IDRiM (2022) 12 (1) **ISSN: 2185-8322**
DOI10.5595/001c.35742

Journal of Integrated Disaster Risk Management

Original paper

Open Science in Seismology: The Role of Citizen Science in the Transition from Seismic Observatory to Science Museum

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Received: 02/05/2021 / Accepted: 18/04/2022 / Published online: 20/05/2022

Abstract Catastrophic events, including worldwide pandemics and natural disasters, may lead to ambivalent attitudes toward science among the public. On the one hand, there may be pessimistic feelings toward the limitations of scientific knowledge and technology. On the other hand, there may be optimistic prospects for science-based solutions to the problems caused by these catastrophes. Science communication plays an integral part in shaping societal attitudes toward science. The aim of this research was to build more fruitful relationships between science and society by improving science communication in the field of seismology. Based on the concept of open science, we conducted action research at a seismic observatory as it transitioned from a science facility to a science museum. The museum adopted a citizen-science approach to communicating the science of seismology. In this approach, citizens not only learned about seismology from scientists, but they worked collaboratively with scientists to do science. The results of our research showed that citizen science can play a critical role in making science more accessible and communicating the science of seismology to society.

Keywords: open science, citizen science, science communication, science museum, seismology

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1. BACKGROUND

1.1 Science communication

In recent years, the occurrence of major earthquakes and tsunamis, a nuclear disaster, disasters caused by typhoons linked to global climate change, and the worldwide spread of the COVID-19 pandemic have underscored the limitations of the knowledge that science brings to society while simultaneously reminding us that science is the only thing that we can rely on to resolve and eliminate such problems. This is the case in Japan, particularly in a deep friction between seismology and society after experiencing the devastating "should-have-been-escaped" catastrophe at nuclear power stations, caused by the "unexpectedly" huge tsunami in the year of 2011 (see also Section 1.3). Having this ambivalent relationship between science and society in mind, this paper takes up the example of seismology – specifically, science communication around seismology – to discuss the relationship between science and society, with "open science" (Nielsen 2011) as a key concept. Open science represents a new approach to the scientific process based on cooperative work and new ways of diffusing knowledge by using digital technologies and new collaborative tools (European Commission (2016, p.33). By using open science in this way, a perspective differing from conventional research and practice will be introduced in connection with the relationship between experts (*i.e.*, seismologists) and the general public in terms of the risk of earthquake disasters, thereby producing results that have not previously been seen.

Chiefly, this paper discusses seismology as an "open science" from the aspect of "citizen science" (*i.e.*, participation by the general public in scientific research or scientific research carried out by members of the public) (National Institute of Informatics Research Center for Open Science and Data Platform 2017). Citizen science is regarded as "bearing a close connection with open science" (Furuya, Sumimoto, and Hayashi 2018, p.37) and it has been pointed out that "a citizen-science perspective is also important and needs to be recognized as a potential outcome for open science" (Study Group on International Trends in Open Science 2015, p. 5). In sum, as seen in Figure 6 below in Section 3, we use open science in this paper as an umbrella concept, encompassing citizen science and open data by using ICT (Information and Communication Technology).

Specifically, we report on action research that we have conducted over the past decade with the objective of developing a seismic observatory which is both a research facility affiliated with a university and an earthquake science museum. In the course of this research, we point out the necessity of realizing science communication not merely as scientific "outreach," which focuses on learning and understanding information about seismology, but rather as something that involves the collaborative planning and execution of seismological observations, experiments, and so forth by scientists and the general public – something that is carried out as "citizen science" – in order to establish seismology in society as an open science.

1.2 Open Science and Citizen Science

Open science is a movement that seeks to transform scientific research into an activity that is open to the public (*i.e.*, to non-experts). In a narrow sense, open science is often used to refer to "open data," which means that more people can gain access to the data and results that form the basis for scientific research. In a broader sense, open science refers to extending conventional science communication in order to build scientific and educational theories for realizing scientific research that more people, including the general public, will be involved with and trust (see also Section 3). In other words, open science is called a social movement that seeks to realize a participatory form of science.

A distinction proposed by Yamori and Iwahori (2016) is useful for understanding the idea of open science while differentiating it, particularly from science communication and outreach, the importance of which has been emphasized previously. This distinction, as noted above, is between the structure of outreach, in which the general public (non-experts) learn/know science from scientists (experts), and the composition of citizen science, in which the general public (non-experts) do/perform science with scientists (experts). In other words, in the outreach model, even when experts come down from the mountaintop to participate in events like science cafes and science labs and the participatory, interactive, and bi-directional involvement of citizens is promoted, there remains a great division between scientists who promote the scientific activity itself and the citizens who learn from and enjoy the fruits of research activities. Therefore, the dichotomy between those who create scientific knowledge and those who learn it remains (see also Figure 6 below in Section 3).

In contrast, citizen science refers to participation, however limited, by the general public in scientific activities (*i.e.*, research activities conducted to produce scientific knowledge). An important characteristic of citizen science is that the general public takes part and plays a role in the research, even if such participation represents only rudimentary work or incidental activities from the perspective of the research as a whole. From a different perspective, the dichotomous structure noted above can be overcome to some extent, if not completely, so that we can position citizen science toward the reorganization of a new "community of practice" (Lave and Wenger 1991; Iwahori, Yamori, Miyamoto, Shiroshita, and Iio 2017) in which scientists and the general public do/perform joint research activities in the name of science as open science.

The collaborative practice of science as "citizen science" or "open science" is far from a pipe dream and is already on its way to becoming a reality. Indeed, open science is not only indirectly helping to transform the relationship between science and society in the medium-to-long term, but is already producing immediate and direct results at the cutting edges of some areas of scientific research. The most typical examples are ecology, which uses data obtained from citizen-reported observations of the ecology of migratory birds and insects (butterfly counting being a notable example); maritime (environmental) studies, which have incorporated citizens' observations of ocean garbage and coral reefs; and astronomy, where the observation of celestial objects by amateur astronomers has long held an important position in academia. Similar moves are also apparent in the social sciences and humanities as well, including the Japanese Psychological Association's "Citizen Science Project" in the field of psychology (Japanese Psychological Association 2019).

