Post-Fukushima radiation education for Japanese high school students in affected areas and its positive effects on their radiation literacy

Masaharu Tsubokura¹,²*, Yuto Kitamura³ and Megumi Yoshida⁴

¹Department of Radiation Protection, Soma Central Hospital, 3-5-18 Okinouchi, Soma, Fukushima 976-0016, Japan
²Department of Radiation Protection, Minamisoma Municipal General Hospital, 2-54-6 Takami-cho, Haramachi-ku, Minamisoma, Fukushima 975-0033, Japan
³Graduate School of Education, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
⁴Itochu Techno-Solutions Corporation, 1-2-2 Osaki, Shinagawa-ku, Tokyo 141-8522, Japan

*Corresponding author. Department of Radiation Protection, Soma Central Hospital, 3-5-18 Okinouchi, Soma, Fukushima 976-0016, Japan. Tel: +81-244-36-6611; Fax: +81-244-22-8853; Email: tsubokura-tky@umin.ac.jp

ABSTRACT

In post-Fukushima Japan, radiation education is very important, and the subject is being actively discussed. However, little information is available about the amount of knowledge students initially had about radiation or about how well radiation education improves their understanding. Using the questionnaire results of 717 students completed before and after radiation lectures held in three high schools in Fukushima, we examined the number of answers to the questionnaire aligned with the evidence base, and classified the students into clusters based on radiation-related behavior and attitudes to assess the effectiveness of the lecture. The contents of the lectures consisted of (i) scientific knowledge relating to radiation, (ii) results of radiation examinations conducted locally following the disaster and (iii) measures and precautions for daily radiation protection. Associations between the type of knowledge and radiation-related behavior and attitude were also examined to determine which type of knowledge was more important for deepening students’ understanding of radiation. This study revealed that radiation education in high schools was effective for students with respect to acquiring relevant basic and practical knowledge; however, the effects of the radiation lecture differed greatly between schools, presumably due to differences in the delivery and atmosphere of the lecture. The present study also suggested that radiation education may positively transform student attitudes and behaviors related to radiation. To enable such a change in awareness, the acquisition of scientific knowledge is essential, for it enables individuals to make better decisions about important matters in their daily lives.

Keywords: radiation education; literacy; Japan; Fukushima; pedagogy; disaster

INTRODUCTION

Radiation education can be considered as including both disaster education and education in disaster risk reduction. However, since radiation education is not necessarily premised on the actual occurrence of a disaster, it seems more legitimate to consider it an independent educational area [1–4]. While radiation education and how it should be conducted in schools has been discussed over many years in many countries [5–7], the Chernobyl disaster aroused interest on a global scale, and various initiatives have been carried out since then [8]. In Russia, for example, local authorities have provided assistance in the production of textbooks and multimedia teaching materials handling the Chernobyl disaster, as well as for 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 assistants [9].

In Japan, however, although much discussion has been held on education in radiation safety over many years, radiation education was not being actively practised in Japanese schools, despite its recognized importance. This was (i) because it had not been explicitly required or recommended in the governmental guidelines for
school curricula and (ii) due to the lack of radiation literacy on the part of educators. At the 24th Meeting of the Radiation Protection Section of the Japanese Society of Radiological Technology held in 2007, Fukushi pointed to the need for and importance of more explicit emphasis on radiation education, not only in higher education but also in the governmental guidelines for school curricula [10]. Furthermore, Okuzaka et al. highlighted the importance of developing safe and low-priced educational materials that would allow easy visualization of radiation concepts by students [11]. Fukutoku surveyed the actual situation with regard to radiation education in elementary and middle schools in Kagoshima prefecture to clarify the degree of radiation literacy and the nature of attitudes toward radiation education on the part of primary and middle school students and their teachers [12, 13]. This survey revealed that the students had been improving their understanding of radiation by informing themselves, primarily via such media as books and television, rather than through school education. As for the teachers, the survey clearly indicated that, despite their understanding of its importance, they were unable to actively engage in radiation education because they did not possess sufficient radiation literacy themselves.

Following Japan’s Fukushima Daiichi Nuclear Power Plant disaster, triggered by the Great East-Japan Earthquake and subsequent tsunami on 11 March 2011, the general public has shown a heightened interest in radiation, and the importance of acquiring accurate knowledge about radiation is now widely recognized [14]. Indeed, it is particularly important that children are sufficiently informed about and have an evidence-based understanding of radiation, since they are likely to find themselves in situations in the future where they will be made acutely conscious of the possible impact of radiation on their health and may worry about it. In fact, following the Fukushima nuclear disaster, in October 2011 the Ministry of Education, Culture, Sports, and Science and Technology (MEXT) of Japan published graded supplementary reading materials about radiation and related matters for use in elementary, middle and high schools so that children may develop the ability to learn, think about and make decisions concerning radiation, radioactivity and radioactive materials [15]. Practical initiatives for radiation education have also been taken in schools in and around Fukushima Prefecture [16, 17]; however, while discussions of radiation education and how it should be conducted have since been repeated [18, 19], little information is available on how much knowledge school students have about radiation and related matters and how well radiation education improves their understanding.

