Disaster learning through a map-based mobile application: an evaluation of its readability and user satisfaction

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Abstract. Mobile technologies have become a key potential learning tool for the public in this digital era, particularly for young people. The Indonesian government, through its National Disaster Management Agency, has developed and launched a mobile application called InaRisk Personal to help citizens become more aware of disasters. This paper aims to assess whether this map-based application is effective and efficient as a disaster learning tool for senior high school students by evaluating its readability (efficiency and accuracy of map interpretation) and overall satisfaction with the application by surveying 361 students in West Java, Indonesia. This study also compared the application with printed disaster maps obtained from local governments to roughly examine its performance. The findings show that both measurements (readability and user satisfaction) were higher for the application. We also found that most students prefer to learn about disasters through cartographic visualization on the mobile application with suggestions for improvements compared to the printed maps.

1 Introduction
One of the main priorities of disaster risk reduction is risk understanding. Understanding the causes, effects, and geographic patterns of local hazards is essential in enhancing awareness of disaster hazards and making educated decisions about how to respond to the threat [1]. Understanding disaster risks may be easier for those with personal experiences in disaster as they can influence one’s disaster knowledge and awareness. However, with these experiences, people are needed to be reiterated of information about disaster risks, to maintain them being well-prepared for the future occurrences. Thus, providing a tool for learning disasters that is usable and widely accepted by people with or without disaster experiences is essential.

Risk understanding may be enhanced through disaster learning by utilizing various tools. Maps can be one of these tools as disasters have a strong spatial component [2]. Hazard, risk, and evacuation maps, both in the printed form and as an interactive tool, are examples of how spatial information is used to learn the geographical pattern of disasters. Printed maps used to be the most common medium, for example, to prepare people for emergency evacuation. Unfortunately, these types of maps are poorly understood and often ignored by people [3]. Advances in mobile and geographic information technology and the revolution in online maps, particularly after the invention of Google Maps in 2005 and its mobile version in 2007 [4], have altered how maps are produced, distributed, and used. Map-mediated risk communication is no longer limited to the use of static or printed maps, which may provide little functional benefit. Maps now are more interactive, allowing users, at the very least, to pan the map, zoom in and out, share their location, and search for points of interest [5]. They are often designed to be more user-friendly and more uncomplicated than desktop Geographic Information System (GIS) and can also be created at a lower cost [6–8].
New freely available digital maps, mostly incorporated into a disaster information system or formed as an application, have become popular tools for coping with disasters [9]. A map-based disaster application on smartphones and tablets with location-based services enables users to locate themselves on real-time geographic data accurately. With this feature, one mobile device can perform various place-based disaster management decision-support functions, from assisting a person’s routing for evacuation based on traffic flows to conveying place-specific disaster warnings [10].

Maps can serve as one of the most reliable tools for people to gain knowledge when they are interpreted correctly quickly. A properly designed disaster app has the potential to improve the public’s preparedness and response [11]. Although some might have argued that a disaster application with a map feature is a more convenient instrument, some may argue that this version of the map causes the information imbalance, making it less readable due to its smaller display. It is also argued that the currently existing hazard maps or online mapping services still lack a good balance between simplicity and complexity with adequate readability and usability for the public [12]. Therefore, the readability of a map-based application is essential.

In the context of information systems and technology adoption, users’ satisfaction can be a significant determinant for technology adoption [13]. Like the concept used in the information system, in cartographic literature, besides the aspect of readability, maps’ usability is also measured by satisfaction. Satisfaction is a part of the standard satisfaction, efficiency (completion time), and effectiveness (accuracy) (SEE) map usability metrics [14]. Therefore, this study also assesses the satisfaction of a map-based disaster application as part of the evaluation.

There have been extensive studies focusing on the applications (with or without maps embedded in the applications) for learning and increasing knowledge about disasters (e.g., [12,15–25]). However, most of the studies were focused on user-centered design evaluation of the applications. These studies also mostly focused on reviews of the applications’ development. Regarding the map-based disaster application, there has been limited research examining their usability and readability. To the authors’ knowledge, the most recent studies on a disaster application were done by Tan et al. in New Zealand, which focused on the usability of the application [11,16,22,26] with a technology management approach.

Map readability for disaster context has been a concern in several studies, although it did not necessarily refer to disaster applications [27–29]. Out of the disaster context, a study done by Herman et al. [30] evaluated user performance in interactive and static 3D maps, including their readability, and found statistically significant differences between the two types of maps in effectiveness, efficiency, and subjective preference. Another study done by Poplin [31] evaluated online map-based applications and revealed several issues related to interactivity, including the need for explanatory text and proper annotations. However, this study did not specifically focus on the disaster context. Considering the existing studies, this paper, therefore, attempts to fill the gap in this literature.

As a country vulnerable to natural disasters, it is essential for individuals in Indonesia to learn about or have knowledge about disasters. The country is threatened by multiple hazards, mainly geological and hydrometeorological risks, such as earthquakes, tsunamis, volcanic eruptions, flooding, and landslides. The national disaster management agency (Badan Nasional Penanggulangan Bencana (BNPB)) has mapped areas prone to disasters across the country, particularly those susceptible to geological disasters, such as earthquakes, tsunamis, liquefaction, volcanic eruptions, and landslides. The maps are accessible through various web sites and mapping portals. In 2019, the BNPB launched InaRisk Personal, a personalized map-based disaster mobile application, to help the public understand disaster risks. This interactive map-based application allows its users to understand the levels of risk of particular hazards in a specific location and learn actions taken before, during, and after a disaster based on different levels of risks. As an attractive, easy-to-use, and up-to-date application, InaRisk Personal has the potential to be utilized as a tool for learning disasters, particularly for young people.