1.3 Open Science in the Field of Disaster Prevention

In fields related to disaster prevention and mitigation, including seismology, which is the focus of the present study, the idea of open science is not only reorganizing the relationship between science and society in the medium-to-long term, but is beginning to produce effects in the short term, as well. For example, the idea of open science has begun to be applied in connection with observation activities in the context of extremely localized and short-term meteorological and flood events, including heavy rainstorms and inland floods, which have become more frequent due to the effects of climate change.

Specifically, the general public observes immediate and short-term meteorological phenomena through their own instruments and sightings, separately from the instruments that experts (at meteorological stations, for example) have already deployed. The results of these observations are used by researchers as predictive data and by local residents for initiatives such as "Local Weather Information" and "Evacuation Switch," which might be useful for their own early evacuation (Takenouchi, Kawata, Nakanishi, and Yamori 2014). In addition, some private-sector weather companies have begun offering services that use local meteorological information provided by users through smartphones and similar devices that are used for more accurate weather prediction, the results of which are then shared with their userbase (WeatherNews 2010). This, too, could be described as an initiative based on open science.

However, as we can easily see, this type of activity is open to a choice of themes and areas. The involvement of the general public in scientific activities – mainly observation – depends not only on the feasibility of observation, but also requires that the results be widely disseminated as systems, activities, and products in the real world; that the general public has direct access to these activities; and that there should be no rejection of the scientific field by society. In other words, there should be no serious conflicts between citizens and scientists, although such conflicts could be used productively in a further stage for deeper understandings between scientists and citizens.

In this sense, seismology would seem to be difficult to reorganize as an open science, like the fields of advanced medicine and nuclear technology but unlike disciplines such as astronomy and ecology, except the case of earthquake prediction in the boundary between legitimate seismological research and folk or pseudo seismology (*e.g.*, Hough, 2009). This is because, first of all, seismology – which generally lacks perceptible phenomena or readily available indicators in daily life – could be considered relatively "inaccessible" to citizens, as compared with meteorology, for example, where, given the strong winds and heavy rains that can be felt on a daily basis, tools like wind speed and rainfall indicators enjoy a high level of social recognition. Secondly, in Japanese society, especially in the wake of the Great Hanshin Earthquake in 1995, killing over 6.4 thousand people, and the Great East Japan Earthquake in 2011, killing over 20 thousand, there has been a strong backlash against seismology and adjacent fields, as evidenced by questions such as "Was the 'myth of safety' a lie?" and "After spending such a large amount of tax revenue on research, is 'unexpected' good enough?" such that the relationship between seismology and the general public is by no means smooth (SSJ 2012). It was in consideration of these adverse conditions that this research deliberately took up the challenge of creating an "open science of seismology."

2. ACTION RESEARCH AT AN EARTHQUAKE SCIENCE MUSEUM

2.1 The Abuyama Observatory Science Museum Project

In this section, we offer a detailed report of the action research that we have conducted over the past ten years, mainly at the Abuyama Observatory, which is part of the Kyoto University Disaster Prevention Research Institute. Specifically, we focused on the reorganization of the observatory, which had previously been a pure research facility, into an earthquake science museum, as well as carrying out related research activities with the aim of establishing seismology as an open science. In addition to ourselves, as constant participant observers, this action research also involved seismological researchers, seismic observation technical staff, museum management and curatorial experts, local government officials, and most importantly, the citizen volunteers who later came to be known as the Abuyama Supporters.

The entire process was observed and documented by the authors who engaged in this project as participant observers. Main information sources for this action research are minutes of monthly meeting of Abuyama Supporters, narrative data obtained from a series of semi-structured interview of the supporters made by the authors, and responses to questionnaire surveys answered by visitors of the science museum. A total of over 100 minutes of Abuyama Supporters' monthly meeting provide very useful information on how science museum has been organized and managed for over 10 years by Abuyama Supports as well as observatory staff. Data from a series of interview we conducted once a year, provides good resources to assess how Abuyama Supporter got involved in this project first, and how they have changed their attitudes. Questionnaire surveys conducted every time after guided tours, mentioned below, with the responses of over 3000 visitors now, are helpful to assess how science museum visitors feel about museum activities and Abuyama Supporter's contribution to the museum.

When the Science Museum Project was first conceived in 2010, the very survival of the Abuyama Observatory was in doubt. Observation systems in which a small number of seismic stations are operated by literal legwork had become a thing of the past, and observation networks that could be operated remotely had spread throughout the country. As a result, the

DOI10.5595/001c.35742

observatory, which played a central role in the older observation network and whose maintenance incurred considerable costs, faced questions about whether its time was at an end.

In response to this situation, we asked ourselves whether we might be able to reorganize the observatory as not merely a research facility, but as a base for carrying out seismology as an open science – in other words as a kind of science museum. As stated in the planning document from that time, "rather than simply being for academic research, perhaps [the observatory] could be reborn as a science museum that interprets the history of seismology, open to the general public as a facility that provides learning to as many people as possible, while being firmly rooted in the local community" (Abuyama Science Museum Concept Project 2011).

Located on the outskirts of Takatsuki in Osaka Prefecture, the Abuyama Observatory (Figure 1) is situated on a small mountain overlooking the Osaka Plain, almost directly above the Arima-Takatsuki Fault Zone, which is on a line extending from the Rokko-Awaji Fault Zone, which is considered to have produced the Great Hanshin Earthquake. The observatory was constructed in 1930. With a modern atmosphere evocative of the early Showa era in which it was constructed, the building was listed in a 2007 report by the Osaka Prefectural government as "notable modern heritage."