One of the co-authors of this paper (Dr Tsubokura) has been working since immediately after the Fukushima nuclear disaster in Soma and Minami-Soma Cities (~20 km away from the Fukushima Daiichi Nuclear Power Plant), providing medical support for the disaster relief [20, 21]. In addition to these activities as a physician, he has also visited local schools and, strongly convinced of the importance of radiation education in schools, has been conducting radiation education at many middle and high schools (lower and higher secondary schools, respectively). In the present study, we examined the effects of the radiation education organized at three high schools in affected areas, based on the field practice of one of the co-authors of this paper, to elucidate what type of radiation education is necessary for children in their teens.

It must nevertheless be noted that actual efforts toward radiation education in schools have been meager and slow, especially considering the enormous damage caused by the nuclear disaster. It is under such circumstances that we have been conducting radiation education, primarily in schools in affected areas, as stated above. Dissemination of the findings from this educational practice is significant in both scientific and societal terms, in that they can help clarify the effects and challenges of radiation education and serve as reference material for future radiation education in school situations.

MATERIALS AND METHODS

In the present study, we analyzed the results of radiation education conducted in the Soso district, which includes Soma and Minami-Soma Cities in Fukushima prefecture, Japan. The Soso district was radioactively contaminated after the Fukushima Daiichi Nuclear Power Plant disaster. Soma and Minami-Soma are situated respectively 43 km and 25 km from the nuclear power station. Census data shows that populations of Soma and Minami-Soma were 37 796 and 70 895, respectively, up until the time of the disaster. On 12 March 2011, Minami-Soma City was subjected to a special evacuation order, with some zones designated for immediate mandatory evacuation and others for eventual emergency evacuation; evacuation was not imposed on Soma City. The coastal area of the Soso district was damaged by the tsunami waves, and a total of 1607 deaths were reported in these two cities.

While continuing our radiation-related medical activities in Soma and Minami-Soma Cities, we lectured on the subject of radiation at three high schools located in the Soso district during the academic year 2013. In the present study, we examined the findings from these lectures, held in the post-Fukushima Soso district, to analyze how much knowledge high school students had about radiation and related matters following the nuclear power plant disaster, and how well radiation education improved their understanding, so as to evaluate its effectiveness.

Description of the schools surveyed

The three high schools covered in the study were selected from among a total of six high schools located in Soma and Minami-Soma Cities. Of the three, High School A is a public school located in Minami-Soma, 25 km from the Fukushima Daiichi Nuclear Power Plant, within a zone formerly designated for evacuation preparation (Table 1). At High School A, classes were suspended on 12 March 2011, and resumed on 9 May 2011 in a temporary school building. High School B and High School C are both public schools in Soma City located 43 km and 44 km respectively from Fukushima Daiichi. A disaster-induced suspension of classes at the two schools was temporary and the schools resumed classes 20 April 2011. Sessions on radiation education were held in January 2014 at High School A, in October 2013 at High School B, and in February 2014 at High School C. Table 1 summarizes the particulars of radiation education at the respective high schools. The duration of one lecture at High School A was ~45 min, slightly shorter than at the other schools (60 min.), but the number of students in attendance at one time was smaller (a total of 146 students in the same school year was divided into two equal groups). At High School B and High School C, all the students in the same school
year were assembled either in the school auditorium or multimedia room to attend the lecture (the total numbers of registered students in the school year were 186 at High School B and 529 at High School C).

**Lecture**

At each of the three high schools, we lectured on radiation, providing the attending students with (i) scientific knowledge relating to radiation, (ii) the results of radiation examinations conducted locally following the nuclear power plant disaster and (iii) measures and precautions for daily radiation protection based on the results. More specifically, under item (i), the lecturer explained radiation, environmental radiation, and the relationship between radiation exposure and damage to physical health (Table 2). Under item (ii), the lecturer discussed the results of environmental radioactivity monitoring conducted continuously since 2011 in Soma and Minami-Soma cities, as well as the results of internal contamination measurements (using whole-body counters) and external exposure measurements (using personal dosimeters) that the students had regularly been conducting on themselves. Finally, the students were advised with regard to daily meals, water, and outdoor activities. The lecture contents had been carefully designed so that learning through this practice would optimize the students’ daily behaviors and attitudes with regard to what is considered appropriate from the perspective of medical health and radiation protection.

**Questionnaire survey**

For the study, identical questionnaires were distributed to the students before and after they attended the lecture at their school to collect data about their knowledge, attitudes, and behaviors related to radiation. The questionnaire was composed of three sections: Section 1 contained 13 questions on daily practical knowledge; Section 2, 18 questions on general scientific knowledge about radiation; and Section 3, 10 questions on radiation-related behaviors and attitudes (Table 2).

The questions on daily practical knowledge and general scientific knowledge about radiation were true–false questions or questions with two or multiple choices for answers. For the questions about behaviors and attitudes, the respondents were asked to choose answers on five-point Likert scales, ranging from ‘Strongly agree’ to ‘Strongly disagree’. While the questions in Section 3 did not specify geographic locales in connection with attitudes and behaviors, the students seem to have answered the questions from the point of view of their actual sphere of daily life.

In general, in Section 3, affirmative responses were considered preferable for questions other than ‘a,’ ‘c’ and ‘e,’ while negative responses were considered preferable for question ‘e’. However, we would like our readers to keep in mind, while reading the remainder of the paper, that there are no right or wrong answers since each individual has his or her own way of perceiving radiation.