By considering the issues mentioned earlier, this study aims to assess the potential usability of the application as a disaster learning tool for high school students by examining its readability and user satisfaction. Senior high school students were selected because they represent the largest group of the
Indonesian population (i.e., under 18 years old) and are part of the group with high penetration of internet use and mobile technology [32]. Moreover, in disaster risk reduction, these individuals belong to the vulnerable group and serve as effective messengers in transferring knowledge, including disasters, to their families [33].

2 Study Context

2.1 Disaster learning for children through maps and mobile applications

Disaster education and learning can improve risk understanding as one of the priorities of disaster risk reduction mentioned in the Sendai Framework for Disaster Risk Reduction 2015–2030 [34]. Disaster learning, which refers to any learning about risks and protective measures, can occur in different environments. This learning can influence individuals’ capacity to anticipate, cope with, and recover from natural hazards. By having a proper risk assessment of disasters, individuals are granted access to information and knowledge of threats and ways to assess them adequately. This information includes what kinds of hazards threaten a community, the adequacy of precautionary measures such as emergency supplies, warning systems, emergency plans and management, how to respond and behave during a disaster, and ways to cope with a disaster’s aftermath.

Currently, child participation is gaining recognition as a critical component of disaster risk reduction. This shift involves fostering children and youth towards making their lives safer and their communities more resilient to disasters through disaster education and learning. Several studies have shown that children can significantly contribute to risk reduction actions [35]. The benefit of having children as agents of disaster learning may appear as their willingness to trust the information sources and convey messages with a meaning shared by their families and friends. Children often have a higher capacity, willingness, and opportunity to absorb new information. Furthermore, a child is embedded within his/her family, and this relationship means that risk information and mitigation actions may be continually reaffirmed.

In recent years, the field of disaster education and learning has grown substantially. New technological advancements, such as social media and disaster applications, have opened additional pedagogical space for learning and disseminating information and knowledge [36]. Mobile applications with increasing map interactivity have democratized mapping and spatial data to the public. Maps have become an integral component of most individuals’ daily activities, ranging from use for navigating when traveling or in shopping centers to frequent use in education. Compared to printed maps, online map services, including their mobile versions, offer advantages such as navigation services, connection and integration with a searching database, satellite, and air-plane view (or displaying landscape features from overhead), and zooming and panning tools.

Mobile applications, particularly map-based or mobile map services, might be practical for individuals to understand disaster risks due to the spatial component of disasters [2]. Producing a map-based public awareness building information system is useful as community learning and public awareness building for natural disasters [18,37]. The applications could enhance resilience to disasters, ensure preparedness, and ensure effective responses [38]. By integrating the applications with mapping features, the application could provide safety information and guide users to safer places and show prediction and visualization of a particularly hazardous area [39,40]. Given that children, especially teenagers, are the group with the highest internet penetration and increased numbers of mobile device users, they can serve as effectively targeted users for disaster learning through a mobile application. These applications can be used as tools of disaster e-learning for children and young people. Digital maps can offer above and beyond traditional maps in the education and learning process [41]. With the location-based features provided by a map-based mobile application, they can see their current location and the maps’ related environment in real-time and with relatively accurate locations. In the case of disasters, this feature is essential in understanding one’s position in areas at risk of natural hazards.

A study done by Meltzer et al. [20] found that hazard maps are the most crucial feature of a disaster application on smartphones in the response phase. Specifically, for the case of respondents who are
within 14-18 years old, they found that information about first aid, information on proper behavior in the case of a natural disaster, GPS tracking, and interactive maps as the most useful functions that a disaster application should fulfill.

2.2 Readability
A simple provision of disaster application does not guarantee that the targeted users will discover the most effective means of using the application for disaster learning. Moreover, although maps can be an ideal way to learn about the hazards spatially due to their strong visual impact, the incorrect use of cartographic techniques can lead to inaccurate interpretations of the message [42]. An application needs to be easy to use and understand by the users for optimizing its utilization. In the context of maps or spatial information, perceived ease of use can be represented as map readability. Map readability is the process of the user’s representation of the information on the map in his/her mind. This representation can be estimated quantitatively by surrogate measures, including the speed of map comprehension and accuracy of map interpretation. Traditionally, cartographers have been responsible for ensuring the readability of maps. However, because of the digital revolution in cartographies, many maps’ readability is not controlled by cartographers.

Readability is a component of map quality and the antecedent of map usability. Readability assessment is usually reflected in rating from “easy to read” to “hard to read.” Traditionally, cartographers were responsible for ensuring maps’ readability. However, because of the digital cartographic revolution, particularly of the use of the Internet, many maps are not controlled by cartographers.

Readability can also be defined as the degree of difficulty in reading a map, the degree of difficulty or ease in obtaining information about objects and phenomena from their cartographic representation [43]. Several studies have highlighted the following problems associated with readability [44]:

- The map is less readable when it provides too much information;
- The message supposed to be conveyed by the map is not clear because graphic semiotics rules are not represented; and
- Users experience difficulties in determining which rules should be applied and how to apply them.

This paper defines readability as the user’s ease (or difficulty), accuracy, and rapidity (speed) of representation (comprehension of content) of the map [43]. Readability is the effectiveness of the man-map system’s functioning, which depends on an aggregate of psychological factors and is manifested in the speed and accuracy (freedom of errors) of the performance of specific tasks. Difficulty or ease is an internal and subjective measurement, whereas accuracy and rapidity are objective external indicators of map reading effectiveness. Difficulty or ease is an internal, subjective aspect of the representation process characterized by the degree of effort expended by the user in reading the map. Speed is defined as the time taken to understand cartographic information, which is an objective external indicator of the effectiveness of this process.

