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<https://hdl.handle.net/2324/7437080>

出版情報 : Journal of Radiological Protection. 42 (1), pp.011506-, 2022-01-17. IOP Publishing
バージョン :

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Development and Effectiveness of Radiation Protection Education Using X-Reality for Visualizing Scattered Radiation Behavior

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[Background] Understanding the behavior of scattered radiation is important for learning appropriate radiation protection methods, but many existing visualization systems for scattered radiation require special devices such as head-mounted displays, making it difficult to use them in educating about radiation protection.

[Purpose] The purpose of this study was to develop teaching material for radiation protection that can help visualize the behavior of scattered radiation with augmented and virtual reality on a web browser, develop a method for using it in education for radiation protection and examine its effectiveness.

[Methods] The behavior of scattered radiation in the room during radiography was calculated using Monte Carlo simulation, and scattered radiation visualization teaching material that can be used with a smartphone or personal computer was created. The material was used in a class for students of the Department of Radiological Technology, and the educational effect was evaluated using a questionnaire created based on the ARCS model. In addition, text mining was used to evaluate impressions objectively.

[Results] Education material on radiation protection was developed that can be used in X-Reality for studying the behavior of scattered radiation. The results of the questionnaire showed that the average value of each item was more than 4 on a 5-point scale, indicating that the teaching material attracted the interest of users. Through text mining, it could be concluded that there was improved understanding of scattered radiation and there was a raise in confidence level for radiation protection.

Keywords:

Monte-Carlo Simulation, Scattered Radiation, X-reality, Education in Radiation Protection, Occupational Exposure

I. Introduction

The use of radiation for examination and treatment is growing rapidly due to the emergence of new equipment based on latest technology. Radiological workers face health risks because of radiation

exposure [1]; therefore, radiation protection methods should be understood and efforts should be made to reduce exposure. In addition, radiation protection should be explained to the medical staff and assistants involved in radiation examinations to reduce their own exposure. Therefore, education on radiation protection is important to obtain knowledge on radiation protection. In particular, understanding the behavior and spread of scattered radiation, which is the main cause of exposure, is important for protection against external radiation.

As scattered radiation is not visible, visualization is necessary to learn about its behavior. Visualization studies on the behavior of scattered radiation include studies using X-Reality (XR), which is a visualization technique similar to augmented reality (AR) and virtual reality (VR) [2, 3]. There are studies that use AR to visualize scattered radiation in various ways during examinations. In a study by J. Kilian-Meneghin et al. [4], a two-dimensional cross-section of the scattered radiation distribution during an angiogram was displayed using Kinect in the examination room on a machine using AR. Some studies have used VR to understand the behavior of scattered radiation. In a study by Matthias Süncksen et al. [5], the user can observe how scattered radiation spreads from the source by wearing a head-mounted display, and can also experience the operation using a special controller. By using AR and VR, three-dimensional observation is possible instead of two-dimensional observation, as in a textbook. There are reports that the use of AR and VR in teaching materials attracted interest in users [2, 3, 6]. However, most studies that use AR and VR to visualize scattered radiation often require special equipment, such as dedicated cameras and head-mounted displays [7, 8]. Therefore, the environment under which such devices can be used are limited, making it difficult to use them for radiation protection education. Using WebXR is a simple method to observe the behavior of scattered radiation using XR on a tablet device or a personal computer, which is currently owned by many people.

WebXR does not require any special devices and can be used, provided there is access to internet. WebXR enables visualization and observation of the behavior of scattered radiation with simple operations. Basically, the features of WebAR and WebVR are different. WebAR can be used on a device with a camera (e.g., smartphone, tablet, etc.). In addition, observation can be done in an intuitive and simple way, as it can be done in any direction by simply moving the device. For example, a study used WebAR to visualize and learn the structure of proteins [9]. WebVR can be used on any device, even if no camera is attached, as long as internet access is available. One study has made it possible to observe and learn about the blood flow in blood vessels using WebVR [10].

The purpose of this study is to propose a method of exercises based on radiation protection education materials using a system to visualize the behavior of scattered radiation using WebXR, and to investigate the educational effect of WebXR.

