Radiation risk communication initiatives using the “Quartet Game” among elementary school children living in Fukushima Prefecture

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After the Fukushima Daiichi nuclear disaster that followed the Great East Japan Earthquake in 2011, the Ministry of the Education, Culture, Sports, Science and Technology of Japan created supplemental texts about radiation. Teachers were then instructed to provide education on radiation, but many were unable to do so because they had not learned a sufficient amount of material. Therefore, we developed a “Quartet Game” that could be used by teachers in school as teaching material to make learning easier for students. In this study, we aimed to investigate whether elementary school students could acquire knowledge on radiation through the Quartet Game and clarified whether it was an appropriate methodology for sharing information. This study was carried out in 2015 in Fukushima Prefecture and included 89 students as study participants. We conducted a questionnaire test on the students before and after the implementation of the game. The results indicated that over 95% of the students understood the rules, enjoyed playing the game, and learned something new. Furthermore, the total knowledge score on the post-test was significantly higher than that on the pre-test. These findings suggest that the Quartet Game is an effective method for teaching radiation education among elementary school students.

Key words: radiation, nuclear disaster, risk communication, elementary school, Fukushima

I. INTRODUCTION

About 10 years have passed since the Great East Japan Earthquake struck the Tohoku and Kanto regions of Japan, leading to a devastating tsunami and resultant accident at the Fukushima Daiichi Nuclear Power Station (FDNPS), which is operated by Tokyo Electric Power Company3). According to the United Nations Scientific Committee on the Effects of Atomic Radiation, the amount of radionuclides released was one-sixth that seen after the Chernobyl disaster in 19862). However, the Fukushima Daiichi nuclear disaster was still ranked as a “Level 7 (major) accident”, the highest value on the International Nuclear Event Scale, the same as the Chernobyl disaster3). Due to the large amount of radionuclides released, the Japanese central government declared the area around the FDNPS as a “Difficult-to-return zone”, forcing a large number of residents to evacuate. In total, over 15,000 residents of Fukushima Prefecture had to evacuate to other regions within or outside the prefecture4,5). After several years, due to extensive decontamination efforts, the government gradually

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lifted “Difficult-to-return zone” classifications, leading to an increase in the number of “Evacuation-order lifted areas”6).

Although radiation exposure is limited among residents of Fukushima7–9), the perception of radiation risk, particularly in terms of the genetic effects of radiation, is substantial10). Furthermore, in Fukushima, it was reported that the proportion of people in need of assistance for mental illness and/or distress was higher than that in other prefectures11). A correlation between radiation risk perception and mental health has also been reported12). The relatively poorer psychological well-being among evacuees is largely explained by their continued long-term, unresolvable concerns about the physical health risks associated with exposure stemming from the accident13). Therefore, opportunities for risk communication in which residents discuss radiation risks to dispel misunderstandings are extremely important.

Risk communication was defined by the National Research Council in 1989 as an interactive process of exchange of information and opinion among individuals, groups, and institutions14). “Interactive” does not refer to one-way communication from experts in central and/or municipal governments, companies, and scientists, but rather to many individuals, affiliates, and institutions discussing issues and opinions about risk, i.e., exchanging information about risk and making a decision among the people involved15). After the Fukushima Daiichi nuclear disaster, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan created two supplemental texts about radiation that describe the accident for elementary, middle, and high school students16). These texts were created to explain radiation and obtain public consent for the continuation of the nuclear program17). Radiation education using these supplemental texts has gradually spread throughout Japan as part of a risk communication initiative. The residents of Fukushima Prefecture, notably children, need to gain more knowledge about radiation to live under existing radiation exposure situations. In 2017, the Mitsubishi Research Institute of Japan conducted a questionnaire survey to gain a better understanding of the awareness of people living in Tokyo regarding the status of reconstruction in Fukushima and the effects of radiation on health. The results of the survey revealed that about half of the residents of Tokyo believed that the current radiation dose in Fukushima Prefecture would cause delayed health and/or genetic effects18), which suggests the importance of educating children about radiation to prevent the self-stigma caused by their misperceptions as they grow up and face life-events in the future. Therefore, in the present study, we focused on radiation education for children. In Russia, for example, local authorities have provided assistance in the production of textbooks and multimedia teaching materials related to the handling of the Chernobyl disaster, as well as in the establishment of information and resource rooms at schools to enable students to collect information on radiation proactively. Seminars have also been organized for teachers and social welfare assistants19). In Fukushima Prefecture, elementary students have received lectures regarding radiation through picture-story shows, radiation measurement practice, and so on20). However, teachers need to learn special techniques for these methodologies, because if students ask them detailed questions about radiation, most teachers still cannot provide an appropriate answer. Therefore, many schools have invited professionals from universities and/or research institutes.