2.3 User satisfaction
Satisfaction is an element of the standard usability performance metrics of an interactive digital map [14]. These performance metrics are employed to assess how easy the product or system is to use. Satisfaction refers to a user’s attitude or preferences concerning a system and is generally regarded as one of the determinants of information system success [13,45]. Satisfaction in this study is defined as the extent to which users believe that each feature of the application meets their expected satisfaction.
3 Methodology

The purpose of this study is to examine the readability and user satisfaction of a map-based disaster mobile application. Readability was measured by two components, namely the speed of response time and accuracy [14,43]. This study also compared the application with printed disaster maps obtained from local governments to identify its performance further.

The study addressed the three following research questions:

- How readable is the map-based disaster learning application? How does the readability of the application differ over respondents’ characteristics? Is the application more readable than the printed maps?
- Are participants satisfied with the application? Is the application more satisfying than printed maps?
- Do participants prefer the application than printed maps in learning about disasters? How do readability and satisfaction may influence this preference?

Overall, this study is descriptive. However, some variables were analyzed using paired t-tests to see how they differ in a particular situation.

3.1 Measurements

While the satisfaction variable was fully measured by items representing users' subjective perceptions, two approaches: objective and subjective, were used to measure the application's readability. These two approaches are sensible since readability depends on an aggregate of psychological factors and is manifested in the speed and accuracy (freedom of errors) of the performance of specific tasks. Furthermore, while the subjective, self-estimate measurement focuses on the difficulty or ease of using the application, the objective measurement one highlights the actual accuracy and rapidity of map reading effectiveness. Two map-use tasks: spatial understanding and pattern recognition [30,46] with focus on the accuracy (whether participants can correctly complete the tasks) and the calculation of the completion time (to measure the speed) for analyzing hazards threatening participants’ school were given during the trial session.

3.2 Materials

To examine the readability and user satisfaction of a map-based disaster application for disaster learning, this study used a disaster application in Indonesia called InaRisk Personal and compared its performance with that of printed disaster maps regularly disseminated by local governments. Although the result may be biased due to the maps’ different contents, this comparison can provide additional insight to illustrate how various types of maps may result in different readability levels. Thus, local governments of the study areas may consider having their own self-developed disaster map-based applications as a complement to their regular disaster map dissemination.

3.2.1 InaRisk Personal. BNPB or the national disaster management agency has mapped areas prone to disasters in Indonesia up to the scale of 1:50,000 (regency level) and 1:25,000 (city-level). These maps can be accessed through several websites, namely Geospasial Bencana (available at http://geospasial.bnpb.go.id), Data dan Informasi Bencana or DIBI (available at https://bnpb.cloud/dibi/) and InaRisk (available at http://inarisk.bnpb.go.id). The public can access various data and information, ranging from the spatial distribution of disaster occurrences, specific locations of disasters, the level of threat, vulnerability, and capacity. However, this geographical information about disasters has not been widely accessed by the public. This low adoption may occur due to the lack of dissemination and limited supportive facilities (e.g., stable Internet connections). Also, the maps are mostly built as web-based and only optimized for a desktop interface. Meanwhile, the high proportion of Indonesian Internet users preferred to use smartphones or tablets to access the Internet (83.44%) according to the Indonesia Internet Service Provider Association’s survey in 2017.

To reach broader audiences and make the application more personal, BNPB collaborated with various institutions and developed a more personal disaster learning application, i.e., InaRisk Personal.
This map-based mobile application is available on Android and iOS platforms. As of July 2020, this application has been downloaded over 100,000 times with a 3.6 rating in Google Play Store. The application can display various location-based disaster risk levels. Initially, there are six kinds of hazards on the app: earthquakes, flooding, flash flooding, landslides, volcanic eruptions, and tsunami. BNPB then added COVID-19 to support risk communication during the pandemic (Figure 1). Users can select their preferred base maps as either satellite, street map, or terrain. The application also provides suggestions on actions that should be taken before, during, and after the disaster. There are also videos about disasters in Indonesia that users can watch to understand dangerous events caused by natural hazards visually. Users can also perform a building assessment to determine how secure the building is resistant to earthquakes.

Figure 1. Examples of InaRisk Personal’s Interfaces on iOS.

3.2.2 Printed maps. There were different numbers and types of maps used at each school, depending on the maps’ availability in each municipality (see Appendices for the maps). This study only used maps that may be applicable for risk communication and disaster learning. Thus, only maps with disaster-related content were selected. Once the maps were obtained from local government agencies, they were next prepared and printed on A3 papers (a typical size used for map dissemination by local governments in Indonesia). In Tasikmalaya 1 and Tasikmalaya 2 senior high schools, there were two maps used for the map reading trial: (1) Spatial Pattern Map and (2) the Earthquake Hazard Map of Tasikmalaya. These two maps were obtained from the Development Planning Agency (Bappeda) in Tasikmalaya. Two maps were also distributed to students in Garut 1 senior high school, namely (1) Spatial Pattern Map and (2) the Disaster-Prone Area Map of Garut. Both maps were collected from the Bappeda of Garut Regency. At Sumedang 3 senior high school, there were three maps given to the participants, namely (1) Earthquake Hazard Map, (2) Flood Hazard Map, and (3) Disaster-Prone Area Map of Sumedang. The maps were obtained from the Bappeda of Sumedang Regency.

3.3 Participants
A total of 362 participants completed this study. Due to missing data, one set of data from a participant was omitted, making the final number of respondents 361. Quasi-experimental testing with pre- and post-questionnaire filling was conducted in February 2020. While the whole survey was not intended only for assessing readability and satisfaction but also for examining the other determinants of the application’s adoption or use, this paper, however, only explains some results of the testing. The results presented in this paper are only related to readability and satisfaction. Students were gathered with the help of local government officers and teachers from four senior high schools from Tasikmalaya, Garut, and Sumedang, West Java, Indonesia. The schools were selected with consideration of types of hazards,
availability of supporting facilities, faculty willingness, and permission. Public schools were selected since they can represent the middle-class population, representing the entire population.

