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MyShake: Using Human-Centered Design Methods to Promote Engagement in a Smartphone-Based Global Seismic Network

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MyShake is a global seismic platform that uses private citizens' smartphones to detect earthquakes and record both ground shaking and users' experiences. The goal is to reduce earthquake risk and provide users with a resource for earthquake science and information. It is powered by the participation of users, therefore, its success as a global network and its utility for the users themselves is reliant on their engagement and continued involvement. This paper discusses the citizen scientist participation that enables MyShake, with specific attention to the human-centered design process that was used to overhaul the mobile application's user interface. After the successful initial launch of the application in February of 2016, we had the opportunity to revisit the user interface based on user feedback and needs. The process began with an assessment of the user and geographic distribution of the original user base through surveys and Google Play Store analytics. Subsequently, through systematic examination of the motivations and needs of community members in the San Francisco Bay Area and iterative evaluations of design decisions, MyShake was redesigned to appeal as a resource to a wider range of users in earthquake-prone regions. The new user interface was then evaluated through interviews, surveys, and meetups with potential users. We highlight the human-centered methodology we employed, as well as the roadblocks we faced, in the hopes that our experience will be valuable to other citizen science projects in the future.

Keywords: human-centered design, citizen science, seismology, global, smartphone

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INTRODUCTION

While there are thousands of seismic sensors around the world, and thousands of earthquakes each year, seismology remains a data-limited field. The global seismic networks typically consist of a few hundred instruments and are able to detect all earthquakes globally with magnitudes >5. However, detailed study of the earthquake source, and the impacts of that earthquake of the human-built environment require sensors in the near-field, i.e., within a few tens of kilometers of the earthquake epicenter. Few countries around the world have seismic networks that are dense enough to provide many seismic records in the near-field for any given earthquake. Therefore, the research community has relied on synthetic datasets to complement what recordings are available (Maechling et al., 2014; Ruhl et al., 2017).

In response to this challenge, multiple groups have explored the use of low-cost MEMS accelerometers in a variety of devices and with varying degrees of citizen participation and science.

The Quake Catcher Network used private/personal laptops with accelerometers in them or USB-attached sensors (Elizabeth et al., 2009; Yildirim et al., 2015). The Community Seismic Network consisted of similar MEMS sensors attached to a PC in a dedicated "box" that could be deployed in homes and offices (Clayton et al., 2012). Others, have explored using the accelerometers in smartphones both as dedicated devices (D'Alessandro and D'Anna, 2013; Naito et al., 2013; D'Alessandro et al., 2018), or via apps like iShake (Dashti et al., 2012). MyShake is a global network of private/personal smartphones with the goal of furthering seismological research by providing data, and reducing the impacts of earthquakes by providing training/education and alerts. The MyShake app uses the onboard accelerometer to detect earthquakes, record the ground shaking observed by the smartphones, archive the data in a central repository for future research, deliver earthquake information and preparedness information to users, and to provide rapid notifications or "alert" of earthquakes underway. Central to its success is the engagement of a large number of citizens who download the app onto their phone. Therefore, it is critical that an evaluation of what "citizens" want and need be central to the design of the app.

Citizen science is not a new trend. Projects like the Cooperative Observer Program (National Weather Service) began in 1890 to provide more widespread daily measurement of temperature and precipitation to define US climate. SETI@Home began in 1999 and uses citizen scientist's idle computers to search for weak signals and certain classes of signals from astronomical data. MyShake has many parallels with the SETI project in that it uses the idle time on consumer electronics to search for signals. The United States Geological Survey has its own earthquake related citizen science project: Did You Feel It?, which allows users in the epicentral region to report their experience of shaking after the event (Atkinson and Wald, 2007). LastQuake is an app developed by the Euro-Mediterranean Seismic Center, which provides earthquake notifications crowdsourced by the reports of shaking from users themselves over social media and the internet (Bossu et al., 2018). Finally, the Earthquake Network app is designed to detect earthquakes using smartphone accelerometers (Finazzi, 2016, Finazzi and Fassò, 2017). It is different to MyShake in that it does not record and archive the ground shaking for future research.

Here we focus on a question directly relevant to the citizen science aspect of the MyShake project which determines the scale of MyShake's network—how to improve the application's user retention rate and grow its user base so that we can build and sustain this global platform. This paper outlines the human-centered design approach that was used to address these questions. Human-centered design is commonly used in product development to understand consumer needs so that products can be built to meet those needs, with the ultimate goal of creating value for the product in the eyes of users and thus increasing the number of consumers who engage with the product. We hope that by applying the same techniques to this citizen science project, MyShake will be able to provide more utility and value to users, promoting their participation. The approaches we took to address this problem will be introduced below. Using user interviews as the basis of potential solutions, a redesigned application and its evaluation will be presented in the hopes of providing useful information to other citizen science projects.

This paper does not cover technical details about MyShake. Details of the network structure and app architecture are presented by Kong et al. (2016b), and a summary of data quality and observables from the existing network can be found in Kong et al. (2016a). Application of the data to building monitoring is covered in Kong et al. (2018a) and an overview of the machine learning components of the entire MyShake system are in Kong et al. (2018c).

CITIZEN SCIENCE DATA AND HARDWARE

The acceleration data that MyShake can provide has research value for the seismological and civil engineering communities. Recordings from cell phones can be used to build a scalable earthquake early warning system around the world, which is a key goal of the MyShake global network. Kong et al. (2016a) report on initial observations from MyShake recorded waveforms and compare them with the nearby seismic stations. The Peak Ground Acceleration (PGA) values show the expected attenuation trend with distance from an earthquake, though the amplitude of MyShake recordings are on average twice the observations of traditional seismic stations. This is in part due to the higher amplitude shaking of buildings compared to free surface sites. With careful calibration of building response contributions to the amplitude, MyShake could provide higher resolution ground motion observations. The waveforms recorded by MyShake could also be used to determine basic earthquake event parameters, such as magnitude, location, and origin time, that is comparable to traditional seismic networks in areas where phone density is high and well-covered azimuthally. MyShake also shows the potential of detecting smaller earthquakes using a dense array approach, which could potentially improve the catalog completeness for small events. Research into the feasibility of these techniques is ongoing. Kong et al. (2018a) reports the potential of using personal smartphones to extract building fundamental frequencies, which opens the door to monitoring building state of health. Kong et al. (2018b) shows the challenges and possibilities of using MyShake for earthquake early warning.

Analysis of what causes an earthquake to grow large or remain small is a continuing area of research (Aki, 1987; Meier et al., 2016). A denser global network, such as that provided by MyShake, could record more local earthquakes in areas with sparse seismic instrumentation before and after large earthquakes to mine any characteristic differences that are present and more fully complete the seismic event catalog. The events detected by MyShake could also be used to improve our understanding of local fault zones. New research on local path effects (Aki, 1993) could be stimulated by collecting data with higher spatial resolution. Moreover, it could help us generate microzonation maps that characterize the ground motions at finer scale. Recording more aftershocks, especially in the near-field, could augment aftershock probability forecasting (Wetzler et al., 2016; van der Elst and Page, 2017) which requires large data sets that capture wide ranges of locations and magnitudes.