The questionnaire survey was conducted for the first time 3–4 days before the lecture on radiation, and for the second time immediately afterwards. Differences between the two surveys were analyzed in terms of the percentage of answers aligned with the evidence base and the contents of the responses.

**Data analysis methods**

To compare the questionnaire survey results before and after the lecture on radiation, only the samples that included the two surveys were retained for analysis. The analysis was done using the following method:

(i) The average numbers of ‘evidence-based’ (i.e. appropriate with respect to the evidence base) answers to the questions in Section 1 (daily practical knowledge) and Section 2 (scientific knowledge about radiation) in the surveys before and after the lecture were determined for each school and gender. To examine the effect of the lecture, the differences in the averages were analysed using a t-test. This analysis was carried out to verify the effectiveness of the radiation education.

(ii) A k-means (non-hierarchical) clustering analysis was conducted, using the answers to the 10 questions (see

---

**Table 1. Participating high schools and students in the lectures**

| Location (km from the power plant) | Date     | Grade | No. of students (girls) | Duration of the lecture |
|-----------------------------------|----------|-------|-------------------------|-------------------------|
| High school A                     | Jan, 2014| 2nd   | 133 (69)                | 45 min                  |
| High school B                     | Oct, 2013| 2nd   | 129 (69)                | 60 min                  |
| High school C                     | Feb, 2014| 2nd, 3rd | 455 (306)             | 60 min                  |

**Table 2. Contents of lectures, and questionnaire survey**

| Contents                                                                 | No. of questions |
|--------------------------------------------------------------------------|------------------|
| 1 Scientific knowledge relating to radiation                             | 13               |
| 2 Results of radiation examinations conducted locally following the nuclear power plant disaster | 18               |
| 3 Measures and precautions for daily radiation protection based on the results | 10               |

**Sections of questionnaire survey**

| Sections of questionnaire survey  | No. of questions |
|----------------------------------|------------------|
| 1 Daily practical knowledge about radiation                                | 13               |
| 2 General scientific knowledge about radiation                             | 18               |
| 3 Radiation-related behavior and attitude                                  | 10               |
Table 5) in Section 3 (radiation-related behaviors and attitudes) before and after the lecture. The purpose of this analysis was to classify the students into clusters based on their behaviors and attitudes.

(iii) Selected students were divided into two groups based on the degree of post-lecture change in their number of ‘evidence-based’ answers to the questions in Sections 1 and 2; in Section 3, the results for the two groups were compared. This analysis was conducted to determine which type of knowledge (that covered in Section 1 or that covered in Section 2) was more important for deepening students’ understanding of radiation.

**Ethics**

This study was approved by the Ethics Committee of Minami-Soma Municipal General Hospital (Approval No: 28-01). The Ethics Committee was aware that the execution of this study required no written consent by the individuals concerned or their legal guardians.

**RESULTS**

**Overall and school-specific tendencies regarding knowledge**

Of the total of 861 students who received radiation education at the three high schools, we analyzed data from 717 students who participated in both questionnaire surveys before and after the lecture. The respondents whose scores were valid for analysis numbered 133 (of which 69 were girls) from High School A, 129 (of which 69 were girls) from High School B, and 455 (of which 306 were girls) from High School C.

Table 3 shows the average numbers of ‘evidence-based’ answers in Section 1 (daily practical knowledge) and Section 2 (scientific knowledge about radiation), for each school and gender before and after the radiation lecture, as well as the differences between the two. For each of the schools and genders, the average numbers of ‘evidence-based’ answers increased significantly after the lecture. For the 717 respondents as a whole, the average number of ‘evidence-based’ answers increased from 5.18 to 8.71 \((P < 0.01)\) in Section 1 (13 questions in total) and from 9.15 to 12.27 \((P < 0.01)\) in Section 2 (18 questions in total). A one-way analysis of variance recognized differences (in terms of the effect of the lecture) between the schools as being significant \((P < 0.01)\). Later, multiple comparisons (Tukey’s test) detected clear differences between the three schools (in terms of the effect of the lecture) in Section 1 (High Schools B, C and A, in descending order) and between two schools [between High Schools C and B (there being no difference between High Schools C and A)] in Section 2.

As for tendencies by school, High School A registered the largest average numbers of ‘evidence-based’ answers before the lecture. This is presumably because High School A is located in Minami-