II. Materials and methods

II-1. Simulation of the behavior of scattered radiation during examination.

To visualize the behavior of scattered radiation, the Monte Carlo particle and heavy ion transport code system (PHITS) ver3.20 [11] was used. The behavior of scattered radiation when using a portal radiography system, which is one of the examinations that many medical workers are involved in, was simulated. First, supine frontal chest radiography was performed. The imaging conditions were a tube voltage of 120 kV, tube current time product of 2 mAs, and source-to-detector distance of 120 cm source to detector distance (SSD) [12]. The detailed geometric arrangement and composition during the simulation were based on the study by Nishi et al. [13]. To observe the shielding effect of using a protective apron for imaging under similar conditions, a plate made of lead with a lead equivalent of 0.35 mmPb was placed on the side of the patient, as shown in figure 1, for simulation. To observe the differences in dose values of scattered radiation arising due to differences in imaging conditions, the simulation was performed assuming frontal imaging in the supine pelvis, with a tube voltage of 120 kV, tube current and exposure time product of 22 mAs , and an SSD of 120 cm.

3D objects were created from the simulation results for use in WebXR. The 3D visualization software ParaView version 5.6.0[14] was used to display the spread of scattered radiation for each specified dose value.

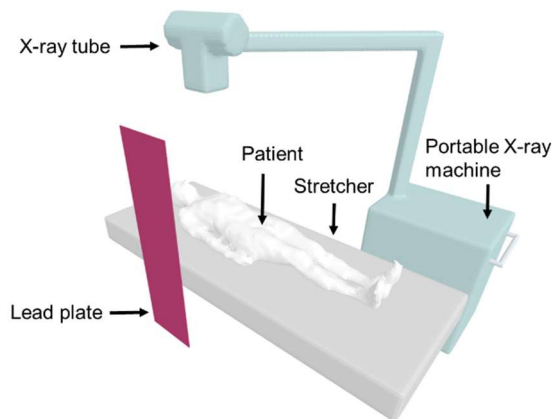


Figure 1: Simulation layout and the location of the lead plate.

II-2. Creating WebXR

WebXR was created based on the 3D data that we created. First, to create WebAR, a web framework A-Frame [15] and a Java script library AR.js [16] were used. WebAR is activated by scanning a QR code with a camera, which then connects to the system's web page . After activating the system, the object is displayed by copying a special AR marker in the device. The detailed development method

and features of WebAR are based on Nishi et al.'s study [17]. WebVR was also created using A-Frame, a web framework. The functions of WebAR and WebVR are the same, and the display screen of WebXR is shown in figure 2 and 3. By pressing the dose display button ((a) in figure 2), the scattered radiation of the marked dose is displayed in 3D (direct X-rays are mainly direct rays from X-rays). The Animation button ((b) in figure 2) displays an animation of a two-dimensional cross-section where scattered radiation spreads after irradiation. By pressing the Scale button ((c) in figure 2), the distance from the center of the irradiation field at a height where the patient is lying and the dose values at the height of the chest at points A (50 cm), B (100 cm), and C (150 cm) are displayed. By pressing the coronal and axial buttons (Fig. 2 (d)), the 2D scattered radiation distribution is displayed, and the buttons (e) in Fig. 2 allow the user to switch between three views: supine chest front view, supine chest front view with lead plate shielding, and supine pelvis front view. In WebAR, there is a rotation button, and when it is pressed, the displayed object rotates (even if the display device is moved, the displayed object can be observed from various directions). WebVR displays can be rotated with a left mouse click, moved with a right mouse click, and scaled with the wheel.