On the other hand, the Quartet Game, a card game mainly used in Germany as an educational tool, in which the player who collects the largest number of pairs of cards (four cards each in eight
colors, for a total of 32 cards) wins\textsuperscript{21}, does not require professional skills or abilities, so it can be used in the classroom by schoolteachers who are not educated about radiation. In Japan, Quartet Games have been developed as countermeasures for influenza A virus subtype H5N\textsuperscript{22}, food safety education\textsuperscript{23}, and rabies prevention\textsuperscript{24}. Based on the results of previous studies, the Quartet Game is an effective educational tool for elementary school students. With this background, we developed a Quartet Game that could be used by schoolteachers as a teaching material to make learning easier for students. The aims of this study were to investigate whether elementary school students could acquire knowledge on radiation through our developed Quartet Game, and to clarify whether it was an appropriate methodology for sharing information.

II. MATERIALS AND METHODS

1. Study participants and question items

This study was conducted in 2015 at two elementary schools in Fukushima Prefecture. In total, 89 students (fourth through sixth grades) were included as study participants. To select the elementary schools for this study, we consulted with the Fukushima Prefectural Board of Education and requested cooperation from the selected schools. The schools that consented to participate were selected for the study. The activity was carried out during a 45-minute class and consisted of "Introduction (8 minutes)\textsuperscript{21}, "Development (30 minutes)\textsuperscript{21}", and "Summary (7 minutes)\textsuperscript{21}. The class was conducted by the coauthor and specialists in cooperation with the schoolteachers.

First, in the introduction part, we asked the following seven true–false questions regarding the card contents: "We are exposed to cosmic rays", "Radionuclides release radiation", "Sieverts (Sv) are the units that represents the scale of health effects on humans", "Artificial radiation is used in the field of cancer treatment", "Dr. Röntgen discovered radiation", "Potatoes are preserved longer by irradiating their buds", and "Radiation has bactericidal effects". All seven question items were correct statements so that the students would not receive wrong information.

Second, in the development part, we distributed cards that contained explanations of the rules and gameplay. Students formed groups and were given sufficient time to read the cards aloud to each other.

Third, in the summary part, we conducted the same quiz as that in the introduction part and asked three additional questions: "Did you understand the rules of this game?", "Did you have fun playing the game?", and "Did you learn something new through playing the game?" The students were asked to respond to the three question items on a four-point Likert scale, from "Very much" to "Not at all". Additionally, at the end of the questionnaire, we asked the students to write freely about their impression of the game using the following open-ended question: "What did you think or feel when you played the game?"

2. The Quartet Game

The Quartet Game is a type of educational card game for young (and older) children that can be played by four or five players at a time. In the present study, the procedures for the game referred to previous studies\textsuperscript{21–24} and were conducted in accordance with the method proposed by its original developers.