| Table 3. Average numbers of ‘evidence-based’ answers |
|-----------------------------------------------------|
| **No. of samples analyzed** | **Section 1 (13 questions)** | **Section 2 (18 questions)** |
|                           | Before the lecture | After the lecture | Difference | Before the lecture | After the lecture | Difference |
|---------------------------|--------------------|--------------------|------------|--------------------|--------------------|------------|
| **High school A**         |                    |                    |            |                    |                    |            |
| Total                     | 133                | 7.21               | 9.38       | 2.17**             | 11.19              | 13.32      | 2.13**     |
| Boys                      | 64                 | 7.63               | 9.23       | 1.61**             | 11.36              | 13.48      | 2.13**     |
| Girls                     | 69                 | 6.83               | 9.52       | 2.70**             | 11.03              | 13.16      | 2.13**     |
| **High school B**         |                    |                    |            |                    |                    |            |
| Total                     | 129                | 4.91               | 10.29      | 5.38**             | 9.52               | 14.92      | 5.40**     |
| Boys                      | 60                 | 5.35               | 10.45      | 5.10**             | 9.75               | 15.28      | 5.53**     |
| Girls                     | 69                 | 4.54               | 10.14      | 5.61**             | 9.32               | 14.61      | 5.29**     |
| **High school C**         |                    |                    |            |                    |                    |            |
| Total                     | 455                | 4.66               | 8.07       | 3.41**             | 8.45               | 11.21      | 2.76**     |
| Boys                      | 149                | 4.68               | 8.03       | 3.34**             | 8.36               | 11.02      | 2.66**     |
| Girls                     | 306                | 4.65               | 8.08       | 3.44**             | 8.50               | 11.31      | 2.81**     |
| **Total**                 | 717                | 5.18               | 8.71       | 3.53**             | 9.15               | 12.27      | 3.12**     |

Section 1 contained 13 questions from Q1a to Q1m; the differences were obtained by subtracting the average numbers of ‘evidence-based’ answers after the lecture from those (corresponding with respect to school and gender) before the lecture. Section 2 contained 18 questions under Q2, Q3, Q4 and Q6; the differences were obtained by subtracting the average numbers of ‘evidence-based’ answers after the lecture from those (corresponding with respect to school and gender) before the lecture. A \(t\)-test was conducted on the numbers of ‘evidence-based’ answers before and after the lecture. \^{**}P < 0.01, \^{*}P < 0.05.
Soma City, which included mandatory evacuation zones, and its students were probably more interested in radiation than the students at the other schools. Furthermore, considering High School A is the most difficult to enter of the three schools in the competitive school admission system, it is possible that the high academic standards were reflected in the numbers of ‘evidence-based’ answers.

Notwithstanding, multiple comparisons revealed that High School B had the largest average numbers of ‘evidence-based’ answers in both Section 1 and Section 2 and also made the greatest improvement in terms of the percentage of ‘evidence-based’ answers. These results indicate that the High School B students benefited most from the radiation education, and the following can be cited as probable reasons. First, unlike the lectures at High Schools A and C, the lecture at High School B included a long question-and-answer period. Second, the High School B students were obviously far more highly motivated to proactively learn about radiation, as demonstrated by their active participation in the question-and-answer period, than their peers at the other two schools. Third, the teacher at High School B who served as coordinator seemed more deeply committed to radiation education than those in the corresponding positions at the other schools. This was easily perceived by the way the teacher explained the objectives of the session in a more detailed manner than that teacher’s counterparts at the other schools.

Change in the students’ understanding

To clarify how the students’ understanding had changed after the lecture, the students were divided into six clusters in two stages, based on their understanding of what attitudes or behaviors to assume regarding radiation (Table 4). Table 5 shows the average scores of the students, divided into three clusters for both before and after the lecture, that were indicative of what they perceived to be the appropriate attitudes and behaviors regarding radiation.

The students’ answers given before the lecture were divided into three clusters: (A) those indicating their degree of anxiety about radiation was relatively high, (B) those indicating their degree of anxiety about radiation was relatively low, and (C) those indicating no interest in radiation. The Cluster (A) students tended to consider radiation as something scary, and many of them believed that they must act accordingly. The Cluster (B) students, in contrast, were interested in radiation, but many of them believed that the negative impact of radiation was limited. The Cluster (C) students, unlike the Clusters (A) and (B) students, took little interest in radiation and felt vaguely annoyed about it.

Then, the students’ understanding was re-evaluated after the lecture. At this stage, the students’ responses were reclassified into three clusters based on their average points: (D) those indicating appropriate knowledge and balanced feelings about radiation, (E) those indicating anxiety about radiation still remained, despite the recently acquired knowledge, and (F) those indicating no interest in radiation. Many of the Cluster (E) students still felt anxiety about radiation, despite acquiring a certain level of knowledge. Participation in the radiation education session for the Cluster (F) students did not greatly deepen their understanding about radiation, and they were not sure what constituted appropriate attitudes and behaviors.

Table 4. Classification of students before and after the lecture based on radiation-related understanding, attitudes and behaviors

| Before the lecture | After the lecture |
|--------------------|------------------|
| (A) Those whose degree of anxiety about radiation was relatively high | (D) Those with appropriate knowledge and balanced feelings about radiation |
| (B) Those whose degree of anxiety about radiation was relatively low | (E) Those with anxiety about radiation still remaining, despite their recently acquired knowledge |
| (C) Those with no interest in radiation | (F) Those with no interest in radiation |

As stated above, the students were divided into three clusters at each stage, based on their states before and after the lecture. Figures 1–3 indicate how the students’ understanding changed after the lecture, classified by school and gender. Detailed school-by-school data are omitted. Among the pre-lecture clusters, many girls, except for those of High School B, belonged to Cluster (A). This is probably because girls tend to feel more anxiety about radiation due to a fear of possible adverse effects of radiation on pregnancy and childbirth. This tendency weakened in the post-lecture clusters.