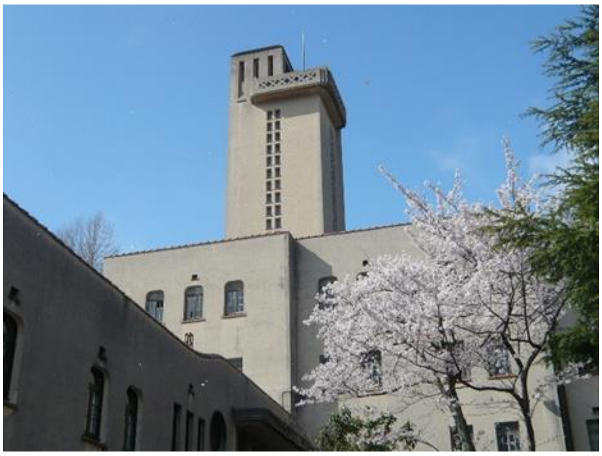

Figure 1. Abuyama Seismological Observatory, Kyoto University

Given its venerable history, the Abuyama Observatory is home to many seismographs of historical value that were introduced in the early days of seismology in Japan, and which supported the subsequent development of the field. Examples include the Wiechert seismograph, a massive early unit weighing approximately a metric ton that took measurements in both horizontal and vertical directions (for reference, the state-of-the-art Manten seismograph described below weighs about one kilogram); and the US-made Press-Ewing seismograph, which was also used to detect nuclear tests during the US-Soviet Cold War. For a more detailed description of the equipment mentioned here, see Abuyama Observatory (2018) and Yamori and Iwahori (2016).

In planning the Science Museum Project, we decided to make effective use of the valuable historical instruments housed at the observatory, and as our first initiative, we arranged for the general public to view these historic seismographs as an exhibition called the "Abuyama Open Lab." However, just as preparations had gotten underway for the exhibit, which was scheduled to start in April 2011, the Great East Japan Earthquake struck, raising concerns about whether or not the event could be held. We observed friction and conflict between science and society represented by voices dominant in society at the time (and which remain persistent even now)

IDRiM (2022) 12 (1) **ISSN: 2185-8322**
DOI10.5595/001c.35742

that questioned whether disaster prevention science was of any use to society and whether seismology was properly communicating risks. In light of the friction and conflict, it was felt that the time was right to begin the attempt, by introducing the perspectives of open science and citizen science, with the aim of rebuilding the relationship between science and society and between scientists and the general public at a fundamental level. With such considerations in mind, the first Abuyama Open Lab was held as scheduled, approximately one month after the Great East Japan Earthquake struck.

Table 1. Basic statistics on the Science Museum Project

YEAR	EVENTS HELD	MINI SEISMOGRAPHY WORKSHOPS	VISITORS TO THE OBSERVATORY	CUMULATIVE TOTAL NUMBER OF "SUPPORTERS"
2011	20	0	799	70
2012	29	0	762	350
2013	51	3	1699	630
2014	20	9	1095	130
2015	53	8	1329	126
2016	73	5	1960	1117
2017	81	5	2332	1005
2018	71	7	2117	1121
2019	67	9	2465	1206
TOTAL	465	46	14558	5755

(Note) Due to seismic retrofitting work, activities were held for only three months in 2014 and four months in 2015.

Since then, events involving public participation related to the Open Lab and science museum (*e.g.*, public lectures) have been held a total of 465 times over the nine years from 2011 to 2019, although their format and names have changed. In recent years, there have been about 70 events a year – or about one event per week. The total number of visitors who have come to the observatory to participate in events has risen to 14,558 (Table 1). This is a remarkable number considering that before this project began in FY 2010, the facility had attracted almost no visitors from the general public.

2.2 Abuyama Supporters: The Existence of Citizen Volunteers

It is important to note that the responsibility of engaging with these visitors – specifically, the role of presenting basic lectures on seismology and serving as guides for tours of the observatory – has mostly (in 90% of cases since 2012) been assumed by the citizen volunteers

 ISSN: 2185-8322
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known as the Abuyama Supporters. As shown in Table 1, the number of active Supporters in recent years has surpassed 1,000 people each year. Specifically, due to the fact that approximately 25 core members take part in activities on a repeated basis anywhere from a few up to 40 times a year, the total number people who participate in activities in a given year is upwards of 1,000 people. Accordingly, if we frame the involvement of general visitors as a "shallow engagement by many people," the involvement of Supporters can be expressed as a "deep engagement by a few."

Abuyama Supporters are citizen volunteers who responded to public recruitment campaigns and attended training courses organized by the observatory, thereby acquiring qualifications that allowed them to assume responsibility for giving lectures and serving as guides on tours of the observatory. Many of these volunteers are ordinary citizens (non-experts) who initially visited the observatory to attend the Abuyama Open Lab. Given that a detailed account of these events is presented in Yamori and Iwahori (2016), here we limit ourselves to presenting the basic background.

As of the end of FY 2019, there were 23 active Abuyama Supporters (of the approximately 80 total registered over the nine years of the project so far). Of these, 20 were men and most were retirees. Although the average age was over 70 years, the members are quite active and have even formed their own organization, called the Golitsyn Association, in honor of Boris Borisovich Golitsyn, the inventor of the seismograph. While promoting mutual exchange and the sharing of information, the association also works to the disseminate information to the greater public, for example, by publishing articles on its own blog (Golitsyn Association 2018). As shown in Table 1, as a result of repeated involvement in activities by about 25 core members, there have been a cumulative total of 5,755 engagements by Supporters in events over the past nine years. During this period, the number of activities grew with each passing year, and since 2016, in particular, the number of engagements grew substantially, with the addition of activities related to analysis, as described below in subsection 2.5. Supporters' motivations for applying to be volunteers are diverse, including participating in seismic observation and research, gaining practical knowledge about earthquake disaster prevention, wanting to learn about the observatory building and its surrounding environment, as well as interacting with peers and contributing to society.