Based on consultations with teachers and school curricula personnel, participants were selected from the 11th and 12th grades and those enrolled in Natural Sciences and Social Sciences. For more details about gender, age, and school origin, see Table 1. Participants agreed to the experimental procedure, participated voluntarily, and could withdraw freely from the experiment at any time (for example, in Garut, some students withdrew from the experiment due to other tasks given by the school or student meetings). All of the participants had a normal or corrected-to-normal vision. One participant from Sumedang, who had slight color blindness, could still distinguish colors appropriately on the map. The environmental conditions were kept constant for all participants except for the Internet connection. Some schools had difficulties in stabilizing the Internet connection.

As seen in Table 1, the participants were mostly female students aged between 16 and 17 years, with an almost equal proportion of those from natural and social sciences. Most (66.2%) of the students had experienced disasters, 72.6% had participated in socialization about disasters at school, and 38.2% had joined disaster simulation(s).

| Table 1. Participants’ characteristics (N=361). |
|-----------------------------------------------|
| Sex                                           |
| Female                                       | Male |
| 202 (56.0%)                                  | 159 (44.0%) |
| School                                       |      |
| Tasikmalaya 1                               |      |
| 53 (14.7%)                                   | 120 (33.2%) |
| Garut 1                                      | 124 (34.3%) |
| Tasikmalaya 2                               |      |
| 64 (17.7%)                                   |      |
| Garut Regency                                | 124 (34.3%) |
| Sumedang Regency                             |      |
| 120 (33.2%)                                  |      |
| Municipality                                 |      |
| Tasikmalaya                                  | 117 (32.4%) |
| Garut Regency                                | 120 (33.2%) |
| Sumedang Regency                             | 124 (34.3%) |
| Age                                          |
| 15 years old                                 | 143 (39.6%) |
| 16 years old                                 | 143 (39.6%) |
| 17 years old                                 | 176 (48.8%) |
| 18 years old                                 | 31 (8.6%) |
| Class Grade                                  |
| XI                                           |
| 302 (83.7%)                                  | 59 (16.3%) |
| Natural Sciences                             | Social Sciences |
| Majors                                       |
| 183 (50.7%)                                  | 178 (49.3%) |
| Prior use of InaRisk Personal before the survey |
| Yes                                          | No   |
| 15 (4.2%)                                    | 346 (95.8%) |
| Experienced disasters                        |
| Yes                                          | No   |
| 239 (66.2%)                                  | 122 (33.8%) |
| Participated in socialization about disasters at school |
| Yes                                          | No   |
| 262 (72.6%)                                  | 99 (27.4%) |
| Joined disaster simulation (s) at school     |
| Yes                                          | No   |
| 138 (38.2%)                                  | 223 (61.8%) |

3.4 Procedure

This research involved several stages. Firstly, students were asked to fill a set of questions about their demographic and other personal characteristics. Before doing trials of the application and static map reading, students were given brief explanations about the applications and the maps by researchers helped by research assistants, teachers, and supporters from local government officials. Before testing, participants were instructed that their response times would be recorded and that it would be ideal to do the tasks in pairs or a group. These response times would further be analyzed as the efficient variable, and one of two items was used to measure readability as a whole. Times were calculated in seconds (and milliseconds, if possible).
As the main task, participants were asked to identify kinds of hazards that may be threatening to their school by performing a set of map-use tasks using the application. These map-use tasks were a combination of two tasks that are usually given to measure the performance of a map: spatial understanding and pattern recognition [14]. Students were given a maximum of 20 minutes (1,200 seconds) for each task. First, students were asked to find the location of their school on the maps. Once they have located the school, students need to interpret the map and identify the types of natural hazards that may threaten their school by analyzing the pattern and shades of hazards coloring their school area. A table with rows showing ten kinds of hazards and four columns of risk levels (high risk, medium risk, low risk, and no risk) and one additional column stating “I do not know” were given to respond to the following question: “Based on the application or the maps, my school is at risk of …”. The ten different kinds of hazards include flooding, flash flooding, landslides, extreme weather, droughts, earthquakes, tsunamis, wildfire, volcanic eruptions, and extreme waves and abrasion. Participants must identify and answer each type of hazard, meaning that all rows had to be checked. Answers given on this table were used to assess the effectiveness or accuracy.

If students could answer kinds of hazards with their risk level correctly, they were labeled 1. They were labeled 0 otherwise. For example, based on the risk map displayed on InaRisk Personal, Garut 1 senior high school is at medium risk of earthquakes, medium risk of flooding, and low risk of volcanic eruptions. Therefore, students from this school were classified as having given a correct answer if they put a check or marked cells representing those three risks. The other three risks (tsunamis, landslides, and flash flooding) displayed on the application but not applicable to the school should be marked as no risk. Students could either put marks on no risk or “I do not know” for the remaining four hazards since they were not displayed on the application.

Once the application trial has finished, students were also asked to answer questions on perceived readability (perceived ease of use the app or maps) and user satisfaction. These two variables were measured with a five-point Likert scale (1 - strongly disagree to 5 - strongly agree). These procedures above were also applied when using the printed maps. The whole session was closed after students answered a set of questions about disaster spatial information source preferences. In the final phase, students were asked whether they preferred InaRisk Personal or conventional static maps.

4 Findings

4.1 Readability

Readability was assessed using two approaches. Firstly, the assessment was based on an objective examination from an experimental session, which included InaRisk Personal and map-reading trials. The second approach was a more subjective assessment based on participants’ perceptions.

4.1.1 Measured readability. The total completion times needed by the participants to examine the types of natural hazards threatening their school (for students with both correct and incorrect answers) by using InaRisk Personal were reported as follows: minimum of 1.90 seconds, maximum of 318.16 seconds, and mean of 34.68 seconds. The minimum time needed for first locating the school on the application was less than one second, as recorded by the participants while the maximum was 76.00 seconds. On average, they need 3.41 seconds. To analyze the types of hazards and their level, which threaten their school from the app’s map, they needed a minimum of one second and a maximum of 317.16 seconds. On average, the time needed to complete this pattern recognizing tasks was 31.27 seconds.