For all the schools and both genders, students with no interest in radiation diminished after the lecture [Clusters (A), (B) and (C) ->Cluster (F)]. At the same time, those with both appropriate knowledge and balanced feelings about radiation increased after the lecture [Clusters (A), (B), and (C) ->Cluster (D)]. Nevertheless, for many schools and both genders, Cluster (E), those who retained a measure of anxiety even after the lecture, constituted nearly half of the total students. The results also revealed that many of the students who felt worried even after the lecture tended to be overcautious, despite the low levels of internal contamination in Fukushima, many believing that certain types of food and water should be avoided, compared with the beliefs of students in the other clusters (Table 5).

Analysis by cluster indicates that many students who had had anxiety about radiation before the lecture actually retained some anxiety, even after obtaining knowledge from the lecture (Cluster (A) ->Cluster (E)). This suggests that the students who initially had strong anxiety about radiation tended to remain somewhat anxious, even after the lecture, and that it is difficult to resolve their anxiety with only a single session of radiation education.

Meanwhile, at High School B, which showed the largest increase in the number of ‘evidence-based’ answers following the lecture, more than half the students who had felt anxiety before the lecture shifted to the cluster with appropriate knowledge and balanced feelings (Cluster (A) ->Cluster (D)). We believe that this suggests that even a single session of radiation education, if designed to effectively
impart appropriate knowledge, can to some extent alleviate students’ anxiety about radiation. As support for our belief, many students in Cluster (B) (those with a low degree of anxiety about radiation) shifted to Cluster (D) (those with appropriate knowledge and balanced feelings), meaning that their anxiety did not increase after they had improved their understanding about radiation through the lecture. (In this regard, some readers might wonder if the lecture had been biased for the purpose of persuading the students that radiation was safe. We would like to add here that the main purpose of the lecture was to provide scientific knowledge, which naturally

### Table 5. Average scores of student clusters

| Question                                                                 | Before the lecture | After the lecture |
|-------------------------------------------------------------------------|--------------------|-------------------|
|                                                                         | Cluster A /B /C    | Cluster D /E /F   |
| a. To prevent external radiation exposure, it is not necessary to be     | 2.13 3.44 2.00     | 4.29 2.66 2.25    |
|   worried about how much time one spends outdoors.                      |                    |                   |
| b. To prevent internal radiation exposure, it is not necessary to be     | 2.31 3.60 2.00     | 4.57 2.83 2.37    |
|   worried about how much time one spends outdoors.                      |                    |                   |
| c. To prevent internal radiation exposure, locally produced food must be| 3.70 2.61 2.15     | 1.66 2.74 1.58    |
|   avoided.                                                               |                    |                   |
| d. To prevent internal radiation exposure, food whose shipment is already| 4.37 3.40 2.79     | 3.39 3.89 2.34    |
|   restricted must be avoided.                                            |                    |                   |
| e. To prevent internal radiation exposure, it is better to avoid tap    | 3.87 2.72 2.44     | 1.60 2.79 1.71    |
|   water.                                                                |                    |                   |
| f. I am going to continue to take part in internal radiation exposure   | 4.00 2.99 2.90     | 3.51 3.66 2.15    |
|   examinations.                                                          |                    |                   |
| g. Continuous internal and external examinations are necessary.         | 4.32 3.29 3.33     | 3.76 3.88 2.13    |
| h. Health issues related to daily habits and the like are more important| 3.35 3.48 3.06     | 4.25 3.58 2.54    |
|   than radiation exposure.                                               |                    |                   |
| i. I want to make an effort to learn more about radioactivity, since it  | 3.95 3.34 3.10     | 4.29 3.90 2.36    |
|   is important to understand it correctly.                               |                    |                   |
| j. The radioactive dose in the area where I live is sufficiently low to  | 2.84 3.24 2.93     | 4.41 3.40 2.68    |
|   allow future daily activities.                                         |                    |                   |

The up arrow (↑) means that a higher score is ‘preferable’ or ‘more evidence-based.’ The down arrow (↓) means that a lower score is ‘preferable’ or ‘more evidence-based.’ The double-pointed arrows (⇔) mean that neither of the above applies.

![Fig. 1. How Cluster (A) students changed after the lecture.](image-url)

Fig. 1. How Cluster (A) students changed after the lecture.
included the risks of radiation, and safety was not given any particular emphasis in the lecture.)

Among the students who had been interested in radiation from the start, few shifted to the cluster with no interest in radiation after the lecture (Clusters (A) and (B) -> Cluster (F)), whereas many students with no interest at first became interested in radiation to a certain extent after the lecture (Cluster (C) -> Clusters (D) or (E)). It should be noted, however, that High School C had a much larger percentage of students with no interest both before and after the lecture (Cluster (C) -> Cluster (F)) than the other schools. Several factors may have been responsible for this, such as individual attributes, environmental differences, and varying degrees of contamination and disaster damage in their sphere of daily life.