Smartphone market penetration is what makes the MyShake platform possible. The number of smartphone subscriptions worldwide was 4.3 billion in 2017, and is projected to grow to more than 7.2 billion by 2023 (Jonsson, 2018). The global median of smartphone penetration was 59% in 2017 and, while this rate is lower in many emerging economies that are susceptible to earthquakes, their smartphone ownership continues to grow. In Indonesia for example, where several destructive earthquakes have occurred this year, the smartphone ownership increased from 21 to 27% between 2015 and 2017 (Poushter et al., 2018). MyShake could transform this pervasive technology into a global seismic network to serve communities that are vulnerable to earthquakes but lack high-quality traditional seismic networks. The archive of dense seismic data generated by MyShake can also be used by the scientific community to tailor hazard reduction strategies to these underserved areas.

Just as smartphone market penetration has increased globally over the past few years, so has the functionality of the hardware inside those phones. The phones' accelerometers, which the MyShake application uses to detect motion, are not as sophisticated as traditional seismic instruments, but collectively across several nearby devices, they can readily discern the complex signature of earth's movement. MyShake also employs the GPS to accurately pinpoint location. An on-board patented artificial neural network (ANN) created by the researchers at the Berkeley Seismology Lab determines whether or not recorded motions are produced by an earthquake or by normal human activity (Kong et al., 2016a). The ANN remains in a quiescent phase until the accelerometer indicates the phone has been stationary for a defined period of time. Once in this "steady state," the ANN classifies subsequent motion into earthquake-like or human-like types and any earthquake-type parameters are sent to the backend cloud server for aggregation with readings from other nearby devices using spatial and clustering algorithm (Kong et al., 2018c,d). In addition, MyShake uploads 5 min of acceleration time-series data from phones in the area of a detected quake, which are archived for research purposes (Kong et al., 2015).

CURRENT STATUS OF THE MYSHAKE NETWORK

As of July 2018, MyShake has been downloaded to more than 296,000 devices with about 40,000 active users and 10,000 users on any given week whose devices actively contribute data. **Figure 1a** shows the distribution of all the users who have downloaded MyShake, and **Figure 1b** shows the distribution of the 10,000 users that contributed data during the week of 2018-07-16. Between February 12th, 2016 and February 12th, 2018, 757 earthquakes were recorded by the system spanning events on almost every continent, as shown in **Figure 2**. The histogram in the figure shows that there are more events detected during night when most of the phones are steady. Many of these recorded events represent only one or two local users and devices, so for MyShake to truly reach its goal of creating a global dense seismic network and significantly increasing the available near-field waveforms for the global catalog, a much larger user base is necessary. Moreover, MyShake can only detect earthquakes and record ground motion on a device when it is stationary and has reached steady state. This is because human motions often are of much higher amplitude than earthquake motions, so they can easily get lost in the noise of human activities. Among our current active users, we have observed that between 1 and 6 a.m. local time, about 90% of the phones running MyShake reach steady state and therefore start monitoring for earthquakes. Between 10 a.m. and 6 p.m., however, only about 20% of phones are able to monitor for earthquakes and, thus, able to contribute data. A large user base in any given region is required to consistently monitor seismic activity given that many users are often moving and interacting with their devices.

Thus, evaluating the effectiveness of MyShake as a research project and global data archive goes hand in hand with measuring the value it provides to current users and new segments of users who can act as seismic sensors. For this reason, in seeking to grow the MyShake project, we treated the MyShake application as a product and undertook a redesign of the application with the goal of increasing participation in the project and retaining participants for longer periods of time. During the redesign, we employed Human-Centered Design, a philosophy whereby products and services are cultivated based on human needs and goals (Goodwin, 2009).

DEFINING THE USER RETENTION PROBLEM

We began our efforts to increase the MyShake downloads and retention rates in August 2017 by examining user install and uninstall behaviors to inform effective changes that could be employed to acquire new users. Of the users who have downloaded MyShake since its release on February 12th, 2016, 38% of users uninstalled the application within a day, 69% uninstalled within a month, and 95% uninstalled within a year (**Figure 3**). This data suggested that while MyShake was able to attract users, especially after our initial global media push and as large earthquake events continued to be mentioned in the news media alongside MyShake, as shown in **Figure 4**, keeping all of these users in the long-term proved challenging. The application is currently only available in English and Japanese, so lack of local language support could also made it a less useful tool to global user groups.

MyShake requires only passive participation from its citizen scientists—to contribute to the project, a user must simply download (and keep) MyShake on their phone. However, according to the Hooked model of product adoption, people are most likely to continue using something when they use it frequently and perceive it to have utility (Eyal, 2014). We therefore decided to address MyShake's low user retention by examining how to increase user engagement with the application and increase its overall value for users. Our first