When using printed maps, students need more time to accomplish the tasks. The minimum total completion time was 21.00 seconds, while the maximum time was 631.00 seconds. On average, it took 153.64 seconds to locate the school and examine the hazard of threatening the school based on the information displayed on the printed maps. See figure 2 to compare the total completion time needed by students for accomplishing each task both when using the application and printed maps. The data were first normalized by having them logged.
Figure 2 shows that the application is more efficient than the printed maps for analyzing hazards, as shown by the shorter time needed for accomplishing the tasks. There was clear evidence that by using InaRisk personal, respondents can more quickly locate the school. Results of paired samples T-tests suggested significant differences at a 5% significance level for all pairs of time differences for all tasks: locating school ($t=-35.27$, df=360, Sig. (2-tailed)< 0.000); analyzing the risk pattern ($t=-24.35$, df=360, Sig. (2-tailed)< 0.000); both tasks ($t=-31.98$, df=360, Sig. (2-tailed)< 0.000).

Table 2 shows how the completion time for analyzing hazards using InaRisk Personal differs over respondents’ demography and other characteristics.

Table 2. Self-reported completion times for examining natural hazards at school using InaRisk Personal by respondents’ characteristics (N=361).

| Respondents’ Characteristics | Time to locate the school (in seconds) | Time to analyze the risk pattern (in seconds) | Total completion time (in seconds) |
|-----------------------------|--------------------------------------|---------------------------------------------|---------------------------------|
|                             | Mean | SD   | Mean | SD   | Mean | SD   |
| Total                       | 3.41 | 6.53 | 31.27| 32.54| 34.68| 34.18|
| School                     |      |      |      |      |      |      |
| Tasikmalaya 1               | 1.19 | 2.05 | 13.50| 10.03| 14.69| 10.17|
| Tasikmalaya 2               | 4.67 | 8.86 | 23.14| 16.62| 27.81| 19.24|
| Garut 1                    | 3.37 | 7.89 | 40.39| 29.35| 43.76| 32.88|
| Sumedang 3                 | 3.77 | 4.41 | 34.23| 42.68| 37.99| 43.03|
| Sex                        |      |      |      |      |      |      |
| Female                     | 3.31 | 6.02 | 32.26| 32.05| 35.58| 32.59|
| Male                       | 3.54 | 7.14 | 30.00| 33.22| 33.54| 36.17|
| Age                        |      |      |      |      |      |      |
| 15 years old               | 1.02 | 0.71 | 20.55| 17.44| 21.56| 17.36|
| 16 years old               | 3.96 | 8.69 | 29.69| 27.19 | 33.65| 29.56|
| 17 years old               | 3.00 | 4.58 | 32.79| 35.54| 35.78| 36.60|
| 18 years old               | 4.13 | 5.09 | 33.71| 40.82| 37.84| 43.41|
| Class grades               |      |      |      |      |      |      |
| XI                         | 3.36 | 6.82 | 30.01| 27.56| 33.37| 29.62|
| XII                        | 3.72 | 4.81 | 37.69| 50.80| 41.40| 51.41|
| Majors                     |      |      |      |      |      |      |
| Natural Sciences           | 3.50 | 6.36 | 28.67| 26.41| 32.17| 28.00|
| Social Sciences            | 3.33 | 6.71 | 33.93| 37.72| 37.26| 39.46|
| Experienced disasters      |      |      |      |      |      |      |
| Yes                        | 3.46 | 7.48 | 33.24| 37.54| 36.77| 37.67|
| No                         | 3.33 | 4.10 | 30.26| 29.70| 33.72| 32.30|
Results show that students from Tasikmalaya 1 senior high school completed the task faster than students from the other three high schools. While female students located the school more quickly than the male students, they needed more time when analyzing the risk pattern. Younger students and those who came from the natural sciences classes performed faster. Lastly, interesting findings also found that those with no disaster experiences completed the tasks faster than those with disaster experiences.

This study found that more students could answer accurately about hazards threatening their school when using InaRisk Personal than printed maps (figure 3). According to InaRisk Personal, Tasikmalaya 1 senior high school is at medium risk of flooding and medium risk of earthquakes. In contrast, Tasikmalaya 2 has a low risk of flooding, low risk of volcanic eruptions, and a medium risk of earthquakes. Garut 1 senior high school, as displayed on the application, is at medium risk of flooding, low risk of volcanic eruptions, and medium risk of earthquakes. Sumedang 3 has a low risk of flooding and a medium risk of earthquakes. One hundred forty students could identify these hazards as those that may affect their school based on the application’s maps.

Table 3 compares the numbers of students who successfully can and cannot identify the hazards at schools by their characteristics when using InaRisk Personal.

|          | #students with correct answer | #students with incorrect answer | #students |
|----------|--------------------------------|---------------------------------|-----------|
| Total    | 140                            | 221                             | 361       |
| School   |                                 |                                 |           |
| Tasikmalaya 1 | 26                              | 27                              | 53        |
| Tasikmalaya 2 | 7                               | 57                              | 64        |
| Garut 1  | 61                              | 59                              | 120       |
| Sumedang 3 | 46                              | 78                              | 124       |
| Sex      |                                 |                                 |           |
| Female   | 90                              | 112                             | 202       |
| Male     | 50                              | 109                             | 159       |
| Age      |                                 |                                 |           |
| 15 years old | 6                               | 5                               | 11        |
| 16 years old | 60                              | 83                              | 113       |
| 17 years old | 67                              | 109                             | 176       |
| 18 years old | 7                               | 24                              | 31        |
| Class grades |                                 |                                 |           |
| XI       | 123                             | 179                             | 302       |
| XII      | 17                              | 42                              | 59        |
| Majors   |                                 |                                 |           |
| Natural Sciences | 90                             | 93                              | 183       |
| Social Sciences | 50                             | 128                             | 178       |
Meanwhile, based on the printed maps, Tasikmalaya 1 senior high school is at a medium risk of earthquakes. Tasikmalaya 2 has a low risk of volcanic eruptions as it is located on the path of volcano lahar and medium risk of an earthquake. Garut 1 senior high school is at a medium risk of earthquakes and a low risk of landslides. Sumedang 3 is at risk of earthquakes. Only four students could accurately identify the hazards and risks the same as what was presented on the maps. One hundred twenty-nine students could at least answer correctly about types of hazards threatening their school but still answered inaccurately for the other types of hazards. For example, a student from Tasikmalaya 1 senior high school has identified accurately that his school was at a medium risk of earthquakes. However, he also verified that his school was at a low risk of landslides and flooding, which was incorrect.