Importance of scientific knowledge

In this section, we would like to show how acquiring scientific knowledge about health issues and radioactivity influences the students' attitudes and behaviors. We removed students who already possessed sufficient knowledge about radiation before the lecture from the sample body. The 'students who already possessed sufficient knowledge' corresponded to those who had 'evidence-based' answers for over 80% of the questions in Sections 1 and 2 before the lecture—in other words, those who had 'evidence-based' answers for 11 or more questions in Section 1, and 15 or more questions in Section 2 in the pre-lecture questionnaire. The remaining students were then divided into two groups, based on whether after the lecture they had a large or a small increase in the number of 'evidence-based' answers to the questions in Section 1 (daily practical knowledge) and Section 2 (scientific knowledge about radiation) separately, and the scores in Section 3 (attitudes and behaviors in relation to radiation) were compared between the two groups (Table 6). The students who had 'a large increase' in the number of 'evidence-based' answers corresponded to those whose number of 'evidence-based' answers increased by four or more in Section 1 and by three or more in Section 2. For the average numbers of 'evidence-based' answers in the respective sections, the numbers were rounded to two decimal places.

Between the group of students who had a large increase in the number of 'evidence-based' answers (the 'large-increase group') in Section 1 and the other group (the 'small-increase group'), post-lecture scores were significantly higher in three items only (Table 6). However, between the large-increase and small-increase groups (classified according to the results in Section 2), a
statistically significant difference was found in many more items. The increase in the number of ‘evidence-based’ answers in Section 2 influenced the students’ scores in Section 3 more positively. Even for the items with no statistically significant difference between the two groups, the large-increase group had preferable scores in most cases.

**DISCUSSION**

The importance of radiation education and how it should be conducted in the schools has been discussed over many years in many countries. The Chernobyl disaster aroused interest on a global scale, and various initiatives have been carried out. In Japan, the importance of radiation education had been recognized before the Fukushima Daiichi nuclear disaster, and discussions on this subject have increased since. However, little information is available on how much knowledge high school students have about radiation and related matters or about how well radiation education improves their understanding.

This study has demonstrated that radiation education for high school students is effective in instilling in them relevant basic and practical knowledge. Of note, the average numbers of ‘evidence-based’ answers to a questionnaire significantly increased for all the schools and for both genders after the radiation lecture in the present study. In fact, the results improved (in terms of aligning with evidence-based research) for all of the questions concerning scientific knowledge, as well as for those concerned with beliefs about safe daily behaviors. At the same time, it is intriguing that the acquisition of knowledge was not uniform among the students or the schools. The effectiveness of the radiation education varied from one school to another. This can be explained in terms of the differences between individual students regarding the amount of knowledge they possessed at the start that could be mobilized for absorbing new scientific knowledge.

High School A demonstrated a higher level of knowledge from the beginning than High School B and High School C, while High School B showed the greatest progress after the lecture (Table 3). Several reasons can be cited for the differences in the students’ initial levels of knowledge. First, there is a difference in academic ability between the students at the respective schools, since the level of difficulty of the entrance examination in the competitive admission system differs between these three high schools. Second, the schools also differ in their location relative to the Fukushima Daiichi Nuclear Power Plant and regarding whether they were inside or outside the evacuation zones. High School A is located in Minami-Soma City near the power plant, in a zone that was designated for eventual evacuation in an emergency. The students commuting to High School A, unlike the students attending the other schools, probably have more occasions to see, discuss, and hear about

| Table 6. Average scores of student groups (Large increase vs Small increase) |
|-----------------------------|-----------------------------|
| Section 1 | Section 2 |
| | n | Large increase | n | Small increase | n | Large increase | n | Small increase |
| a | To prevent external radiation exposure, it is not necessary to be worried about how much time one spends outdoors. | (⇔) | 346 | 3.40 | 342 | 3.20* | 386 | 3.42 | 297 | 3.13** |
| b | To prevent internal radiation exposure, it is not necessary to be worried about how much time one spends outdoors. | (↑) | 345 | 3.58 | 342 | 3.45 | 385 | 3.66 | 297 | 3.28** |
| c | To prevent internal radiation exposure, locally produced food must be avoided. | (⇔) | 346 | 2.05 | 342 | 2.21 | 386 | 2.08 | 297 | 2.19 |
| d | To prevent internal radiation exposure, food whose shipment is already restricted must be avoided. | (↑) | 346 | 3.40 | 338 | 3.50 | 385 | 3.49 | 294 | 3.39 |
| e | To prevent internal radiation exposure, it is better to avoid tap water. | (↓) | 347 | 1.98 | 341 | 2.32** | 386 | 2.00 | 297 | 2.36** |
| f | I am going to continue to take part in internal radiation exposure examinations. | (↑) | 345 | 3.41 | 341 | 3.38 | 384 | 3.43 | 297 | 3.33 |
| g | Continuous internal and external examinations are necessary. | (↑) | 347 | 3.62 | 340 | 3.57 | 385 | 3.63 | 297 | 3.51 |
| h | Health issues related to daily habits and the like are more important than radiation exposure. | (↑) | 344 | 3.74 | 341 | 3.67 | 385 | 3.79 | 296 | 3.58** |
| i | I want to make an effort to learn more about radioactivity, since it is important to understand it correctly. | (↑) | 347 | 3.91 | 338 | 3.79 | 386 | 3.93 | 294 | 3.70** |
| j | The radioactive dose in the area where I live is sufficiently low | (↑) | 345 | 3.82 | 340 | 3.63* | 386 | 3.84 | 294 | 3.56** |

A t-test was conducted. **P < 0.01, *P < 0.05. The underlined points are considered preferable for each item.
radiation-related subjects on a daily basis, and this could have enriched their initial knowledge.