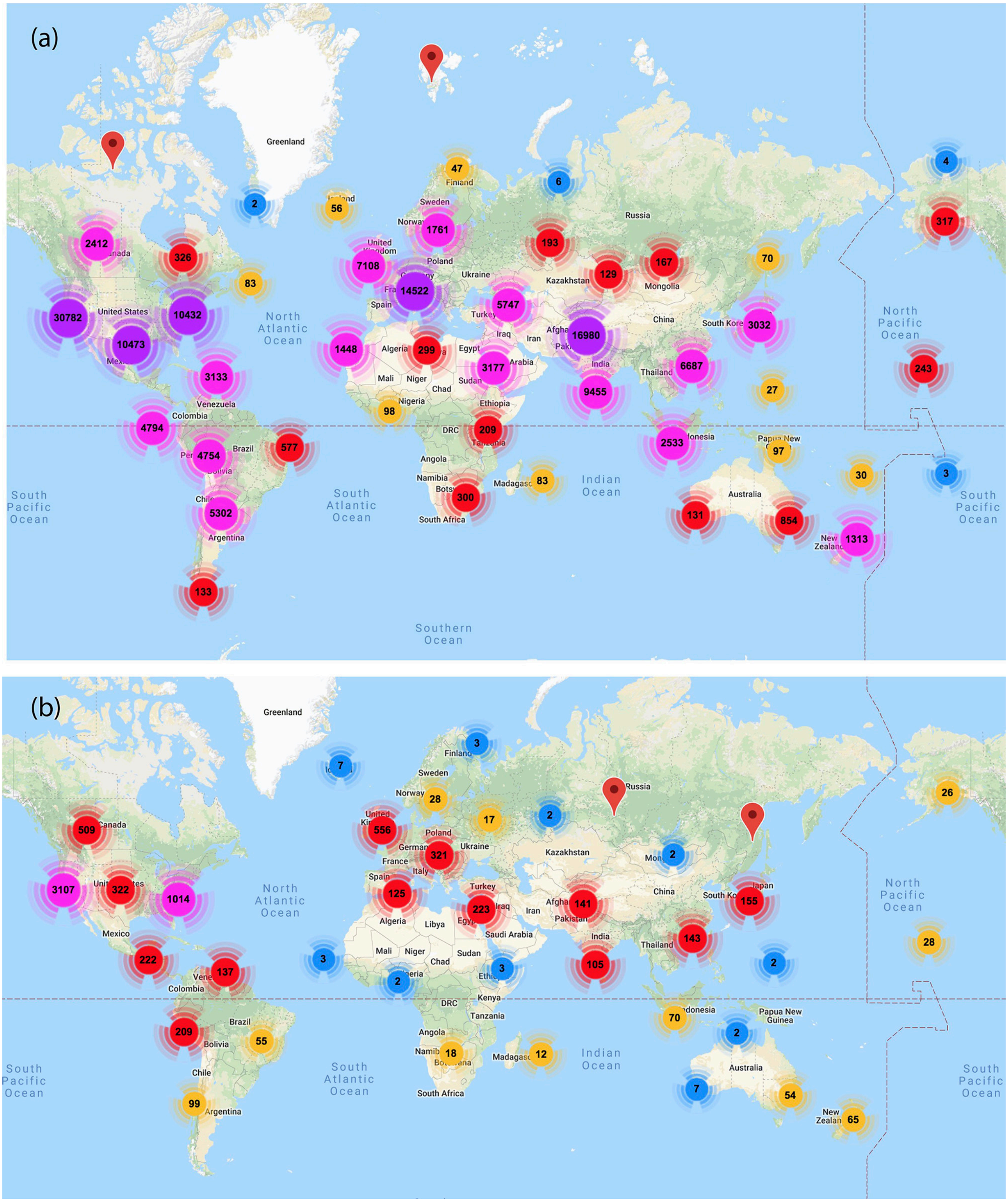

FIGURE 1 | (a) World map of MyShake application downloads, between February 12th, 2016 and July 25th, 2018, clustered by location showing the global reach of the MyShake network. Map data: ©2018 Google. **(b)** The active users that contribute data weekly for the week of 2018-07-16.

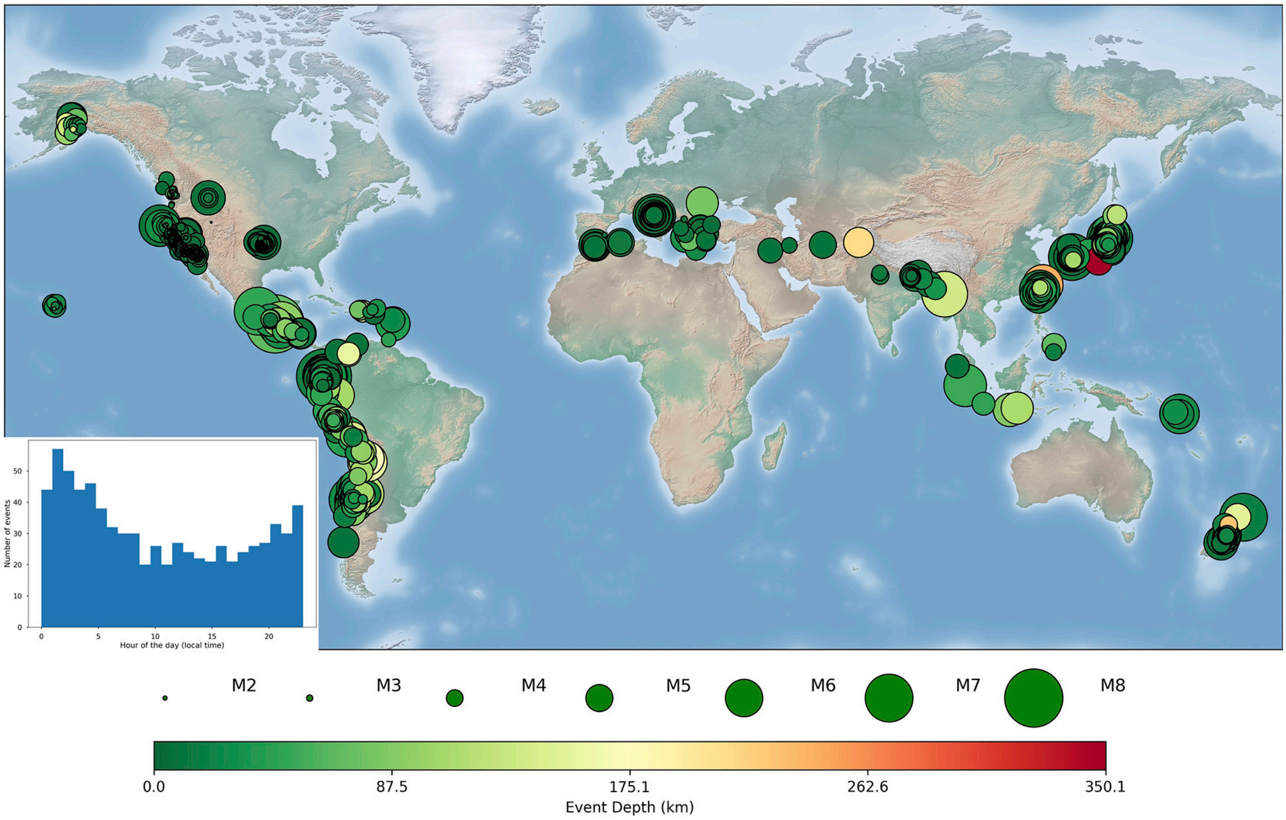

FIGURE 2 | Earthquakes recorded globally on the MyShake seismic network. The size of the disks represents earthquake magnitude M2-8 and are centered at the earthquake epicenter. The color of the disks denotes the event depth from 0 to 350 km below the earth's surface. Map data: NatGeo World Map. The histogram at the left bottom corner of the map is the local time hour of the events detected.