Having presented an overview of the Abuyama Seismological Observatory as a science museum, we next consider three challenges to using observatory-based activities to realize open science in the field of seismology. The first of these is the aspect of guidance already mentioned. As it relates to seismology and observation instruments, guidance is an activity that falls into the category of 'outreach' (see subsection 1.2). However, if we consider the fact that ordinary citizens (Abuyama Supporters) are assuming the role previously held by scientists (*i.e.*, experts) in terms of outreach, we can say that this is an approach to open science that is rooted in citizen science.

The second aspect relates to activities for realizing citizen participation in observation, which has traditionally been at the center of open science, as evidenced by the examples of astronomy and ecology mentioned in subsection 1.2. In other words, although the Abuyama Observatory has begun to function as a science museum, it has not lost all of its original observation and research functions and remains an active seismic observatory. The main activity of the observatory in which the general public participates is observation. Specifically, Abuyama Supporters and others take part in advanced observation activities pertaining to inland earthquakes that are led by the Abuyama Observatory – the next-generation dense seismic observation system, nicknamed the "Manten Project" (Iio 2011, 2012).

The third aspect is analysis. A step beyond observation, this is an activity in which Abuyama Supporters take part in the interpretation of seismic waveform data obtained by the aforementioned Manten Project. In addition, there is also a related project known as Minna De Honkoku (Kanō 2017), in which members of the general public work to decipher records of seismic activity contained in historical documents. Public participation in this kind of analysis can also be said to deepen an open science centered not on learning science, but on doing/performing science collaboratively.

2.3 Guidance

In this subsection, we summarize citizen participation in seismology as an open science by focusing on the guidance roles that Abuyama Supporters have played at the Abuyama Observatory. Here, guidance refers to activities such as the basic lectures on seismology and seismic observation (which usually last about one hour) as well as the guided tours (also generally about one hour in length) of the observatory and the many historical seismograph installations. Several Supporters are in charge of this two-part tour (see Figure 2). The guidance carried out by citizens (*i.e.*, Supporters) has been very well received. A report by Yamori and Iwahori (2016), based on the results of a questionnaire survey conducted at the end of these tours, found that tours led by Supporters were rated more highly (sometimes much more so) than those led by observatory staff (scientists).

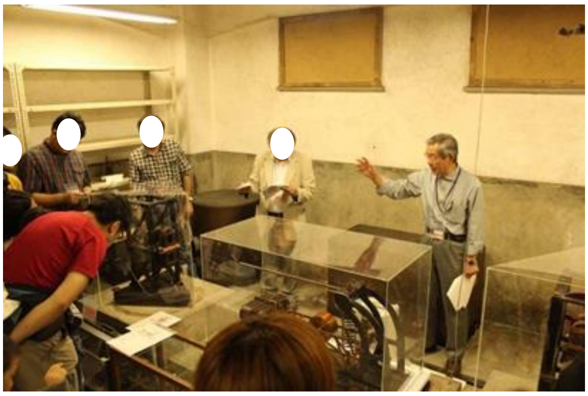

Figure 2. Guided explanation of the observatory by an Abuyama Supporter

Next, we would like to point out that the activities of the Supporters, which initially began with guidance at events such as Open Lab, have entered a new stage in the last few years. One such example is the PET Bottle (Simple) Seismograph Workshop, which began in 2013 (Figure 3). Supporters are in charge of all aspects of the planning and execution of this program, which is targeted primarily at children. Table 1 shows the number of times these workshops have been held each year. Although the workshops have also been held at the observatory, most have taken place outside the facility.

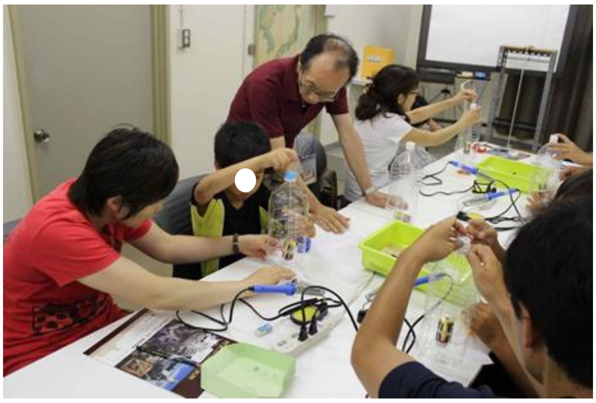

Figure 3. A workshop on making PET bottle seismographs

These facts show that the guidance activities carried out by Supporters, which were started as a substitute for the outreach activities that had previously been carried out by scientists (*i.e.*, seismology experts), had even received the high praise of experts. The scientists have recognized the real possibility of doing/performing the activities of outreach and education in relation to seismology, which they had previously been in charge of, together with ordinary citizens. Certainly, unlike activities such as analysis, which are discussed below, guidance might be considered to have only a slight degree of involvement in the main work of seismology. However, in light of the fact that the general public has taken on the role of scientists in terms of outreach, this too could be described as an attempt to further an attitude on the part of scientists and citizens to do/perform science together – in other words, to bring them ever closer to open science by producing personally meaningful products together.

2.4 Observation

The activities of the Abuyama Supporters are not limited to guidance. It is important that Supporters also participate in observation undertaken as part of an ongoing study at the Abuyama Observatory, namely, the Manten Project mentioned above. The Manten Project (officially "Next-Generation Dense Seismic Observation Research") differs from conventional observation networks in that it requires seismographs to be installed at an extremely high density in seismically active areas. This study aims to investigate the mechanisms of inland seismic activity with unprecedented accuracy (see Iio 2011, 2012). For this research plan, a new type of seismograph – the Manten seismograph – has been developed, which is far less expensive than conventional seismographs and much easier to install and maintain. The Abuyama Observatory serves as the base for the implementation of the Manten Project.