4.1.2 Perceived readability. Eight items were compared to assess the application’s perceived readability and that of the printed maps (Table 3). Items with the highest ratings for InaRisk Personal are those related to the ease of locating the school and home and ease in finding risks threatening the school, with mean scores of 4.24, 4.22, and 4.16, respectively. The item with the lowest rating is “I can distinguish areas prone to disasters” (mean=4.06). Similar to those of InaRisk Personal, for the printed maps, items stating, “I can easily locate my home” and “I can easily find out risks of any hazards threatening my school” have the highest ratings (mean scores of 3.56, and 3.51, respectively). Moreover, participants also showed the highest agreement on the easiness of finding risks threatening the home when asked about their perceived readability of the printed maps (mean=3.53). The item with the lowest rating for printed maps is “It takes a short time for me to read the maps” (with mean=3.21).

Table 4. Comparing the perceived readability (PR) of both tools (N=361).

| Items | Mean (SD) | Paired differences (InaRisk Personal – Maps) |
|-------|-----------|---------------------------------------------|
|       | Printed Maps | InaRisk Personal | Mean (SD) | SE Mean | t | df | Sig. (2-tailed) |
| PR 1 - It takes a short time for me to read the maps. | 3.21 (0.84) | 4.10 (0.70) | 0.89 (1.03) | 0.05 | 16.34 | 360 | 0.00 |
| PR 2 - I can easily locate my position now. | 3.36 (0.91) | 4.14 (0.63) | 0.78 (1.01) | 0.05 | 14.71 | 360 | 0.00 |
| PR 3 - I can distinguish areas prone to disasters. | 3.44 (0.85) | 4.06 (0.66) | 0.63 (1.01) | 0.05 | 11.76 | 360 | 0.00 |
| PR 4 – I can easily locate my school. | 3.48 (0.89) | 4.24 (0.61) | 0.76 (0.98) | 0.05 | 14.60 | 360 | 0.00 |
| PR 5 - I can easily locate my home. | 3.56 (0.89) | 4.22 (0.65) | 0.66 (1.03) | 0.05 | 12.14 | 360 | 0.00 |
| PR 6 - I can easily find risks of any hazards threatening my school. | 3.51 (0.81) | 4.16 (0.60) | 0.65 (0.91) | 0.05 | 13.61 | 360 | 0.00 |
| PR 7 - I can easily find risks of any hazards threatening my home. | 3.53 (0.80) | 4.13 (0.62) | 0.61 (0.92) | 0.05 | 12.50 | 360 | 0.00 |
| PR 8 - I can easily find risks of any hazards threatening any areas. | 3.43 (0.79) | 4.12 (0.62) | 0.69 (0.93) | 0.05 | 14.21 | 360 | 0.00 |
The paired samples T-test results indicate that there are significant differences at the 1% significance level for all pairs of the perceived readability items. The most significant gap in means was noticed for the statement, “It takes a short time for me to be able to read the maps.”

Table 5 compares how the means value of perceived readability items differ by respondents’ characteristics. The composite value of perceived readability shows students from Tasikmalaya 1, female students, younger students, and those from Natural Sciences and have ever experienced disasters are likely to have higher perceived readability.

### Table 5. Perceived readability of InaRisk Personal by respondents’ characteristics (N=361).

| Respondents’ Characteristics | PR1 | PR2 | PR3 | PR4 | PR5 | PR6 | PR7 | PR8 | PR |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| **School**                  |     |     |     |     |     |     |     |     |     |
| Tasikmalaya 1               | 4.32| 4.36| 4.13| 4.38| 4.47| 4.26| 4.25| 4.28| 4.31|
| Tasikmalaya 2               | 3.98| 4.09| 4.08| 4.22| 4.23| 4.17| 4.09| 4.00| 4.11|
| Garut 1                     | 4.12| 4.11| 4.00| 4.18| 4.10| 4.16| 4.17| 4.16| 4.12|
| Sumedang 3                  | 4.04| 4.10| 4.09| 4.26| 4.21| 4.11| 4.07| 4.07| 4.12|
| **Sex**                     |     |     |     |     |     |     |     |     |     |
| Female                      | 4.13| 4.20| 4.09| 4.29| 4.27| 4.19| 4.18| 4.15| 4.19|
| Male                        | 4.05| 4.07| 4.03| 4.18| 4.15| 4.12| 4.08| 4.08| 4.09|
| **Age**                     |     |     |     |     |     |     |     |     |     |
| 15 years old                | 4.27| 4.45| 4.27| 4.45| 4.45| 4.45| 4.36| 4.45| 4.40|
| 16 years old                | 4.12| 4.15| 4.03| 4.24| 4.26| 4.13| 4.11| 4.11| 4.14|
| 17 years old                | 4.08| 4.13| 4.09| 4.24| 4.17| 4.18| 4.13| 4.11| 4.14|
| 18 years old                | 4.03| 4.06| 4.03| 4.17| 4.19| 4.10| 4.19| 4.19| 4.11|
| **Class grades**            |     |     |     |     |     |     |     |     |     |
| XI                          | 4.12| 4.16| 4.06| 4.22| 4.17| 4.13| 4.13| 4.13| 4.15|
| XII                         | 4.00| 4.07| 4.08| 4.25| 4.19| 4.14| 4.15| 4.05| 4.12|
| **Majors**                  |     |     |     |     |     |     |     |     |     |
| Natural Sciences            | 4.20| 4.22| 4.09| 4.27| 4.19| 4.17| 4.16| 4.16| 4.20|
| Social Sciences             | 3.99| 4.06| 4.03| 4.19| 4.16| 4.13| 4.10| 4.07| 4.09|
| **Experienced disasters**   |     |     |     |     |     |     |     |     |     |
| Yes                         | 4.17| 4.21| 4.11| 4.30| 4.30| 4.24| 4.21| 4.18| 4.21|
| No                          | 3.96| 4.00| 3.97| 4.13| 4.05| 4.01| 3.99| 4.00| 4.01|