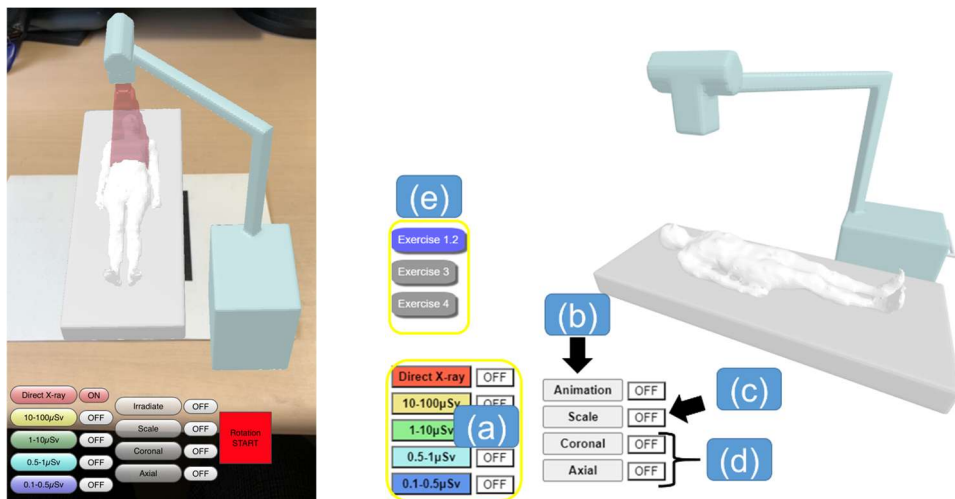


Figure 2: Explanation of WebXR screens and functions (Left: WebAR, Right: WebVR)