However, the Manten Project had significant challenges to overcome. As noted in Yamori and Iwahori (2016), these challenges consisted of securing land for the installation of a vast number of seismographs and the task of maintaining the seismographs themselves. The researchers lacked the time and resources to find a suitable location for the installation of such a large number of seismographs (orders of magnitude greater than before), to secure the rights to use the land, or to perform regular inspections of the equipment once installed. Therefore, we decided to promote the establishment of a system to jointly implement these activities with ordinary citizens (including children) who were interested in seismology, as well as local residents in the communities where the seismographs would be installed. We felt this would be effective in promoting understanding of seismology and raising interest in earthquake disaster prevention, as well as helping to alleviate the friction and conflict between society and the field of seismology mentioned earlier.

Here, we briefly present the achievements of this project. There are two main areas in which the general public have been deeply involved in observation. One of these is in western Tottori Prefecture, a seismically active area that includes the site of the epicenter of the Western Tottori Earthquake in 2000. In 2014, it was here that, as part of the Manten Project, we began the One-Tenth Manten Project, with the aim of installing 1,000 seismographs (*i.e.*, one-tenth of the full 10,000; for details, see Matsumoto, Iio, Saki, and Katō 2018). Around 1,000 seismographs were installed within a circular diameter of approximately 35 kilometers. Ordinary citizens participated in the installation of 375 of the 1,000 seismographs, and continue to play an important part in terms of maintenance as well as the observation activities themselves. Most of those involved are residents of the local community (including some local elementary school students). However, Abuyama Supporters have also taken part in activities in the field on seven occasions for a total of 19 days, serving as leaders of citizens who volunteered after being recruited and trained in Tottori. Seismological results from this observational study have already been published as Hayashida, Matsumoto, Iio, Sakai, and Kato (2020).

The other achievement is public participation in a rapidly organized aftershock monitoring program that was conducted in northern Osaka Prefecture in the immediate aftermath of the Northern Osaka Earthquake, which occurred in 2018, more or less right under the Abuyama Observatory. As reported in Iio (2020), in just the four days after the earthquake, an emergency aftershock grid consisting of 100 stations had been laid out by several university research institutes, including the Abuyama Observatory. Of these, Abuyama Supporters were in charge of the installation work at 12 locations (Figure 4). Monitoring of aftershocks in the immediate aftermath of an earthquake is extremely important in seismology and requires the rapid

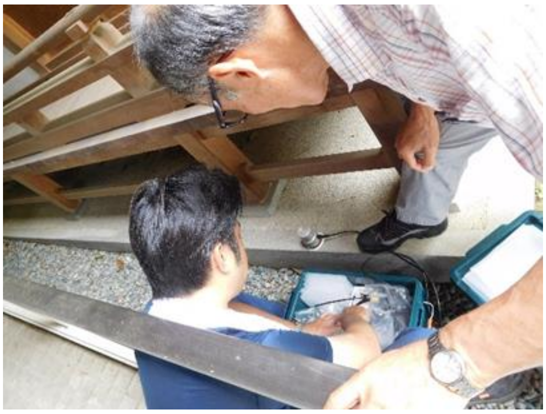

Figure 4. Installation of a seismograph by Abuyama Supporters
(part of the aftershock observation activities in the wake of the Northern Osaka Earthquake)

installation of seismographs. This was another scenario in which citizens provided support for research activities. Notably, the implementation of a second phase of aftershock monitoring activities in this area was scheduled to begin in 2020–2021, and an open call has gone out for volunteers. Here, too, there is the expectation of participation by Abuyama Supporters and other citizen volunteers. The project also contributes to local people's higher attention to, and better understanding of scientist's continuing effort of observing and predicting possible aftershocks in the locality.

2.5 Analysis

The reading of seismic waveform data by Abuyama Supporters is an important step forward for open science, particularly for citizen science, in which ordinary citizens, rather than simply learning scientific knowledge, take part in the production of that knowledge. The first step in the analysis of earthquake data is to determine the epicenter of the earthquake. To that end, it is necessary to accurately 'decipher' the point at which the seismic waves reached each observation point. This is a task that has been performed for more than 100 years, and that is essentially still done manually.

The basic concept of the Manten Project being carried out by the Abuyama Observatory is to acquire a large volume of seismic data, and the amount of work required to 'decipher' that data is enormous. Accordingly, the conventional system, in which only researchers are involved, is no longer tenable. And although the accuracy of automatic processing by computers is improving, the results cannot be used for detailed analysis at present.

Therefore, as mentioned in subsection 2.4, Abuyama Supporters who had taken part in the installation of Manten Project observation points and were well-versed in the details of the plan itself were called upon to participate in the task of reading the data (*i.e.*, the arrival time of seismic waves). After receiving the support of many Abuyama Supporters, expert-led training seminars were held, and these Supporters began reading data in 2016 (Figure 5). The analysis that began at the Abuyama Observatory in this way has continued over the past five years, reaching a total of 787 work sessions (with several Supporters conducting as many as 100 sessions each) with a total working time that has already exceeded 5,000 person-hours. Moreover, the data obtained through this project are being made available for academic analysis to elucidate the eruption mechanisms of inland earthquakes such as the Western Tottori earthquake in 2000. These results have already been published as a research article in one of the top international journals in the field of seismology (*e.g.*, Iio *et al*. 2020).

Figure 5. Abuyama Supporters reading seismic waveforms

With regard to analysis, although not an activity carried out directly by the Abuyama Observatory, we should mention Minna de Honkoku, which is a closely related activity carried out by Kanō *et al*. (2017). Minna De Honkoku is a project involving public participation that aims to decipher historical records of earthquakes. By deciphering historical records of natural disasters such as earthquakes, volcanic eruptions, and storms and floods and producing full-text reprints (in which cursive Japanese script [kuzushiji] has been deciphered and converted into electronic type), this project is playing a role in expanding the perspective of disaster science – which has more or less been limited to records no older than the modern period – into the premodern past. It has also contributed to the promotion of interdisciplinary joint research with fields such as history, geography, informatics, and Japanese literature.