3. Contents of the Quartet Game

The game that was used in this study was created by referring to the contents of supplemental texts prepared by MEXT\textsuperscript{16}. The members of the present study group were experts on radiation health effects, disaster victim support, and food, as well as people who actually provided support. The
Quartet Game examined here consisted of the following eight themes: “Around Us”, “Work”, “Change”, “Measurement”, “Use”, “Impact”, “History”, and “Disaster Prevention” (Figure 1). For example, “Space”, “Ground”, “Air”, and “Food” comprised the theme of “Around Us”, and a comment regarding the contents was written on each card, e.g., “We are exposed to radiation from space” (Table 1).

4. Procedures for playing the Quartet Game in the present study

(1) The Quartet Game is played by four or five people. It can be played by six or more people, but it becomes more difficult with more players.

(2) Cards are shuffled and distributed to all participants (the contents of the cards are hidden).

(3) There are 32 cards in total, four cards each in eight colors.

(4) The participants play “rock paper scissors” with the winner going first; turns proceed in clockwise order.

(5) Each player asks another if they have a card they need (want).

(6) The asked player must look at their cards and hand over the requested card honestly if he or she has it.

(7) If the player gets a card, he or she can continue playing. The player does not have to ask the same participant each time. If the asked player does not have the card, it is the next player’s turn.

(8) The color is shown on the left-hand side of each card so that all players can see which four cards belong to the same set.

(9) When a player has a set of four cards in his or her hand, he or she says, “quartet” and places the four cards side by side in front of the other players.

(10) If a player runs out of cards, when his or her turn comes, he or she asks the other players the same questions as before and collects the cards.

(11) As soon as no one has any cards left, the player with the most colors on the table wins.

5. Statistical analysis

We used McNemar’s test to compare the corresponding categorical variables. For the corresponding continuous variables, we conducted the Shapiro-Wilk test and confirmed a nonparametric distribution. We used the Wilcoxon signed-rank test for all analyses. Furthermore, for independent continuous variables such as a comparison of gender and grade, we conducted the Mann-Whitney U test and the Kruskal-Wallis test. All data were statistically analyzed using SPSS statistics (version 25.0; IBM, Tokyo, Japan). A p-value < 0.05 was considered statistically significant.

6. Qualitative analysis

We analyzed qualitative data using "KH coder"26-28, which is free text-mining software used to
analyze text-type materials. We extracted specific words and the number of times they occurred in the questionnaire. Furthermore, we constructed a “co-occurrence network” used by KH coder to reveal associations among the qualitative data. If compound words were not read by the system, the system was preprocessed to force the extraction of compound words so that they could be analyzed correctly. The minimum number of occurrences of words used in the co-occurrence network was set