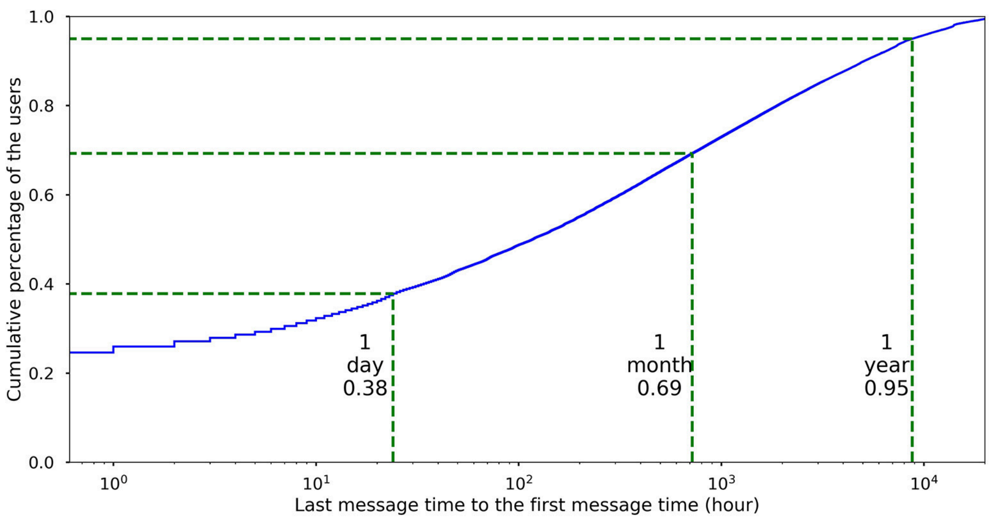

FIGURE 3 | The graph shows the cumulative percentage of users over all time who have kept the app registered on their phone measured as the time difference between the first registration message time and the last heartbeat time measured on that registered device. Thirty-eight percent uninstall within the first day of downloading, 69% within the first month, and 95% within the full year.

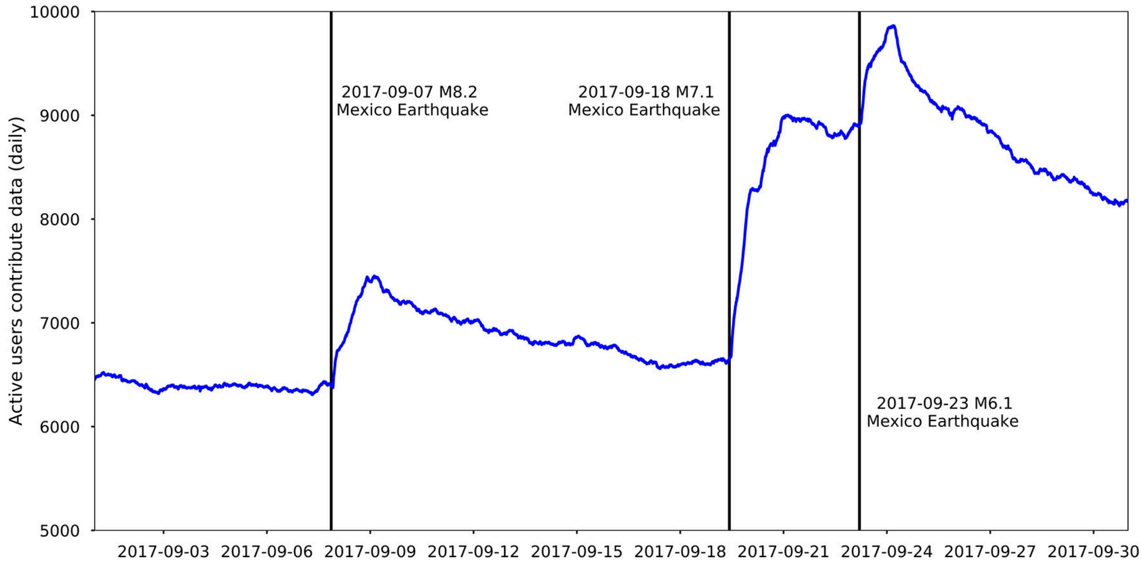

FIGURE 4 | The changes of the active users that contribute data during the Mexico events.

step was to discern in-depth user needs, behaviors, and pain points in relation to earthquakes using Human-Centered Design methods. We first assessed the current state of MyShake's engagement and value by reviewing user feedback on the Google Play store and in email comments. Chief among user complaints was that MyShake consumed too much battery. Users who left comments or sent emails also frequently requested metrics about their contribution to the project and information about the earthquakes they helped detect. We bookmarked these suggestions for our redesign brainstorm later in the process. These insights guided our redesign efforts by allowing us to devise new functionalities and evaluate current features through a lens of usability and utility for our target audience.

USER INTERVIEWS

Feedback on the content and functionality of the initial application was an important first step, but reaching out into the user community through interviews was essential to discover the needs and interests of these volunteers to encourage their sustained involvement in the project. For this reason, human-centered design was at the core of efforts to grow MyShake's user base. In human-centered design methodologies, human factors including user needs and gaps in meeting those needs are assessed using methods like user interviews and surveys. Based on the results, a design solution is devised and subsequently tested by users in an iterative cycle to ensure usability. Ideally, this results in a product that helps users fulfill unmet needs efficiently and enjoyably, thus conferring value to the product (Goodwin, 2009). By having conversations with potential MyShake participants about their needs, which were unmet by the initial MyShake application offering, we were able to focus all redesign efforts on providing utility to users and in turn persisting their engagement.

The goal of using human-centered methods was to build empathy amongst the MyShake team for the audience of the application. Our information seeking about users was not intended to match the rigor of human subjects research or produce broad findings about the population that we were targeting. After review by the Berkeley Human Research Protection Program, our investigations were exempt from review as they were deemed to be Quality Assurance/Quality Improvement activities which are not considered human research. However, the insights we gained nevertheless helped guide product decisions throughout an iterative application development process. At crossroads in the design and implementation process, we were able to draw on the needs expressed by our desired citizen science user base instead of making uninformed assumptions.

Our analysis of the user retention problem, which looked at the user base as well as install and uninstall trends, showed that MyShake was able to generate organic interest as installs continued over time, even outside of the global media coverage spikes we observed. However, it was unable to sustain interest among a majority of these users, and even those who kept the application on their phones requested additional features to better engage them as citizen scientists. While underserved by the current application, former users and new segments of users had the potential to grow into a large active user base if MyShake could provide them more utility. We chose to identify the audience of MyShake's redesign as: adults of all ages, who own smartphones, and who live in seismically active areas. To understand how MyShake could evolve into a resource for these users, we examined attitudes and behaviors of a subset of this group, with an emphasis on their unmet needs, in relation to earthquakes.

Our first human-centered design strategy was to conduct qualitative user interviews with residents of the San Francisco Bay Area. Qualitative methods were well-suited as they provided the depth and flexibility of inquiry necessary to better understand user needs in this specific context (Budiu, 2017). Popular quantitative user research methods, like remote surveys, would have been limited in this respect as questions would be standardized making it difficult to ask specific follow up questions based on a participant's response. Additionally, since the goal of these interviews was information seeking for product research, rather than to produce generalizable knowledge about this segment, these interviews allowed us to explore a wide range of different topics with participants producing insights about needs we may not have even known to be looking for. One drawback to this approach is that the freeform answer style does not allow for statistical sampling of responses in the way that a more structured survey with limited response options would.