Even so, the biggest feature of Minna de Honkoku is its mechanism for public participation, which can appropriately be called open science. The deciphering and transcribing (honkoku) of historical documents requires an enormous investment of time and effort, for which public participation is indispensable. Thus, Minna de Honkoku has devised several strategies to make the work of transcription easier and more appealing to the general public. Examples include the introduction of an "automatic cursive script recognition apparatus" that provides support for the task, as well as a system that encourages communication and collaboration with fellow transcribers engaged in the same task (*e.g.*, when someone suggests a particular way of reading some text, their work might be checked and revised by other participants, or they might be given hints for deciphering the text). The latter is particularly important, as evidenced by comments from participants that "the experts will fix it for us later, so this is an opportunity to study" because it functions as an effective mechanism for maximizing the benefits of open science by generating a so-called "collective knowledge" (see subsection 3.2 below).

3. DISCUSSION: THREE TYPES OF SCIENTIFIC LITERACY AND THE CONCEPTUAL LADDER OF CITIZEN SCIENCE

In this section, we discuss a program of action research focusing on the activities of citizen volunteers (the Abuyama Supporters) at the earthquake science museum introduced in the previous section. Together with a supplementary discussion of related research and practical examples, we consider this program from three main perspectives before summing up the research as a whole. The first perspective comprises the three aspects introduced as the typological axis of activities conducted by the Abuyama Supporters, namely guidance, observation, and analysis. The second perspective adopts Shen's (1975) elementary arrangement of scientific literacy into its practical, civic, and cultural aspects. The third perspective is the conceptual ladder of citizen science presented by Furuya, Sumimoto and Hayashi (2018) and Hayashi (2018), which is a typology that classifies citizen science based on the degree of public participation in science.

3.1 The three aspects of observation, analysis, and guidance

First, we will describe observation. As mentioned in Section 1, observation is a style of participation that has become a core part of fields such as astronomy and ecology, which could be called the pioneering fields in open science. Compared with these areas, it is more difficult to introduce public participation in observation activities for seismology. However, in this action research, we have been able to bring public participation to observation activities in the field of seismology through a system in which Abuyama Supporters and local residents were involved in the installation, maintenance and inspection of a large number of seismographs used for the observation of inland earthquakes.

In fact, in recent years, another activity contributing to the realization of observation in the field of seismology has been attracting increased attention, namely, the “Did You Feel It?” project, commonly referred to as DYFI. Launched in 2004 by the United States Geological Survey (USGS, 2004), DYFI is a system through which members of the general public, upon feeling an earthquake, can use the Internet to report the intensity of the quake motion they felt at the time of the earthquake and describe their own reactions or behavior as a result of the quake, as well as any damage to the surrounding area. Although DYFI takes citizen scientific approach in the area of observation (Goltz, Nakano, Park, and Yamori, 2020), DYFI represents a system through which a very large number of citizens can have a “broad, shallow involvement” in scientific activities via the Internet. It is quite different from the present study, in which a few Supporters have a “long-term, deep involvement” in seismology, while also collaborating with the aspects of analysis and guidance. Nevertheless, there is little doubt that observation will continue to play an important role in making seismology an open science.

Second, we will discuss analysis. Generally speaking, analysis is more closely associated with the core of scientific activities compared with observation and requires more deeply specialized knowledge and skills. For this reason, the realization of public participation in this aspect is considered to be less feasible, and seismology is no exception. In fact, it could be said that there is little room for discretion on the part of citizens in the reading of waveform data from seismic motions that has been carried out as part of this action research because the direction is fixed by the researchers. However, as pointed out by existing theories of education and learning such as the concept of legitimate peripheral participation (Lave and Wenger 1991), the very distinction between experts and non-experts should not be considered in terms of binary opposition. Rather, the work involved in analysis has room for incremental progression from basic to more specialized stages.

For example, with regard to the waveform reading activity at the Abuyama Observatory, scientists (experts) and ordinary citizens (non-experts) cannot (and should not) be regarded as professionally equivalent simply by virtue of performing this task. However, as suggested by the theory of legitimate peripheral participation, securing a conduit between the two groups that allows for various degrees of involvement in the scientific activity in question and devising a way for more people to come and go through that conduit might help to reduce friction

DOI10.5595/001c.35742

between society and science and link the two in a more productive manner. In that sense, analysis at the Abuyama Observatory can also be promoted as a first step toward involvement in the work of seismology itself – in other words, a first step toward scientists and citizens doing/performing science together.

With regard to the Minna De Honkoku project introduced earlier as another example of analysis, the relationship with "collective knowledge" (*e.g.*, Nishigaki 2013), which can also be seen in such examples as Wikipedia and open-source software, is important. This kind of attempt to collectively refine knowledge – including the fact that knowledge and information can be "overwritten" by a large number of people, which can sometimes lead them in the wrong direction, as well as the existence of open databases needed for such attempts – is one that can appropriately be called open science.

Also, the mentality expressed in the words of the participants mentioned in subsection 2.5, that "the experts will fix it for us later, so this is an opportunity to study," indicates that the analysis aspect of open science not only contributes to the scientific activities themselves (*i.e.*, the refinement and accumulation of knowledge), but also exerts a positive effect on each participant's attitude toward science (see the cultural element featured in the next subsection).

Third, let us briefly mention guidance. As we have repeatedly noted, guidance is, in itself, a normal dissemination and enlightenment activity – that is, the transfer of scientific knowledge from "someone who (already) has it" to "someone who does not (yet) have it" – and thus should be classified as a kind of outreach. In this sense, it may not be a part of open science. However, through this action research, we managed to run an earthquake science museum in a way that led ordinary citizens (Abuyama Supporters) to take on the role of instructors in the context of outreach. If we focus on this structure – that is, a structure in which ordinary citizens take over educational and outreach activities related to seismology conventionally performed by scientists – this could then be called an approach to an open science that includes elements of citizen science.