### Table 1 The contents of Quartet Game

| Theme          | Contents                                      | Comments                                                                 |
|----------------|-----------------------------------------------|--------------------------------------------------------------------------|
| Around us      | Space                                         | We expose radiation from space.                                           |
|                | Ground                                        | Radiation is emitted from the ground.                                    |
|                | Air                                           | We inhale natural radionuclides by breathing.                            |
|                | Food                                          | We ingest natural radionuclides from food.                               |
| Work           | Pass Through                                  | Radiation has the ability to pass through things.                        |
|                | Strengthen                                     | Radiation has the ability to strengthen the materials.                   |
|                | Exterminate                                    | Radiation has the ability to kill the bacterias.                         |
|                | Resolve                                        | Radiation has possibility to resolve the harmful chemicals.              |
| Change         | Radionuclides                                 | Radionuclides emit radiation                                             |
|                | Change                                        | Radionuclides change another thing as time goes by.                      |
|                | Half-life                                      | The time it takes for the amount of radionuclides to be reduced by a factor of two is called the “half-life”. |
|                | 30 years                                      | Half-life varies depending on the radionuclides.                         |
| Measurement    | Haharw-kun                                    | Radiation can be measured by dosimeter.                                  |
|                | Sievelt                                        | It is a unit of measurement for the amount of radiation a body receives.|
|                | Place                                         | Let’s measure various places around your school.                         |
|                | Age                                           | The age of the pottery can be determined by measuring the radiocarbon that emits radiation in the pottery. |
| Use            | X-ray Photography                             | Radiation can be used to look at fractures and injuries.                |
|                | Power Generation                              | Radionuclides can be produce electricity                                 |
|                | Tire                                           | The rubber is irradiated to create strong and durable tires.             |
|                | Potato                                         | Radiation prevents buds and allows for longer storage.                   |
| Radiation      | 2.1                                           | In Japan, the amount of radiation received from natural radiation in a year is about 2.1 mSv per person. |
|                | Artificial Radiation                          | Artificial radiation is used in the treatment of cancer and other diseases.|
|                | Burn                                           | If exposed to a lot of radiation, get burned.                            |
|                | Cancer                                         | If receives a lot of radiation, more likely to develop cancer in the future. |
| History        | Dr. Roentgen                                   | Dr. Roentgen found radiation in 1895, and received a novel prize.       |
|                | Mr. and Mrs Curie                              | Mr. and Mrs. Curie found radionuclides in 1898.                          |
|                | Atomic Bomb                                   | Atomic bomb was dropped on the Nagasaki and Hiroshima in 1945           |
|                | Nuclear Power Plant                            | Nuclear Power Plant accident was occurred because of the Great East Japan Earthquake in 2011. |
| Disaster Prevention | Information Acquisition                     | Listen carefully to information from the radio and TV.                |
|                | Evacuation                                    | When evacuating from one’s home, turn off the gas and electricity and lock the door. |
|                | Water                                         | Prepare a week’s supply of food and water.                               |
|                | Confirmation                                  | Let’s talk about what to watch out for at school and at home.            |
to two, and the Jaccard coefficient was set to 0.329.

7. Ethical considerations and approval

We explained to elementary school students that participation was voluntary and that they would not be penalized in any way if they chose not to participate. Only elementary school students who provided consent answered the questionnaire. This study was approved by the ethics committee of the National Institute of Public Health (No. NIPH-IBRA#12068).

8. Patient and public involvement

This study involved the public, especially elementary school students. Before the study began, we informed and obtained consent from the Fukushima Prefectural Board of Education and president of the elementary schools for the students to participate in this study.

III. RESULTS

In total, 89 elementary school students (48 [53.9%] boys, 39 [43.8%] girls; two students [2.2%] did not respond) completed the questionnaire (Table 2). After playing the game, 86 students (96.6%) reported that they had understood the rules, 86 (96.6%) reported having fun, and 85 (95.5%) reported learning something new (Table 2).

According to the results of the analysis of the qualitative data, the most frequently mentioned word was “learn” (33 times), followed by “radiation” (32 times) and “fun” (22 times) (Table 3). Some responses included “I enjoyed learning”, “It was very easy to understand. It was also really fun and I want to do it again. I learned a lot”, “I know that radionuclides have good and bad aspects”, and “There was something I didn’t understand with radiation, but I’m glad I found out when I played the game”. The “co-occurrence network” is shown in Figure 2. Connections were identified regarding the “impression of the card game” and the “contents of the card game” (Figure 2).

| Table 2 | Demographic factors of the participants. |
|---------|-----------------------------------------|
| Question | Response | n (%) |
| Gender   |           |       |
| Male     | 48 (53.9) |
| Female   | 39 (43.8) |
| Unanswered | 2 (2.2) |
| Did you understand the rules of this game? |       |
| Very much | 78 (87.6) |
| Somewhat | 8 (9.0)   |
| Very little | 2 (2.2) |
| Not at all | 1 (1.1)  |
| Did you have fun playing the game? |       |
| Very much | 82 (92.1) |
| Somewhat | 4 (4.5)   |
| Very little | 0 (0.0) |
| Not at all | 3 (3.4)  |
| Did you learn something new through playing the game? |       |
| Very much | 68 (76.4) |
| Somewhat | 17 (19.1) |
| Very little | 2 (2.2) |
| Not at all | 2 (2.2)  |

Table 3 Word frequency in the open-ended question.