### 4.2 User satisfaction

While Table 6 shows the measurements of user satisfaction for InaRisk Personal, Table 7 displays those for the printed disaster maps. Seven items were used to measure user satisfaction in the application (Table 6). Simultaneously, for the printed maps, there were three items (Table 7)—these different numbers are due to different the contents that each type of map provides to the users. In the case of InaRisk Personal, users can watch videos about disasters, earthquake notifications, and brief suggestions of protective actions besides the common hazard or risk maps. Meanwhile, the printed maps can only provide geographical information about at-risk areas.

In general, participants were relatively satisfied with the information given both by the maps and InaRisk Personal shown by the high ratings as the means are all above 3.00. For InaRisk Personal, the three highest ratings were on the information and disaster maps, kinds of hazards displayed on the application, and the protective action suggestions (with means 3.96, 3.95, and 3.93, respectively). For the printed maps, participants rated their satisfaction highly with the information about areas prone to disasters visualized on the maps.
Table 6. User satisfaction items for InaRisk Personal (N=361).

| Items                                                                 | SD | D  | N   | A   | SA  | Mean (SD)   |
|-----------------------------------------------------------------------|----|----|-----|-----|-----|-------------|
| I am satisfied with the information and suggestions on the actions that should be taken before, during, and after disasters | -  | 1.1% | 24.7% | 54.8% | 19.4% | 3.93 (0.69) |
| I am satisfied with the kinds of hazards displayed on InaRisk Personal. | -  | 0.3% | 23.5% | 56.8% | 19.4% | 3.95 (0.66) |
| I am satisfied with the videos explaining disasters caused by natural hazards on InaRisk Personal. | -  | 1.4% | 41.8% | 42.9% | 13.9% | 3.69 (0.72) |
| I am satisfied with the videos explaining how to operate InaRisk Personal. | -  | 1.9% | 40.2% | 44.0% | 13.9% | 3.70 (0.73) |
| I am satisfied with the earthquake notifications on InaRisk Personal.  | -  | 1.1% | 27.7% | 51.8% | 19.4% | 3.89 (0.71) |
| I am satisfied with the information and disaster maps displayed on InaRisk Personal. | -  | 0.8% | 23.8% | 53.5% | 21.9% | 3.96 (0.70) |
| I enjoy using InaRisk Personal.                                       | 0.3% | 1.4% | 24.7% | 51.2% | 22.4% | 3.94 (0.74) |

As there are different numbers of items to measure each tool's user satisfaction, this study only utilized one item for comparing the user satisfaction of both types of maps. The statement representing whether users enjoy using the application, and the maps were chosen for the evaluation. Findings indicated that students enjoyed more using InaRisk Personal than the printed maps (means: 3.94 and 3.46, respectively). The paired samples T-test results indicate a significant difference between that of the InaRisk Personal and the maps at a 1% significance level (t: -9.804, df: 360. Sig. (2-tailed): 0.000).

Table 7. User satisfaction for the Printed Maps (N=361).

| Items                                                                 | SD | D  | N   | A   | SA  | Mean (SD)   |
|-----------------------------------------------------------------------|----|----|-----|-----|-----|-------------|
| I am satisfied with the information about areas prone to disasters visualized on the maps. | 0.6% | 6.4% | 39.6% | 42.1% | 11.4% | 3.57 (0.80) |
| I am satisfied with the various kinds of hazards displayed on the maps.  | 0.8% | 7.5% | 42.1% | 41.8% | 7.8%  | 3.48 (0.78) |
| I enjoy using the maps.                                               | 1.7% | 8.0% | 41.8% | 39.6% | 8.9%  | 3.46 (0.83) |

4.3 Preferred tool for disaster learning

In terms of user preferences and the two different tools, almost all participants preferred InaRisk Personal (344 (95.3%)) to the printed maps for learning about disasters. Most participants (95.6%) would recommend the application to their family members and friends, though they faced lagging and bugs during the trial. As proposed by the participants, some suggestions to improve the performance of the application are as follows:

- Making the application still accessible even without an Internet connection;
- Increasing the speed of operation;
- Using more vivid colors if colors are too pale;
- Enabling of reading out loud or voices;
- Displaying percentages of levels of disaster risk; and
- Adding more features such as weather forecasts and earthquake warning notifications.
5 Discussion

The main questions investigated in this paper regarding the readability and user satisfaction of a map-based disaster application called InaRisk Personal have been addressed. Although more tasks with more comprehensive ranges of users are required to support more reliable results, this study has significantly proven that the application may be practical for learning disasters indicated by the high readability and satisfaction. The application may improve individuals’ geographical knowledge of hazards.

The application also provides greater accuracy and efficiency for learning the geographical distribution of hazards than the printed maps. Findings also show that students rated higher for enjoyment when using the application. These findings provide valuable inputs into a map's readability aspects for specific user groups (i.e., high school children/teenagers).