If we were to generalize the significance of this system, we could say that it is important to avoiding the fixation and rigidity of a structure that differentiates between "one who teaches" and "one who is taught." This binary structure may very well be essential for education and learning in the short term. However, there is no need for the terms to be fixed or rigidly defined as "scientist" and "citizen," respectively. Rather, actively and intentionally working to make this structure more fluid is essential for educational and learning activities at a deeper level, such as transdisciplinary academic movements. In fact, the theory of legitimate peripheral participation described above emphasizes that the degree of participation in a community of practice established by a given social practice (of which science is one) is always diverse (there will be novices, veterans, and everyone in between) and always changing (novices soon gain experience, and the middle rank eventually become veterans).

The same can be said of the Abuyama Supporters. Even though citizens have taken over the role of "instructors" in science communication from scientists, what is important is that further change is still possible. In other words, if this position were to become fixed, things would simply revert to the same binary structure as before, albeit with a slight shuffling of roles. Some Supporters who had originally been only chance visitors have become involved in observation and analysis. From the perspective of new recruits, these men and women are now quasi-experts. In that sense, preserving the fluidity seen in the relationship between veteran and novice Supporters, and thus in the broader community of practice, will also lead to preservation of the fluidity between ordinary citizens (potential Supporters) and current Supporters, as well as between veteran Supporters, who have reached the level of quasi-experts, and the experts themselves (for example, technical staff recently assigned to the observatory). Accordingly, we have realized that in the future, it will be necessary to hold training seminars for Supporters (which have thus far been held up until the third term) more frequently, as well as promote turnover at the science museum as a community of practice made up of observatory staff, Abuyama Supporters, and potential Supporters (*i.e.*, ordinary citizens who may become Supporters in future).

3.2 Three types of scientific literacy: *practical, civic,* and *cultural*

A second perspective from which to summarize the results of this study is the categorization of scientific literacy by Shen (1975) into practical, civic, and cultural forms of scientific literacy.

First, practical scientific literacy in the field of seismology corresponds to the acquisition of practical knowledge and skills – like methods of seismic retrofitting and reinforcement and the use of earthquake early warning systems – as well as the scientific knowledge behind them. Next, civic scientific literacy is expected of citizens as upholders of democracy. This refers to the ability to recognize whether activities related to a given scientific area (and the results generated therein) are being incorporated into society in a form that is compatible with the common-sense values of most citizens and that is consistent with the workings of a democratic society, so that problems can be acknowledged and resolved. In the context of seismology, this is the scientific literacy required to ask questions such as those posed in the wake of the Great East Japan Earthquake, such as “Could the huge tsunami that caused the nuclear disaster actually have been predicted?” and “Has science (as well as scientists) played an appropriate role in the process of determining advance tsunami countermeasures?” Finally, cultural scientific literacy refers to the consumption of scientific information as a form of intellectual entertainment or amusement, and the discovery of joy in learning about science itself.

Now, the problem here is that although it may be easy to recall and illustrate specific examples of the practical and civic aspects of seismology, it is more difficult to do so for the cultural aspects. In other words, at least in contemporary Japanese society, seismology is generally accepted as a science that provides society with practical knowledge. For this reason, seismology is arguably positioned as something that citizens are obliged to pay attention to in terms of whether or not that knowledge is being used in a manner that benefits only certain organizations or interest groups. However, compared with fields such as astronomy or ecology, seismology has not yet been established as a science in which citizens find intellectual enjoyment, something that would seem to be an obstacle to seismology becoming an open science.

On the flip side, therefore, we can think that the promotion of seismology as an open science might be realized by placing greater emphasis on the cultural aspect of scientific literacy as it relates to seismology. In that sense, it is noteworthy that the activities of the Abuyama Supporters have properties that are more strongly associated with this cultural aspect than with the practical or civic aspects. We can see this by looking at the motivations given by respondents for applying to become Abuyama Supporters (subsection 2.2). First, we do not find any motivations that could be classified as civic. Although many of these motivations mention an interest in seismology, references to things like practical earthquake prevention measures – in other words, practical aspects (utility to disaster prevention) – seem more or less limited to “contributing to disaster prevention” and “leading to opportunities to participate in disaster prevention and mitigation activities.” Rather, as a whole, there is a strong inclination toward cultural aspects, as in “learning more about specific ideas, like the correct knowledge and science-based prediction technologies,” “[having] taught earth science and biology at a high school,” “I’ve been interested in earthquakes and other global phenomena for a long time,” and “an interest in seismology (especially active faults and archaeo-seismology), which I am now studying.”

Moreover, it is important to note that this orientation toward cultural aspects on the part of the Abuyama Supporters seems to be supported not only by seismology and seismic observation research, but also by the general scientific and intellectual aspects of the environment surrounding the observatory. This is precisely the attitude of someone who is poised to absorb and enjoy scientific information as a form of intellectual entertainment and amusement. For example, in statements such as “global environmental problems,” “the building and its atmosphere,” “forest volunteer,” “volunteer guide at ancient ruins,” and “a qualification as an environmental counselor, and I’m interested in the natural environment,” we can see that people’s motivations for applying to be a Supporter relates not only to an interest in seismology in a narrow sense, but also the support of scientific and cultural activities in general.

As described above, when science is done/performed not by scientists alone but in collaboration with ordinary citizens – in other words, when it involves citizen participation and contribution to a cross-section of scientific activities, whether in terms of guidance, observation, or analysis – it leads to the acquisition of pragmatically useful scientific knowledge and skills (the practical element) and ensures that the need to put the brakes on “runaway” science (or scientists) is monitored from the citizens’ perspective (the civic element). Citizens watch and monitor scientific activities, and, if needed, can stop scientists not to move forward without social approval, when they try to develop and implement morally or ethically problematic technologies, for example. Also, as a cultural activity in and of itself, it brings intellectual satisfaction and collective enjoyment to the citizens who participate in these activities. The fact that the Science Museum Project at the Abuyama Observatory was able to promote this cultural aspect could be the key unlocking the door for open science in seismology.