| Rank | Extracted word | Number of occurrences (times) |
|------|----------------|------------------------------|
| 1    | Learn          | 33                           |
| 2    | Radiation      | 32                           |
| 3    | Fun            | 22                           |
| 4    | Game           | 18                           |
| 5    | Enjoy          | 14                           |
| 6    | Know           | 13                           |
| 7    | Play           | 13                           |
| 8    | Understand     | 12                           |
| 9    | Quartet        | 10                           |
| 10   | Easy           | 8                            |

The items with a significantly higher correct rate in the post-test compared with the pre-test were: “We are exposed to cosmic rays (pre-test vs. post-test: 55% vs. 84%, respectively; \( p < 0.001 \)”, “Artificial radiation is used in the field of cancer treatment (70% vs. 85%, \( p = 0.004 \)”, “Dr. Röntgen discovered radiation (29% vs. 87%, \( p < 0.001 \)”, “Po-
tatoes are preserved longer by irradiating their buds (51% vs. 87%, \( p < 0.001 \))”, and “Radiation has bactericidal effects (53% vs. 81%, \( p < 0.001 \))” (Table 2 and Figure 2).

Furthermore, in the pre-test, the mode was four, whereas in the post-test, the mode was seven. The total score on the post-test was higher than that on the pre-test (Figure 4). The total score on the post-test was significantly higher than that on the pre-test (median [first quartile – third quartile]: 4 [3–5] vs. 7 [5.5–7], respectively; \( p < 0.001 \)) (Figure 4). Moreover, based on the results of the pre-test and post-test distributed by gender or grade, no statistical significant difference was found between

| Question item                                           | Before playing the game, \( n (%) \) | After playing the game, \( n (%) \) | \( p \) value |
|---------------------------------------------------------|-------------------------------------|-------------------------------------|--------------|
| We are exposed to cosmic rays.                          | 49 (55)                             | 75 (84)                             | < 0.001      |
| Radionuclides release radiation.                        | 82 (92)                             | 85 (96)                             | 0.549        |
| Sieverts (Sv) are the unit that represents the scale of health effects on humans. | 69 (78)                             | 77 (87)                             | 0.096        |
| Artificial radiation is used in the field of cancer treatment. | 62 (70)                             | 76 (85)                             | 0.004        |
| Dr. Röntgen discovered radiation.                      | 26 (29)                             | 77 (87)                             | < 0.001      |
| Potatoes are preserved longer by irradiating their buds. | 45 (51)                             | 77 (87)                             | < 0.001      |
| Radiation has bactericidal effects.                     | 47 (53)                             | 72 (81)                             | < 0.001      |

McNemar’s test
Figure 3 Comparison the number of samples in a total score between pre-test and post-test
White-bars shows the number of sample in pre-test, and black-bars shows the number of samples in post-test.

Figure 4 Compare of pre-test and post-test regarding total score of the knowledge on radiation. Y-axis shows total score of the knowledge on radiation. Wilcoxon signed-rank test; aMinimum, bFirst-quantile, cSecond-quantile (Median), dThird-quantile, eAverage, fMaximum, gOutlier
genders (pre-test: male, 4 [3-5] vs. female, 4 [3-5]; \( p = 0.442 \)) (post-test: male, 7 [5-7] vs. female, 7 [6-7]; \( p = 0.255 \)) or grades (pre-test: 4th grade, 4 [4-6] vs. 5th grade, 4 [3-5] vs. 6th grade, 4 [3-5]; \( p = 0.47 \)) (post-test: 4th grade, 7 [6-7] vs. 5th grade, 6 [5-7] vs. 6th grade, 7 [5.75-7]; \( p = 0.191 \)).

IV. DISCUSSION

In this study, as a result of playing the Quartet Game, we found that more than 95% of the students understood the rules, enjoyed the game, and learned something new through playing (Tables 2 and 3, Figure 2). The rules of this game were based on the rules of quartet card games that have long been used in many countries\(^{30-33} \). The rules of the game were designed to be understood by children all over the world. The material used to explain the rules in this study were changed to a Japanese version and could be understood easily by elementary school students. It is highly possible that the Quartet Game used in this study also contributed to student motivation, as reported in a previous study\(^{32} \).