The effects of the radiation lecture differed greatly between the three schools. While High School B had an increase in Sections 1 + 2 of 10.8, High Schools A and C had an increase of ~4.3 and 6.2, respectively. High School B’s points increased after the lecture more than High School A’s, whose original points had been the highest. Although the reasons for this difference could not be determined, the manner and atmosphere in which the lecture was conducted at each high school may have been factors. For example, at High School B, the lecture, although attended by a large number of students, was followed by a long question-and-answer period in an atmosphere conducive to positive exchanges between the lecturer and the audience. Moreover, whether or not a relationship of trust could be built between the high school teachers and the external lecturer would probably have affected the effectiveness of the educational practice. The High School B teachers showed a friendlier attitude toward the external lecturer than those at the other schools.

It should be noted that differences existed between the genders regarding the degree of anxiety about radiation. In our cluster analysis, many female students were in the cluster of those with anxiety before the lecture [23.3% of males and 34.8% of females belonged to Cluster (A)]. Females tend to be more anxious about radiation accidents because of their anticipation of pregnancy and childbirth. On the other hand, the reason may simply be attributable to higher anxiety of the girls in our study. Approximately 30% of the students in Cluster (A) were reclassified into Cluster (D), which suggests a lessening of anxiety after the lecture. However, >60% of the female students in Cluster (A) were reclassified into Cluster (E). This suggests that a single session of radiation education has a limited effect on the acquisition of knowledge and that radiation education should be planned to occur in a continuing mode.

The cluster analysis indicated that radiation education had some impact, even on students who had shown no interest in radiation before the lecture, arousing their interest to some extent. This was observed in the shift of ~70% in Cluster (C) students (no interest) who were reclassified into Clusters (D) or (E) after the lecture, suggesting a response to the radiation lecture for a reason to be determined.

Our study suggests that it is essential for students to acquire scientific knowledge in order to positively influence their attitudes and behaviors. This assumption is supported by the findings that the more the students’ scientific knowledge increased after the lecture, the more likely was their tendency to shift to the supposedly preferable responses in Section 3 relating to attitudes and behaviors. Moreover, the same can be said of the observation that students with a sufficient scientific understanding of radiation are likelier to adopt more balanced attitudes to and behaviors with regard to radiation, becoming more positive about improving their radiation literacy. On the other hand, radiation education primarily consisting of the transmission of solutions for dealing with specific symptoms of radiation has only limited effects. This can be surmised from the finding that the improvement in the responses in Section 2 was greater than that in Section 1 in Table 6. In radiation education, it is essential that students learn to think about radiation in connection not only with familiar objects and activities in their daily environment, but also with higher-level matters, while cultivating a rational mind. In this sense, it is deemed more effective to transmit knowledge of radiation, ensuring it is in the context of basic scientific knowledge of physics and other disciplines.

There are several limitations to consider regarding this study. First, since we conducted radiation education only at three high schools in the Soso district, our sample could have been slanted, with an unrecognized bias. Similar sessions of radiation education could have had different effects at other high schools in unaffected areas. Second, we should not overlook the fact that people’s anxiety and ideas about radiation can be influenced by society. The lectures in our study were given in the academic year 2013, only 2–3 years after the disaster. Third, we evaluated the effect of the radiation class only before and after the class, and have not evaluated their long-term understanding. While a long-term follow-up survey was not practicable this time, in the future we would like to formulate an improved study design including long-term follow-up. Fourth, the results of this study are affected by a response bias caused and amplified by the combination and the designs of the questionnaire study and the lecture.

General interest in radiation has been gradually subsiding in Japan. In fact, in Fukushima, radiation is discussed less and less on a daily basis. As reconstruction and restoration advance, it is becoming possible to maintain everyday life without being conscious of the problem of radiation. At the same time, however, new problems have been emerging. Numerous cases have been reported in which people who were in an accident in Fukushima are called hibakusha (victims of radiation sickness caused by the nuclear power accident), and people from Fukushima can be subjected to discriminatory treatment when they consider marriage or childbirth. In such situations, radiation education is not merely for acquiring scientific knowledge or basic knowledge for daily life. It protects today’s youth from societal isolation, exclusion, and attacks, including discrimination, and encourages independent thought. It is therefore extremely important to conduct radiation education indefinitely into the future. We hope that the findings in our research will be of assistance in implementing more effective radiation education.

CONCLUSIONS

This study showed that radiation education in high schools was effective in terms of students acquiring relevant basic and practical knowledge. The effects of the radiation lecture differed greatly between schools, presumably due to differences in the manner and atmosphere in which the lecture was conducted. The level of trust between the teachers and the external lecturer could have added to the effectiveness of the radiation education in a particular school.

The present study also suggested that radiation education can lead students to positively transform their attitudes to and behaviors in relation to radiation. To enable such a change in awareness, the acquisition of scientific knowledge is essential, for it enables individuals to better absorb the knowledge necessary for their daily lives and make better decisions about important matters.