The discussion above shows that open science activity at the Abuyama Observatory, with the improvement in all of three types of scientific literacy, does not simply promote learning and understanding of seismic science. But it brings deeper ownership and commitment to the citizens and fosters mutual trust between scientists and citizens by jointly observing and analyzing the aftershocks of the 2018 local earthquake mentioned in section 2.4. Discovering one's own capacity and feeling joy in the participation in scientific activities is important, particularly now, when we face societal-ecological crises like climate change and pandemics. It is true that what has been achieved at the Abuyama Observatory is small yet, but it is a solid step towards resolving societal distrust of science following the 2011 catastrophic event.

3.3 The 'conceptual ladder' of citizen science

A standard 'conceptual ladder' exists for citizen science, or rather for scientific activities in which ordinary citizens take part (Furuya, Sumimoto, and Hayashi 2018). Figure 6 presents our own framework of this conceptual ladder. Based on an awareness of the widening gap between researchers and citizens in the context of traditional science – which in the case of seismology is attested to by comments such as those concerning the "collapse of the myth of safety" and "unexpectedness" described in subsection 1.3 – outreach from scientists to citizens in the form of activities that seek to convey research outcomes in a manner that is easily understood has taken on increased emphasis. Premised therein, however, remains the belief that those who conduct research and those who enjoy the outcomes of that research are in diametric opposition, and that knowledge and skills flow unidirectionally from the former to the latter. In contrast, citizen science is conceived of as a new form of science predicated on a cooperative relationship between scientists and citizens. And, as described in subsection 1.2, open science, while using citizen science and open data as two wheels on the same axle, is positioned as a movement aimed at realizing a public participatory model of science.

Incidentally, Furuya, Sumimoto, and Hayashi (2018) distinguish four different levels (like steps on a ladder) of citizen science, with a focus on the degree of collaboration involved (Figure 6). It is important to note that, as suggested by the word "level," these four types carry the implication that higher levels are more advanced and therefore more desirable. For example, in this study, the observation realized by Abuyama Supporters would correspond to Level 1 (assisting with data collection), whereas analysis would correspond to Level 2 (data classification). Thus, the activities of the Abuyama Supporters have yet to reach Levels 3 and 4, and in that sense could be evaluated as being only midway along the path to citizen science. Prospectively, we would also like to aim to introduce activities that would correspond to what are described here as Levels 3 and 4.

IDRiM (2022) 12 (1) **ISSN: 2185-8322**
DOI10.5595/001c.35742

OPEN SCIENCE					
CITIZEN SCIENCE (DO / PERFORM SCIENCE)	Level 4	Joint research	Collaborative relationships between researchers and citizens	+	Open data (utilization of ICT)
	Level 3	Participation in scientific discussions			
	Level 2	Data classification			
	Level 1	Assisting with data collection			
OUTREACH (LEARN / KNOW SCIENCE)			One-way relationship *from* researchers *to* citizens		
TRADITIONAL SCIENCE			Separation of researchers and citizens		

Figure 6. Conceptual ladder of open science and ‘citizen science’

However, we would also like to call attention to the fact that there are some aspects in which this is not the case. In the context of citizen science, where the aim is for scientists and ordinary citizens to do/perform science together, what is here imagined as Level 4 – that is, for citizens to engage alongside scientists in professional discussions and carry out joint research as equal partners –is itself seen as the (ideal) goal of citizen science. But this is not necessarily always the case. The impression of an Abuyama Supporter that although “this was my first experience, […] I felt a sense of purpose knowing that I was only just beginning to get involved,” would also seem to suggest that public participation in observation (*i.e.*, what is considered to be Level 1), has just as must potential as Levels 3 and 4 to act as a bridge connecting science with society, and scientists with citizens.

Finally, in closing this paper, we wish to touch on some of the negative aspects of open science. In this paper, we have described the open science movement as though it were something that should be promoted without precondition. And in fact we, in principle, evaluate open science positively as an important direction for building (or rebuilding) the relationship between science and society in the future. However, we are also aware of the negative aspects that this might entail, as well as the pitfalls of this movement.

Specifically, first, and as mentioned in Section 3.2, is the potential for the binary structure of "one who teaches" and "one who is taught" to be reproduced by the shuffling of roles; this should be kept in mind as something to be wary of. It is also worth noting that this point has been discussed elsewhere as a theory of risk communication based on the idea of the "double bind," and that concrete countermeasures have been proposed (see *e.g.*, Yamori 2020).

Second, in connection with the civic aspect of scientific literacy described above, public participation in scientific activities in the context of open science, especially when attempted merely as a formality, can be intended solely to give the science (or scientist) the excuse (or license) to say that the research is "democratically run" or "open to the public." This is also something that has long been discussed by people such as Yagi (2009), who has been assiduously studying the dialogue between scientists and citizens while reviewing a variety of participatory methods and dialogue techniques.

Furthermore, unlike fields such as ecology and astronomy, which have already gained a social presence as open science, it must be pointed out that the foundations of open science are still vulnerable in the context of relative latecomers such as seismology. As with the initiatives undertaken at the Abuyama Observatory, such attempts rely on the creativity and enthusiasm of a limited number of researchers, as well as the cooperation and support of a small number of like-minded citizens. As such, it cannot be said that there is yet sufficient momentum for research organizations (*e.g.*, universities) and their related academic societies to come together to promote open science. To overcome this situation, it will be necessary to open up future prospects in two ways. One is to systematically collaborate with activities related to outreach, which has taken on increased relevance in recent years among (seismological) academic societies. The other is to establish an organization, for example, through the incorporation as a non-profit organization and educational organization like schools and science centers, so that it does not depend entirely on the personal efforts of particular researchers and the transient cooperation and support of citizen volunteers.

As mentioned above, simply saying that something is "open science" is no guarantee that the traditional challenges associated with the relationship between science and society will be overcome or that everything will proceed smoothly. What is required of open science is careful planning and prudent management that is simultaneously focused on both the positive and negative aspects presented herein.

ACKNOWLEDGMENTS

We wish to thank everyone who supported the Abuyama Observatory Science Museum Project. In particular, we want to express our sincere gratitude to the Abuyama Supporters and other citizen volunteers for their many years of dedicated support for this project.

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