Residents of the San Francisco Bay area were used as they comprise a portion of our overall target user group and live in earthquake prone region, thus potentially having use for the earthquake resources MyShake could provide them. Given the various ages and time spent living in earthquake country among interviewees, this group allowed us get perspectives across a spectrum of past experiences with earthquakes. We also interviewed a few tourists, to understand points of view of those outside of the area. That being said, because our user research was conducted only with English speakers and in a region of the world whose population is highly technologically fluent, with smartphone adoption rates in the US above 80% since 2013 (Poushter et al., 2018), it is not representative of every population segment globally we hope MyShake can access and results will be biased toward this type of user.

Our tool was a script of questions designed for in-person interviews lasting roughly 10 min (see **Supplementary Materials**). It was developed to collect ethnographic information—about activities and mind-sets—from our redesign audience (Hall, 2013). The questions focused on attitudes toward earthquakes, reflection on past earthquake experiences and actions that were taken, as well as challenges faced in preparing and responding to earthquakes. We chose to cast a broad net in our information gathering since we were still trying to understand how MyShake could provide utility to users in the multifaceted context of earthquakes. While not all of these inquiries illuminated unmet needs that MyShake could fulfill, information regarding areas where user needs were already satisfied allowed us to save development time attempting to address them. Importantly, most questions we followed up with "Why?" to reveal decision making and emotional responses surrounding behaviors related to earthquakes. The script also included demographic questions to provide more context to each participants' responses, however no personally identifiable information was recorded. While this demographic information did not end up presenting immediate trends in responses, it was important to collect it in case distinct sub groups of users among demographic categories became apparent.

Four members of the MyShake team conducted "man on the street" interviews in Downtown Berkeley, near Frank H Ogawa Plaza in Oakland's City Center, and near the Ferry Building in the Financial District of San Francisco to save on time and costs related to subject recruitment, and to include groups with different relationships with earthquakes, (i.e., homeowners and lifelong residents of earthquake country vs. newcomers). Interviews were conducted on August 15th and 16th of 2017, a Tuesday and Wednesday, respectively, around lunch hours, between roughly 11 a.m. and 2 p.m., when the public spaces were busy. Anyone over 18 who was not otherwise occupied was considered as a potential participant. Team members approached potential participants, asked if they were interested in participating in an anonymous interview for the UC Berkeley Seismology Lab, and, if they consented, were interviewed on the spot. In total, 78 such interviews were conducted. While this is not a statistically significant sample of all residents of earthquake prone regions, it provided us with information about the needs and attitudes of real people, allowing us to make design decisions based on their input rather than our own assumptions about what people wanted from an earthquake application.

In conjunction with user interviews, we also interviewed six experts in fields such as earthquake outreach, emergency management, and emergency behavioral response. We used findings from these interviews, about behavior relating to earthquakes, to begin to draw out meaningful statements and observations from our interviews with users that aligned with expert insights. After discussions and brainstorms among the MyShake team, we organized our takeaways from all interviews through personas and task analysis to draw meaningful insights about the earthquake experience that could be used to shape improvements to MyShake.

HUMAN CENTERED DESIGN RESULTS

Personas are sample archetypes that represent the distinctive needs and challenges of different user segments, while also highlighting consistent themes in these areas among all users. Our goal with using personas was to produce a snapshot of the needs, habits, and challenges of potential core users that the team could revisit when making product decisions. We began by reviewing all of the interview notes as a team question by question and highlighting interesting insights and commonalities for each question. We used these results to identify interviews from ideal target users. These were people that already showed some engagement with earthquakes, who had pressing needs related to earthquakes that they cared about being fulfilled, or otherwise indicated that an earthquake resource would be valuable to them. For each persona, we kept an especially compelling quote from an interview in its group (**Figure 5**). We then grouped similar target user responses together and created a persona for each group, pulling demographic information right from an interview. Finally, we identified background information, needs, and challenges for each persona using interview insights. We supplemented these developed personas with findings from the expert interviews and looked for overlaps, especially instances

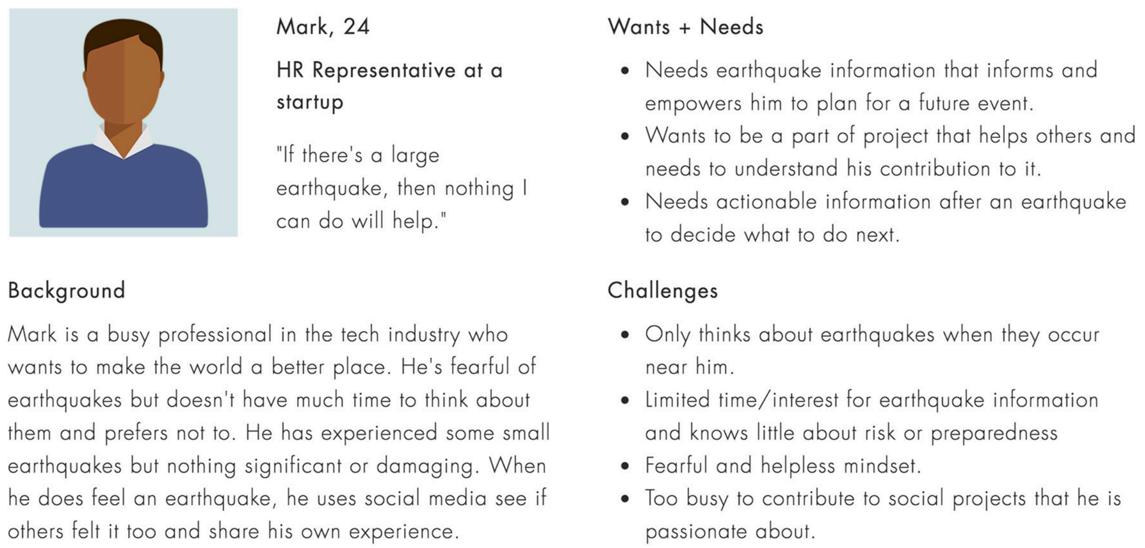

FIGURE 5 | Representative persona that was developed from the user interviews.

