect head by bag or book as possible

c. Cover under table, or squat down against wall or pole, protect head by bag or book as possible

d. Stay near window or door, easy to escape or rescue

7. You are taking subway, a strong earthquake happens

a. Follow the crowds

b. Go consult staff

c. Break the window by life hammer, then escape along the track

d. Hold on seats or ring, or squat down and hold on seats' legs, protect head by handy item as possible, and follow staff instruction after shaking

8. You are in office, a strong earthquake happens

a. Do not care and keep working

b. Cover under the working desk and hold on desk legs, or squat down far away windows and file cabinets, protect head by handy items as possible

c. Immediately run outside by stairs

d. Fast escape by elevator

9. What items should be prepared in the emergency kit? (Multi choices)

a. Copies for ID cards

b. Valuable ornaments

c. Some cash

d. Drinking water

e. Can food

f. Coat

10. You are on a bridge, a strong earthquake happens

a. I am riding on bike and speed up to leave the bridge immediately

b. Run fast away from the bridge

c. Stop and squat down, hold on handrails or railings to avoid fall, after shaking, quickly leave the bridge

d. Stay in the middle of the bridge

11. After shaking, what should you do first?

a. Contact my family

b. Put out fire

c. Open the door

d. Read news

12. When you receive tsunami warning, what should you do?

a. Go to the nearest shelter by car

b. Contact and wait for family to escape together

c. Immediately walk to shelter with the emergency kits

d. Take valuable items to shelter

13. What items should be prepared in the emergency kit? (multi choices)

a. Household medicine and medicine for special illness

b. Tissue and wet tissue

c. Woman's items in case of needs

d. Tableware

14. Your are in bath, a strong earthquake happens

a. Immediately put on clothes and prepare to run outside

b. It's too late to get dressed, so run out immediately

c. Squat down against a solid wall or bathtub, and use a towel to cover your head

d. Lying by the side of the bathtub

15. You are in toilet, a strong earthquake happens

a. Immediately put on clothes and run outside

b. Immediately open the bathroom door, squat down, cover your head with the items at hand to prevent tile fragments, and don't go out rashly

c. Immediately put on clothes and run to the room, looking for a place to hide

d. The bathroom is relatively small and sturdy, and it is a relatively safe place during an earthquake. sit on the toilet and wait for the shaking to slow down

16. You are in public or vehicles

a. Immediately return to residence

b. Immediately call family and friends to confirm safety

c. Continue with unfinished business

d. Follow the instructions of the broadcast or the staff, listen to the follow-up information, and determine whether you need to evacuate

17. You are by water, a strong earthquake happens

a. Run a little far from water and then squat down, protect head by handy items, escape far from the water after shaking.

b. Squat down immediately, and protect head

c. Follow other people

d. Keep playing after shaking

18. Which are correct?

a. There is no need to check and fix items in the room that are prone to collapse and fall

b. It is important to keep calm during a strong earthquake

c. It is important to participate in earthquake evacuation drills

d. I don't need to know the earthquake resistance level of the residence

19. What should you do during a strong earthquake?

a. Take my valuables then escape

b. Contact my family and friends

c. Protect myself first of all

d. Put the fire out

20. Where should you get information after a strong earthquake

a. From official medias

b. From neighbors

c. From friends

d. From some private social medias

21. What items should be prepared in the emergency kit? (multi choices)

a. Baby items in case of needs

b. Quilt and pillow

c. High-calorie, small-volume and easy-to-preserve food

d. Thin and light warm products

22. You are driving in a long tunnel, a strong earthquake happens

a. Drive fast out of the tunnel

b. Stay in car, and drive out of the tunnel after shaking

c. Back the car out of the tunnel

d. Stay in car, and walk out of the tunnel after shaking

23. Which of the following options are correct? (multi choices)

a. It is important to be familiar with escape routes

b. No need to know the location of the safe passage

c. It is very important to prepare an emergency kit

d. Knowing where the nearest shelter is important

e. It is important to keep calm in earthquake

24. You are in parking, a strong earthquake happens

a. Drive away quickly

b. Hide between cars or open places, protect your head, and leave on foot after the shaking stops

c. Hide between cars or open places, protect your head, and drive away immediately after the shaking stops

d. Park the car in the parking lot and leave immediately on foot

25. You are in supermarket, a strong earthquake happens

a. Immediately rush to the exit

b. Squat down away from the shelf, protect your head, and follow the instructions of the staff to evacuate after the shaking is suspended

c. Squat next to the shelf, and try to use the items at hand to protect the head, and follow the instructions of the staff to evacuate after the shaking is suspended

d. Get into a panic and stay where you are, not knowing what to do