How readable is the map-based disaster learning application? How does the readability of the application differ over respondents’ characteristics? Is the application more readable than the printed maps?

As demonstrated by this study's results, the application is moderately readable, and it is more readable than printed maps. Respondents locate the school more quickly on the application and interpret the hazards more correctly. For the first task, locating the school, when the completion time was compared to the respondents’ characteristics, it is likely that female and younger students were faster in doing the task. This situation also applied to students from the Social Sciences. For the second task, the results show that male and younger students performed the task faster. However, for this task, students from the Natural Science class did it faster. Overall, the total completion time indicated that male and younger students did both of the tasks faster.

This study found that more female and younger (Class XI) students can accurately interpret the geographical information about hazards. More students from Natural Sciences can correctly interpret the maps. It is interesting because the Social Science students learn and have Geography as one of their curriculum subjects. These findings matched the results of perceived readability.

It is evident that the application demonstrated significantly higher accuracy and shorter completion times than the printed maps. The data indicated that the hazard pattern recognition task might have been more complicated than the locating task because participants took longer to solve it. However, it should be noted that a longer duration is not associated with the effort that led students to the correct answers. This result also applied for the subjective examination of readability as, for all items, the application has higher ratings or agreements regarding its readability than locally produced maps. The findings suggest that the application is easier to use, the information is easier to understand, and the user needs a short time to read the map.

Some issues may be related to the application’s higher readability. First, it is expected that the functional search and location-based features of the application help users to navigate the map. Furthermore, the application is also equipped by various base maps and zooming-panning tools, helping users locate something more accurately on the map displayed on the application. The transparency feature may also help users understand hazard visualization more quickly because it displays quantitative distinctions or differences in importance or intensity. This transparency is often used on data layers to interpret the base map and thematic symbolization [47]. Moreover, the app has an option to show the summary of all hazards threatening a point on the map (see figure 1).

This finding may also be biased due to the quality of the printed maps. Users may find it challenging to locate the school on the printed maps because the scale was too small, meaning that they cannot clearly distinguish sufficient labels and annotations do not accompany buildings; some, the maps. Printed maps with a larger scale, such as at least 1:5,000 or higher, may deliver more accurate results. Moreover, in Tasikmalaya, the maps are not informative enough since there are no sufficient labels and annotations that can help users more easily position themselves on the maps. Furthermore, coloring may also be an issue in understanding the maps. In Garut, for example, the disaster-prone area map used different coloring. On most hazard or risk maps, zones of increasing risk to the hazard are color-coded, commonly using a traffic light color scheme, with red representing a high or unacceptable risk and green
indicating an acceptable or low-risk category. However, on the Garut’s map, different levels (very low, low, medium, and high) of hazards (earthquakes, landslides, and volcanic eruptions), except for the tsunami hazard, are mixed and classified with similar purple to pink hues and saturation. To helping users more accurately interpret a map, the numbers of hues and values should be limited as [5] less color variation is more potent for the map interpretation. One of the printed maps in Sumedang is created with no apparent hazard. Areas prone to disasters were colored with a traffic light scheme, though it cannot be assured what kind of hazard was visualized with the colors. Future research should examine similar information and visualization with different delivery (interactive and printed mapping) to avoid these biases.

Are participants satisfied with the application? Is the application more satisfying than printed maps?
Participants strongly agreed and agreed that the application was satisfying. Students rated highly for the information about disaster maps, suggestions on actions that should be taken before, during, and after disasters, and various kinds of hazards displayed on InaRisk Personal. Compared to the printed maps, the students found that it was more enjoyable when using the application.

Do participants prefer the application than printed maps in learning about disasters? How do readability and satisfaction may influence this preference?
A combination of prior findings on readability and user satisfaction is further corroborated by the participants’ answers to the final study questions concerning the preferred tool to learn about disasters and what they want to recommend to their family and friend. Almost all participants preferred the application (95.3%) to commonly distributed printed maps by local governments for learning about disasters. The application was chosen as the one that most participants would recommend to their family members and friends.

6 Conclusion
Mobile technologies have become a valuable learning tool for the public in this digital era, particularly for young people. With ever-changing technology and the distinct end-user environment, it is necessary to continue evaluating whether this technology is effective. This study has taken the first step towards fulfilling this objective by evaluating readability and user satisfaction of a map-based application developed by the government as a medium for communicating the risks and learning disasters. These two aspects are essential in further evaluating the effective use of the application. This study has found that InaRisk Personal, to some extent, is readable and satisfying, indicating that the application might have good potential for learning disasters, particularly for young people. This part of the population is highly exposed to the Internet; thus, it is reasonable to have them as the application’s prioritized targeted users. When the application was compared to the printed maps, it was also found that the application is more preferred, readable, and satisfying than the regular maps for disaster learning among high school students. Most students prefer to learn about disasters through cartographic visualization on the mobile application with suggestions for improvements compared to the printed maps. Thus, local governments of the study areas may consider having their own self-developed disaster map-based applications as a complement to their regular disaster map dissemination.

This study has several limitations; firstly, the contents provided by the application and the map were different from each other, making some biases. The biased results of the printed maps may be due to the map design quality, which is poor (i.e. selection of colors and absence of labels and annotations). Next, some researchers have considered the use of students as a limitation. However, the study assumes that students are a representative percentage of the population of Internet users.

In summary, the study has roughly evaluated the performance of a disaster learning mobile application for high school students. This paper is a step in the right direction and recommends further research in the field.
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Appendix A

Figure A1. Printed Maps used in Tasikmalaya 1 and Tasikmalaya 2 SHS
Appendix B
Appendix C

Figure B1. Printed Maps used in Sumedang 3 SHS
(b)

Figure C1. Printed Maps used in Garut 1 SHS
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