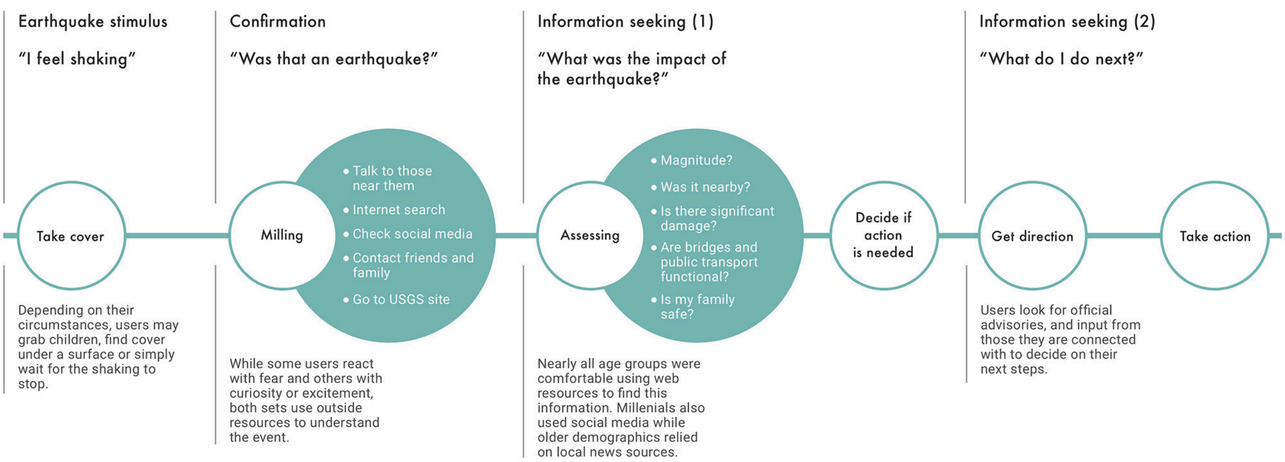

FIGURE 6 | Task analysis infographic depicting the four distinct action types personas engage in after an earthquake event.

when an expert had some insight and a user expanded on the same issue.

Our key insights from creating personas were:

1. Participants expressed feelings of fear toward earthquakes, as well as feeling helpless to prepare themselves for a large event.
2. Participants reported avoiding thoughts of earthquakes, only engaging with earthquake and preparedness information when they either experienced one or saw one in the news.
3. Respondents wanted information about how an earthquake affected the areas where their loved ones and homes were.
4. Respondents relied on several different resources for news after an earthquake, including: social media, local news, search engines, and the United States Geological Survey website.

The responses to the "Experience" section of the user interview were also used to create a task analysis (**Figure 6**) to build out a broad flow of actions that users described taking, or thought they would take, after experiencing an earthquake The questions were:

- Have you experienced an earthquake? What did you do?
- How do you get information immediately after the earthquake?
- What is the information you are looking for? Did you find it?

A clear pattern of four distinct actions was taken across the identified personas: Recognition, Confirmation, Initial Information Seeking and Secondary Information Seeking.

This mental model for responding to earthquakes matches many overarching themes in the Protective Action Decision Model (PADM)—a model for emergency behavioral response.

The PADM asserts that individuals decide how to respond to an emergency situation by seeking information from social circles, media outlets, and authorities so that they can confirm environmental and social cues indicating they are at risk. Moreover, as individuals proceed in their decision-making about how to respond once risk has been confirmed, they continually seek new information (Lindell and Perry, 1992, 2012).

After an earthquake, respondents often used conventional news sources to confirm there was an earthquake and get basic information like magnitude and epicentral location. However, when attempting to figure out the impact to different areas of their community and what routes of transport would be accessible to them, respondents reported having trouble finding clear guidance. With this information and guidance from models like PADMin hand, we moved on to brainstorming potential improvements to the MyShake application that could address the identified pain points and align with user mental models surrounding earthquakes.

BRAINSTORM AND REDESIGN

Our redesign needed to provide more utility to users in order to reach our goal of expanding MyShake's global network to ultimately provide rapid earthquake notifications and data for research. However, we also needed to weigh potential new features that could add utility with their technical feasibility. New feature requests could have impact on data usage, which could adversely incur a cost to a user if they are not connected to Wifi. Extra monitoring features could complicate the battery usage. User privacy considerations are also always at the forefront of design decisions. MyShake does require location information in order to pinpoint the earthquake site, but we do not want to link this to any other personally identifiable information. So personalized registration, interaction, and data viewing features needed to be carefully scrutinized before implementation. We attended to each of these concerns by developing a set of ideal features for users, and then undergoing many cycles of iteration to optimize their usability and technical viability.

Our first step in identifying this set of ideal features was combining our findings from user interviews with expert knowledge and literature in disaster preparedness, emergency behavior, and citizen science in an Affinity diagram. This diagram was assembled by first grouping information with its source (either users, experts, or literature), then rearranging into clusters of shared characteristics, before finally summarizing the common theme expressed by each cluster. Through this process, we identified multiple broader needs, three of which we had the technical ability to address:

1. Need highly local information about surroundings (e.g., road damage and building damage) so users can assess what actions, if any, to take next. This information preferably comes from their community news outlets or social networks.
2. Need to understand their contribution to citizen science projects through metrics and acknowledgment of their participation.
3. Need resources that empower them to learn more about earthquakes and preparedness, without inciting fear and despair.

Through a brainstorming process that included: comparing this set of needs with the limitations of our previous personas, using rapid prototyping techniques to explore different design solutions, and discussions with our technical team about the most efficient and optimal path forward, we created an initial iteration of the MyShake redesign. The main functionality addresses the three identified user needs. The design solution for the first need of hyperlocal information on the state of infrastructure is met through a brief after-earthquake survey that can be filled out by users in the range of an earthquake called an "*Experience Report*" (**Figure 7**). Among other questions, the report asks for user input on any visible damage to buildings or roads in their vicinity. For each earthquake, user responses can be visualized graphically or on a map clustered in one kilometer hexbins, which addresses user privacy concerns by protecting individual user locations. Users can both quickly assess the overall impact of an earthquake and zoom into important locations—like their neighborhood, the area around their child's school, as well freeways or bridges they use regularly—to check their condition. Studies into earthquake damage reporting behavior of users of the LastQuake mobile app suggest that reports from users at damaging shaking levels may be more challenging to collect (Bossu et al., 2017). Research on the accuracy of the Did You Feel It crowdsourced shaking intensities also indicate that "reporting and sampling biases can account for historical earthquake intensity biases as high as two intensity units and for the qualitative difference in intensity distance decays for modern vs. historical events" (Hough, 2013). However, crowdsourcing road damage has proven to be useful for traffic apps like Waze and their Connected Citizens Program[1]. We opted to include the feature in the new User Interface design to increase user functionality and meet the need that users would find value in road and building damage reports. To mitigate biases and difficulty in reporting for large shaking levels, we limited the options for response to only four levels: none, light, moderate, and severe. The Modified Mercalli intensity scale ranges from I-X, so having only four levels smooths the responses such that errors even as great as two intensity units would not have large impacts on our user map.

We included pages called *My Data* (**Figure 8**) and *My Earthquake Log* (**Figure 9**) to provide users with information about their contribution to the project. *My Data* shows users' individualized metrics like the number of earthquakes they have been near and the number of *Experience Reports* they have submitted. It also provides statistics on the network as a whole, such as how many total earthquakes MyShake has successfully detected and how many total *Experience Reports* have been submitted to the system, to provide them with context for the larger cause that they are helping to support. The *My Earthquake Log* page provides a timeline of past earthquakes for which users were near the estimated area of felt shaking. For events

[1]Waze. Available online at: https://www.waze.com/ccp (Accessed November 15, 2018).