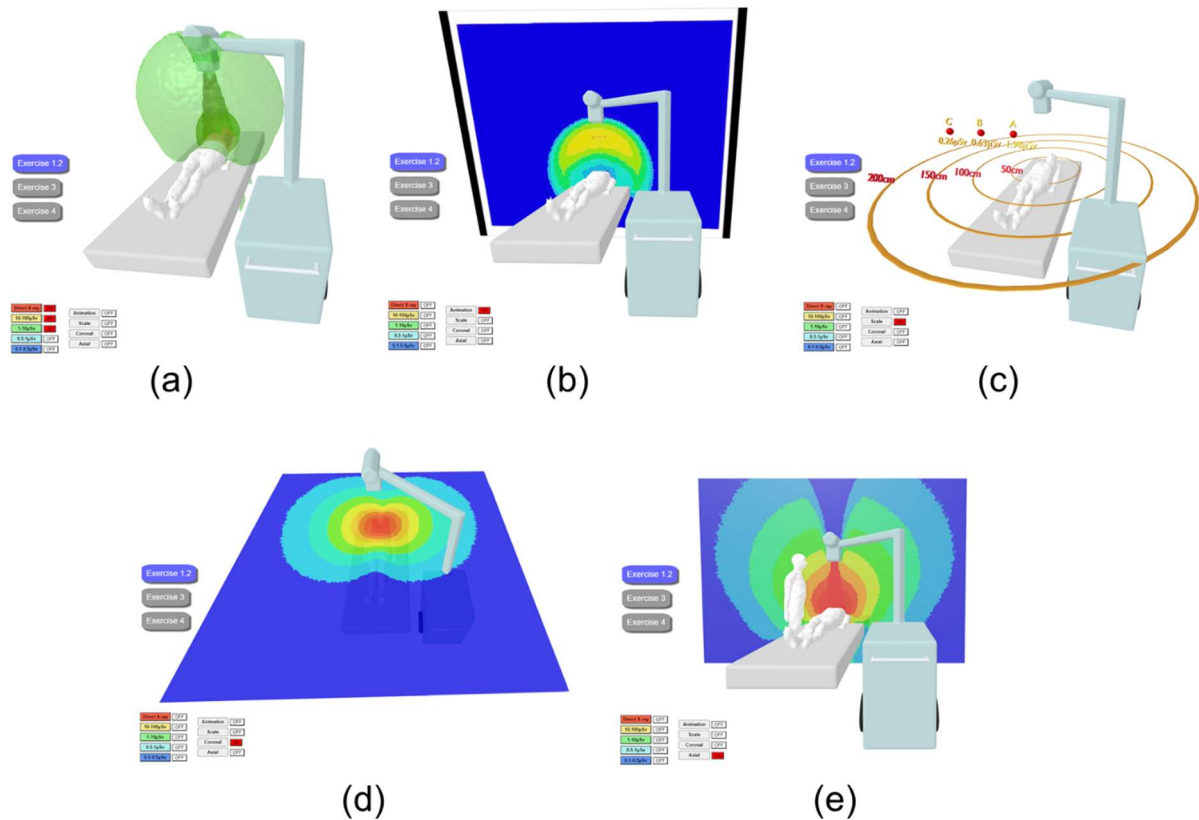


Figure 3: Display screen for each function of WebVR

(a) 3D display of scattered radiation, (b) Animation of scattered radiation, (c) Display of distance and dose value, (d) Two-dimensional coronal cross section of scattered radiation, (e) Two-dimensional axial cross section of scattered radiation.

II-3. Creating Web-based teaching materials

Teaching materials for the class were created based on the developed web system. The contents of the teaching materials included items that are to be observed and exercises based on the three principles of radiation protection. Nine exercises were developed. The exercises are listed in Table 1. A questionnaire was created to evaluate the effectiveness of education. It was based on ARCS model [18, 19]. The ARCS model is based on motivation to learn by considering the following four factors: Attention: A, Relevance: R, Confidence: C, and Satisfaction: S, and was proposed to analyze the motivation of learners to learn in classes and the effectiveness of teaching materials and to enhance their motivation to learn [18]. The questionnaire consisted of 12 questions on attention, 9 questions on relevance, 9 questions on confidence, and 6 questions on satisfaction; a total of 36 questions. The questionnaire asked the users to answer each item on a 5-point scale, and the average values of each item (A, R, C, and S) were calculated and evaluated. However, some of the questions in the questionnaire were negative, and the evaluation scores were reversed for those questions. The Mann-

Whitney U test was then used to examine whether there was a difference in the evaluation of WebAR and WebVR, assuming that the null hypothesis for the four items did not differ between WebAR and WebVR. The Mann-Whitney U test was performed using EZR statistical software [20]. Similarly, the average scores of the exercises were analyzed using the U test to evaluate whether there was a difference between WebAR and WebVR. Two additional free-response questions were also included in the questionnaire. The content of the questionnaire was the student's impression of the WebXR system and the overall impression of the class in using WebXR. To evaluate the class objectively from the responses of the questionnaire, text-mining analysis was conducted. KHCoder software was used for the analysis [21]. KHCoder was developed by Higuchi.K of Ritsumeikan University, Japan, and consists of the programming language "R" and the language morphological analysis system "ChaSen" as a backend program [22, 23]. Words that appeared more than three times in the sentences were extracted and summarized. Cluster analysis was used to create a figure to clarify the relationship among the extracted words.

Table 1: Contents of the exercises

Number	Content of the Question
1	Choose the correct one regarding the spread of scattered radiation.
2	Choose a location with low radiation dose when assisting with supine frontal chest imaging.
3	Choose the correct one about the difference of exposure dose by height.
4	Choose the correct relationship between the distance from the center of the irradiation field and the dose value at that point.
5	Choose the one that is considered to be close to the dose value at a point 200 cm from the center of the irradiation field.
6	Choose the correct one regarding the spread of scattered radiation when using a protective apron.
7	Choose the correct one for the dose at point A (50 cm from the center of the irradiation field) behind the protective apron.
8	Choose the correct one that describes how the scattered radiation spread during pelvic imaging is different compared to chest imaging.
9	Choose the correct dose value for pelvic imaging, referring to the imaging conditions, to see how it differs from the dose value for chest imaging.

II -4. Classes using WebXR

The class of 35 third-year undergraduate students at Kyushu University, majoring in radiation technology science was instructed using WebXR. The class was divided into two sessions: 18 students in the first half and 17 students in the second half. In this study, to investigate whether WebAR and WebVR have different educational effects, the first half of the exercise was conducted using WebAR and the second half using WebVR. The class began with an explanation of occupational exposure in

examinations that dealt with radiation. Then, the purpose of the class and how to use WebAR or WebVR were explained. After explaining the operation and checking the operation, the students were asked to make observations and perform exercises using WebXR. The students were asked to fill in the answers to the exercises on the answer sheets, which were collected, and then the answers to the exercises were explained. After that, the whole group was divided into two groups to perform additional exercises to deepen their knowledge on radiation protection. One group wore actual radiation protection aprons and radiation protection glasses to experience what it was like. The other group used AR to observe the behavior of full-scale scattered radiation on a real stretcher. When everyone completed the two additional exercises, a questionnaire was given to them.