ACKNOWLEDGEMENTS

We would like to express our heartfelt gratitude to the organizations and individuals concerned in Soma and Minami-Soma Cities in
Fukushima prefecture, including the teachers and students at the three participating high schools and the students’ parents for their kind understanding of our study and their generous cooperation with it. Author contributions were as follows: conceptualization: MT; methodology: MT, YK, MY; software: MY; validation: MT, YK; formal analysis: MY; investigation: MT; resources: YK; data curation: MY; writing (original draft preparation): MT, YK, MY; writing (review and editing): MT, YK, MY; visualization: YK, MY; supervision: YK; project administration: YK. All authors approved the final draft of the manuscript.

CONFLICT OF INTEREST
The authors declare that there are no conflicts of interest.

REFERENCES
1. Nielsen S, Lidstone J. Public education and disaster management: is there any guiding theory? Aust J Emerg Manage 1998;13:14.
2. Petal M, Shaw R, Krishnamurthy R. Education in Disaster Risk Reduction. Disaster Management: Global Challenges and Local Solutions. India: Universities Press, 2009, 285–301.
3. Shaw R, Shiwaku K, Takeuchi Y (eds). Disaster Education. Bingley UK: Emerald Group Publishing Ltd, 2011.
4. Selby D, Kagawa F. Radiological education in schools: a possible teaching topic? Phys Educ 1975;10:412–6.
5. Fremlin J. The Windscale Inquiry and its implications. Phys Educ 1978;13:333–6.
6. Toth E, Marx G. Nuclear literacy—Hungarian experiences. In: Toth E, Marx G, eds. Proceedings of the International Conference: Nuclear Option in Countries with Small and Medium Electricity Grids, 7–9 October 1996, Opatija, Croatia, p. 133. Croatian Nuclear Society.
7. Baloga V, Kholosha V, Evdin O (eds). Twenty years after Chernobyl catastrophe. Future outlook. National Report of Ukraine. All-Ukrainian Research Institute of Population and Territories Civil Defense from Technogenic and Natural Emergencies (ME of Ukraine), Atika, Kiev, Ukraine, 2006.
8. Ministry of the Environment. Lessons from the Chernobyl Nuclear Accident—Practice and Challenges of a Quarter of a Century in Belarus. Nuclear Accident Environmental Impact Survey Team Iwaki Project Meeting, 2013 (in Japanese). http://phmradiation.jp/content/pdf/20130926.pdf (6 April 2017, date last accessed).
9. Fukutoku Y. [Survey on scientific literature relating to the understanding of radiation of elementary and middle school students in Kagoshima Prefecture]. J Jpn Soc Radiat Saf Manage 2009;8:141–8 (in Japanese).
10. Fukushi M. [Present situation and challenges of radiation safety education—for education for students]. J Radiat Prot Sect Jpn Soc Radiol Technol 2007;24:5–6 (in Japanese).
11. Okazawa M, Muraoka Y, Ogashiwa Y. [Low-cost development of educational materials that realize safe and low-cost visualization of radioactivity]). Gunma Univ J Kyokiku Jissen Kenkyu 2009, 26:33–8 (in Japanese).
12. Murakami M. [Evaluating risk communication after the Fukushima disaster based on nudge theory. Asia Pac J Public Health 2017;29:1935–2005. doi:10.1177/1010539517691338.
13. Ministry of Education Culture Sports Science and Technology. Supplementary reading on radiation, etc. http://www.mext.go.jp/b_menu/shuppan/sonota/detail/1311072.htm (6 April 2017, date last accessed).
14. Tsunoyama Y, Umeshita H. [Trial primary radiation education in the higher grades in elementary school]. J Jpn Soc Radiat Saf Manage 2012;11:146–9 (in Japanese).
15. Kudo K, Kito K. [Practice and challenges of radiation education for secondary school teachers, youths and adults]. J Atom Energy Soc Jpn 2013;55:274–6 (in Japanese).
16. Akiba E. [Radiation education in Minami-Soma]. J Atom Energy Soc Jpn 2011;53:664 (in Japanese).
17. Ministry of Education Culture Sports Science and Technology. Supplementary reading on radiation, etc. http://www.mext.go.jp/b_menu/shuppan/sonota/detail/1311072.htm (6 April 2017, date last accessed).
18. Ministry of the Environment. Lessons from the Chernobyl Nuclear Accident—Practice and Challenges of a Quarter of a Century in Belarus. Nuclear Accident Environmental Impact Survey Team Iwaki Project Meeting, 2013 (in Japanese). http://phmradiation.jp/content/pdf/20130926.pdf (6 April 2017, date last accessed).
19. Ministry of the Environment. Lessons from the Chernobyl Nuclear Accident—Practice and Challenges of a Quarter of a Century in Belarus. Nuclear Accident Environmental Impact Survey Team Iwaki Project Meeting, 2013 (in Japanese). http://phmradiation.jp/content/pdf/20130926.pdf (6 April 2017, date last accessed).
20. Tsubokura M, Kato S, Nomura S et al. Reduction of high levels of internal radio-contamination by dietary intervention in residents of areas affected by the Fukushima Daiichi Nuclear Plant disaster: a case series. PLoS One 2014;9:e100302. doi:10.1371/journal.pone.0100302.
21. Tsubokura M, Murakami M, Nomura S et al. Individual external doses below the lowest reference level of 1 mSv per year five years after the 2011 Fukushima nuclear accident among all children in Soma City, Fukushima: a retrospective observational study. PLoS One 2017;12:e0172305. doi:10.1371/journal.pone.0172305.