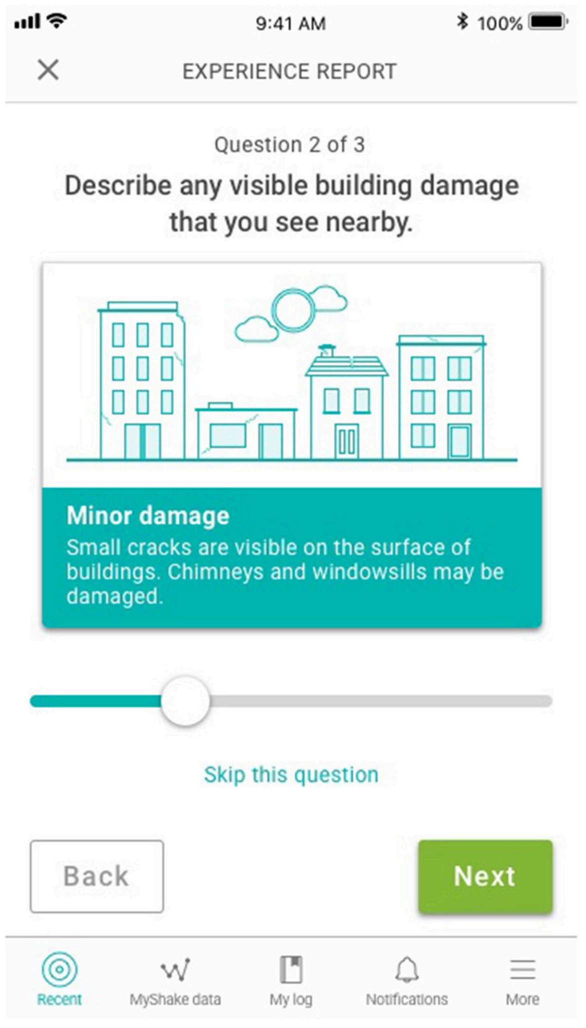

FIGURE 7 | *Experience Report* page where user can input any visible damage they see nearby.

FIGURE 8 | *My Data* page where users can visualize their contributions to the MyShake project and the reach of the project as a whole.

where users have submitted an *Experience Report*, the timeline also includes a summary of their responses to the survey. This way users can see data that they have contributed as well as, for target users in earthquake prone regions, understand the seismic activity in their community, thus highlighting the import of the MyShake project. Finally, we addressed the need for approachable, empowering earthquake information throughout the application. *The Earthquake Details* pages (**Figure 10**) contain engaging map and graphical visualizations of *Experience Reports* and allow users to explore seismic activity worldwide represented in a visually interesting and readily understandable format. Additionally, features like *My Earthquake Log* and *My Data* empower users by allowing them to track their past earthquake experiences, providing context for their personal earthquake history.

Armed with this list of new user-focused functionalities, we performed an iterative design cycle to translate these new objectives into functional wireframes for hard coding. Starting with rapid pen and paper prototypes, mockups for the application were created, evaluated on the basis of usability and technical feasibility, and edited based on these factors before evolving into a higher fidelity mockup. This process continued through Lo-Fi, Mid-Fi, and Hi-Fi mockups until we had a functioning prototype. Throughout these stages usability was assessed by ensuring the mockups and information architecture of the application complied with the Nielson Norman Group's 10 Heuristics for User Interface Design (Nielson, 1995).

Technical practicality was judged by backend, frontend, and phone-side developers on the MyShake team, who conferred with the UX designer to weigh functionality for users with development time and effort. Several technical challenges required balancing user experience with MyShake's capability as a research tool. Chief among them being the Doze state and App Standby, included in Android 6.0 and subsequent versions, that turn off the background functionality of applications when the

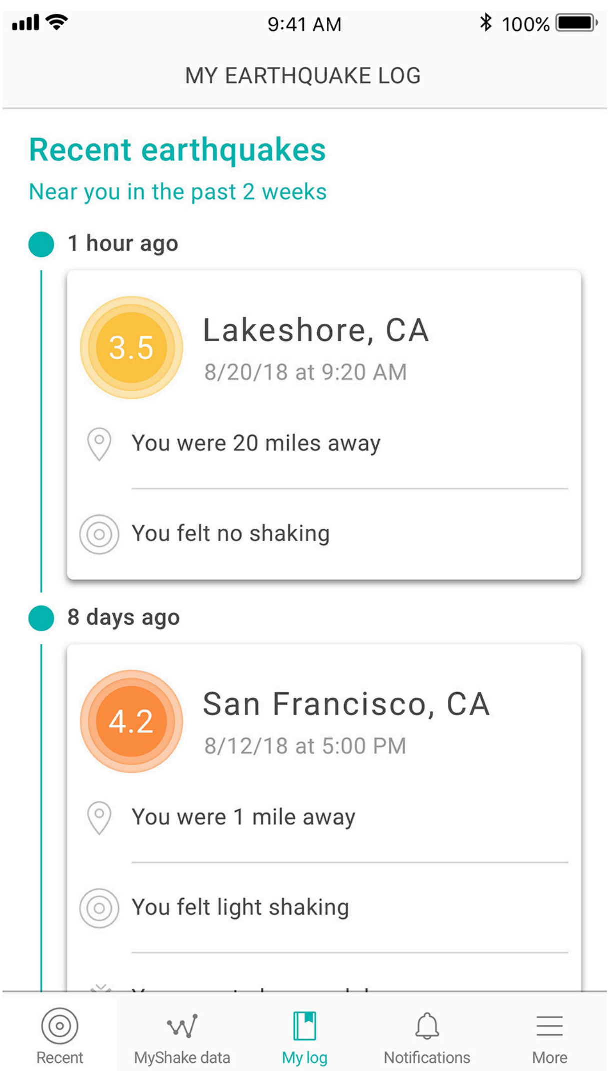

FIGURE 9 | *Earthquake Log* page showing hypothetical earthquakes and Experience Report responses to illustrate how a user could track their past experiences.