III. Results

III-1. Exercise Scores

In the class using WebAR, the average score of 18 students was 8.89. In the class using WebVR, the average score of the 17 students was 8.71. The P value of the U test for the scores of the exercises when using WebAR and WebVR was 0.19, which was greater than the significance level of 0.05. No significant differences were found, and the null hypothesis was not rejected. Therefore, there was no difference in the mean scores of the WebAR and WebVR exercises.

III-2. Results of ARCS Evaluation

The evaluation results of the ARCS model are presented in Table 2. All items had a mean value of 4 or higher. The item with the highest value for both WebAR and WebVR was the confidence item. The evaluation of the ARCS model for each class using WebAR and WebVR is summarized in figure 4. The P values of the U test conducted for each item were 0.582 for item A, 0.723 for item R, 0.536 for item C, and 0.296 for item S. All P values were greater than the significance level of 0.05, and no significant difference was found; the null hypothesis was not rejected. Therefore, differences between the evaluation of the ARCS model of WebAR and WebVR cannot be said to exist.

Among the items in the questionnaire, there were three question items that received high ratings ((4.5 or higher) when using WebAR and WebVR. The first is "This educational content contains too much information and it was difficult to pick up and remember the important points". The second is "I am convinced that I could learn how to protect against scattering lines by using this educational content". The third is "I did not understand most of the educational content in this exercise" In contrast, there were two question items that received low ratings of less than 4 when using WebAR and WebVR. The first is "I learned something amazing and/or unexpected through this educational content." The second was "The advice and other feedback I received after training helped me feel like my efforts had paid off."

In addition, among the 36 questions, there were three questions in which the difference in the mean

values of the evaluation between WebAR and WebVR was larger than the others. The first was "I learned something surprising and/or unexpected through this educational content," which was rated 0.43 higher for WebAR. The second was "The educational content was not relevant to my needs because I already knew most of it," which was rated 0.57 higher for WebAR. The third was "I was able to relate the content of this educational content to what I have seen, done, or thought in my previous learning," which was rated 0.57 higher for WebVR.

III-3. Extraction of words using text mining

First, the words included in the comments on WebXR that were entered more than three times were extracted. The results are presented in Table 3. In both cases, "See," "Feel," and "Understand" were frequently included in the users' impressions.

Table 2: Evaluation results of ARCS models

Evaluation Items	Mean Value	
	WebAR	WebVR
A : Attention	4.25 $\pm$ 0.23	4.21 $\pm$ 0.38
R : Relevance	4.24 $\pm$ 0.22	4.25 $\pm$ 0.37
C : Confidence	4.36 $\pm$ 0.27	4.44 $\pm$ 0.25
S : Satisfaction	4.17 $\pm$ 0.24	4.25 $\pm$ 0.34