A comparison of pre- and post-test scores regarding radiation knowledge showed significantly higher correct rates on the post-test for the following items: “We are exposed to cosmic rays”, “Artificial radiation is used in the field of cancer treatment”, “Dr. Röntgen discovered radiation”, “Potatoes are preserved longer by irradiating their buds”, and “Radiation has bactericidal effects” (Table 4). These items can be learned from the game contents, suggesting that the students may have acquired knowledge of radiation through the card game. On the other hand, the correct rates for “Sieverts (Sv) are the units that represents the scale of health effects on humans” were not significantly different between the pre- and post-tests. We considered that this was because the percentage of correct answers on the pre-test was already high. Comparing the number of samples for the total scores on the pre- and post-tests, the pre-test showed an approximate parametric distribution; nevertheless, many students had the highest score on the post-test, so the distribution differed from that for the pre-test (Figure 3). Although two items were not significantly different between the pre- and post-tests, the total score for radiation knowledge on the post-test was significantly higher than that on the pre-test (Figure 4). It is therefore highly possible that many students could acquire radiation knowledge in the game, which was conducted during a 45-minute class, and we considered that the Quartet Game used in this study was effective as a teaching material. In Japan, after the accident at the FDNPS, elementary school students have had opportunities to learn about radiation health effects using supplemental texts devised by MEXT; however, it is difficult to teach this material because teachers have not learned a sufficient amount about the health effects of radiation\(^{34} \). Therefore, the Quartet Game developed in this study appears to be useful for radiation education among elementary school students. Moreover, because the game use and rules are simple, even teachers who do not have deep knowledge of radiation can easily use it in the classroom.

The steps of risk communication are “raising awareness about the problem”, “providing and sharing information”, “discussing and co-considering”, “building trust”, “stimulating behavioral change”, and “building consensus”\(^{35} \). In this study, the Quartet Game was shown to be an easy to use tool for “providing and sharing information”, the second stage of risk communication. The use of the Quartet Game may therefore provide an opportunity for students to learn more about radiation. The introduction of a more advanced version of the game into the curriculum of elementary school students, especially those living in Fukushima Prefecture, could deepen their knowledge on basic radia-
tion and represent a step forward in the next phase of risk communication.

This study had several limitations. First, we only targeted residents of Fukushima Prefecture. We could measure the effects of the Quartet Game further by conducting it in an area where little information on radiation is available. Second, since the number of participants was limited, it was not clear whether the Quartet Game had an overall effect on learning. Third, it is possible that the children could have learned about radiation from sources such as their parents, TV programs, and news articles before the class. Fourth, the post-test in this study was conducted immediately after the intervention, so the results may not have reflected the knowledge retention from the intervention. Fifth, we conducted this study in a limited number of schools and with a small sample of students. Sixth, because this study was translated into English from text written in Japanese, there may be some discrepancies with the contents intended by the participants. Seventh, the results of the text mining in this study are likely to be difficult for English-speaking readers to understand. Eighth, the contents of Quartet Game were not covered all contents of supplemental texts by MEXT.

V. CONCLUSION

In this study, elementary school students in Fukushima Prefecture were able to enjoy the Quartet Game while acquiring knowledge on radiation. The Quartet Game therefore appears to be effective for sharing information on radiation with children and should be further developed as a risk communication methodology by enhancing the content of the game.

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CONFLICT OF INTEREST

None of the authors declare any potential competing interests.

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AUTHOR CONTRIBUTIONS

TY and IH conceived and designed the study. TY implemented the statistical analysis and wrote the manuscript. IH reviewed and edited the manuscript. TY and IH contributed to the discussions about the statistical methods and the interpretation of the findings.

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