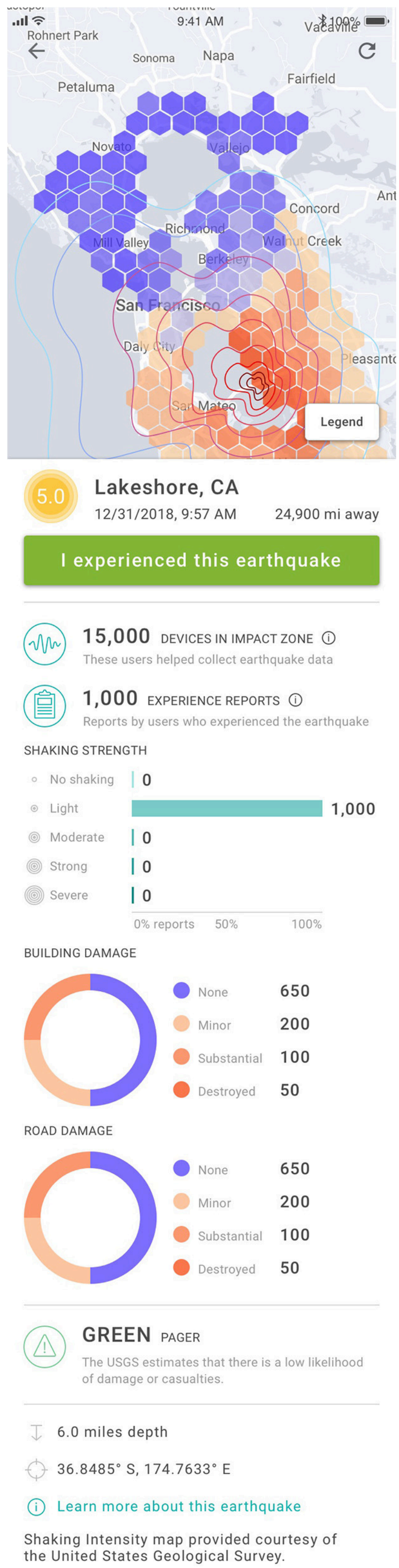

FIGURE 10 | *Earthquake Details* page with sample user data to show how hexbins and data visualizations would present user Experience Report data.

phone is inactive or an application is used infrequently (Optimize for Doze App Standby, n.d.).

Without active background processes, MyShake is unable to monitor sensors in the phone and detect earthquakes. Our developers were able to sustain the application's background function for longer periods of time by sending a persistent notification from the application to the phone, indicating the application is in use. However, this notification results in a fixed icon and message in the user's notification tray. While we had received previous feedback that this lingering message bothered some users, we chose to continue using the scheme to preserve MyShake's ability to monitor phone sensors in non-battery saving mode. Another challenge was MyShake's battery consumption. As noted earlier, this was a major user complaint that arose with the first version of the application. We remained cognizant of this issue during the redesign and in this case chose to prioritize user experience over maximum data collection per device. Instead of monitoring all the time, the redesigned MyShake defaults to battery saving mode, that only allows the application to monitor sensors when a device is plugged into power. While it decreases the data that is collected by a single device every day we hope that this change will mean a major improvement in user experience such that more users will continue to keep the application installed on their phone for longer periods of time.

After technical questions were addressed and we reached the stage of creating a functional prototype, we embarked on user testing to ensure our designs were functional and valuable to users.

DESIGN EVALUATION

We approached user testing by using a methodology similar to that of our initial user needs research. To avoid the expenses and time of recruiting and to get access to users with an array of backgrounds, we approached community members in Downtown Berkeley and near Frank H Ogawa Plaza in Oakland's City Center. Interviews were conducted by four MyShake team members on June 30th and 31st of 2018, a Wednesday and Thursday, respectively, around lunch hours, between roughly 11 a.m. and 2 p.m. Similar to the earlier survey study, any adult who was not otherwise occupied was considered for the interview. Prospective interviewees were asked if they would be willing to be interviewed by the Berkeley Seismology Lab and were able to freely give or refuse consent. No personally identifiable information was collected from the subjects.

Each interview began by asking about the subject's experience with earthquakes and their normal reaction to these events. The users were then asked to pretend that an earthquake had just occurred, and to use the application to find information they would be interested in had such an event occurred. Since the prototype had a fully functioning interface but was not yet supported by a functioning backend or user contributions, a set of data from past earthquakes was used to populate the main earthquake map and placeholder data was used to show hypothetical user responses to the experience reports for each event. Users were asked to complete a few key tasks, but for the most part they were allowed to navigate the application freely while sharing their thoughts and questions about the pages they encountered aloud. At the end of each user testing session, we also asked users: if they found the functionality of the application useful, how they felt about the overall experience of using the application, any features that they'd like to see included or removed from the application, and if the application were available today if they'd want it on their phone.

We organized our findings feature by feature to evaluate their usability and functionality, as well as assessed the application redesign as a whole based on user feedback. Overall the feedback we received about the new prototype was positive. Users were especially interested in the map and data visualizations of user experience responses and expressed many use cases when it could be an important tool in their own lives. We do note that for many earthquake events, there may not be enough responses from users to populate the user generated shaking, road, and building damage portions of the report.

We identified several usability issues that impacted user experience and prevented users from fully utilizing certain features of the application. One such issue was found with the *Experience Report* map—specifically the map legend. Many users had difficulty finding the legend as the button had no text and a symbol users did not associate readily with a map legend. Before finding the legend, users were confused about what data was being represented on the map, but upon a tester helping them find the legend, users immediately understood what information was being shown and its value to them personally. The map legend was clearly essential to facilitating the overall user experience of the map. We improved this experience by changing to symbolic button to a clearly labeled button simply stating "Legend." Another challenging user experience was found in the *My Data* page. While users understood that they were being shown metrics about their hypothetical contribution, vague terms like "hours of data collected" and "earthquakes nearby" left them unsure exactly what these metrics meant. Based on this feedback, the page was redesigned with clear phrasing such as "total experience reports submitted" and "total earthquakes in log."

At this point, after revisions were made, final designs were committed for development. Our group expects to release the newly updated version of the MyShake app in Winter of 2018 to select beta testers and to the general public in the Spring of 2019.

CONCLUSION

The MyShake citizen science project was overhauled from end to end to attract new users and increase user retention. Human-centered design methods were employed to ensure that we were building a global seismic platform which benefited the individual users as well as the research community. A larger, denser user base translates to more data for researchers to tackle unanswered seismological questions, while a user-focused application can also provide great benefit to users at risk of earthquake hazards. While providing rapid earthquake notifications will likely be a key motivator for users in the future, we also hope that the improved functionality of the app will enhance the desire of users to install and keep the app such that more areas reach target density to begin providing these services. Further investigations after the application's release will be required to measure the effectiveness of this redesign process.

ETHICS STATEMENT

This study was granted Exempt Status from Full Committee review by the UC Berkeley Office for Protection of Human Subjects under Category 2 of the Federal Policy for the Protection of Human Subjects (45 CFR 46) as no identifiable information was collected from subjects. Each potential subject was asked if they were interested in participating in an anonymous interview for the UC Berkeley Seismology Lab with the purpose of improving an earthquake mobile application. The study only proceeded if a subject provided verbal informed consent.

AUTHOR CONTRIBUTIONS

KR designed the human-subject research study and executed design methodologies. QK ran data analysis. KR and JS wrote sections of the manuscript. All authors helped collect user feedback and contributed to manuscript editing and revision.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2018.00237/full#supplementary-material

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