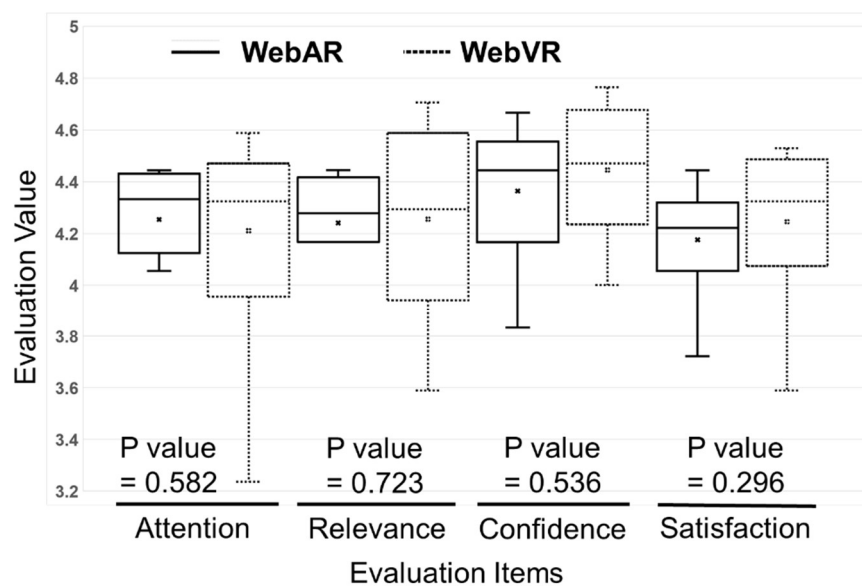


Figure 4: Comparison of ARCS model evaluation between WebAR and WebVR.

Table 3: Words and number of occurrences in comments on the WebXR system.

WebAR system	WebVR system
Scattered (5)	See (5)
Use (5)	Feel (4)
AR (4)	Scattered (4)
Feel (4)	Use (4)
Understand (4)	Actually (4)
See (3)	Boot (3)
Spread out (3)	Spread out (3)
Actually (3)	New (3)
	Understand (3)

Next, the same thing was done to evaluate the overall impression of the class using WebXR. The results are presented in Table 4. In both cases, "Understand" was included in many of the users' comments.

Table 4: Words and number of occurrences in comments on WebXR-based classes.

WebAR based class	WebVR based class
Understand (9)	Understand (8)
Radiation (7)	Protection (4)
Protection (5)	Scattered (3)
AR (3)	Visually (3)
Scattered (3)	Content (3)
Use (3)	
First time (3)	
Deepen (3)	

III-4. Cluster Analysis Using Text Mining

Cluster analysis was performed on the impressions of the WebXR system, and the relationship among the extracted words is summarized in figure 5. Similarly, figure 6 shows the relationship among the words extracted for the feedback in the classes from the WebXR system.

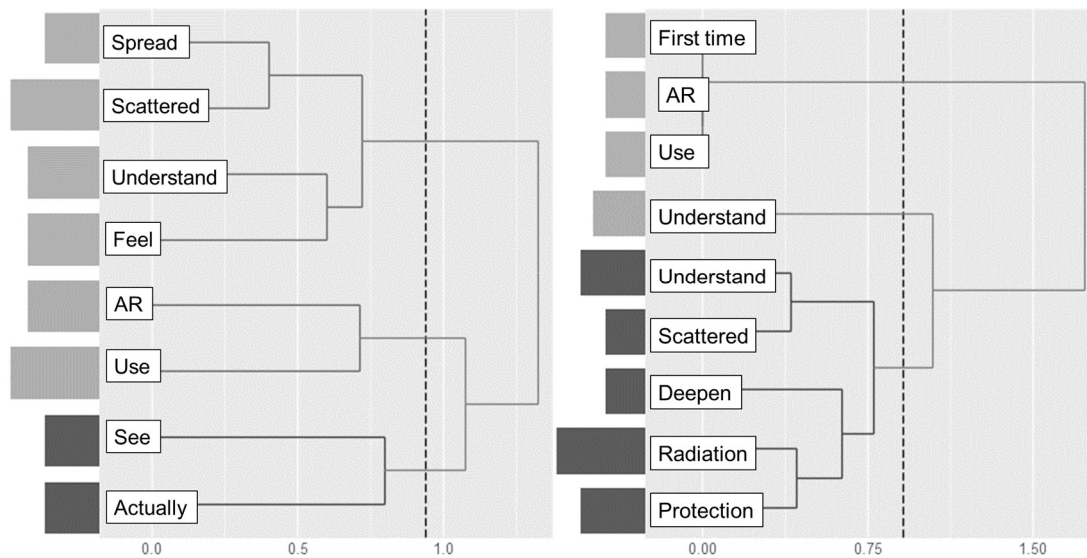


Figure 5: Relationships among words included in the feedback on WebXR
(Left: WebAR, right: WebVR).

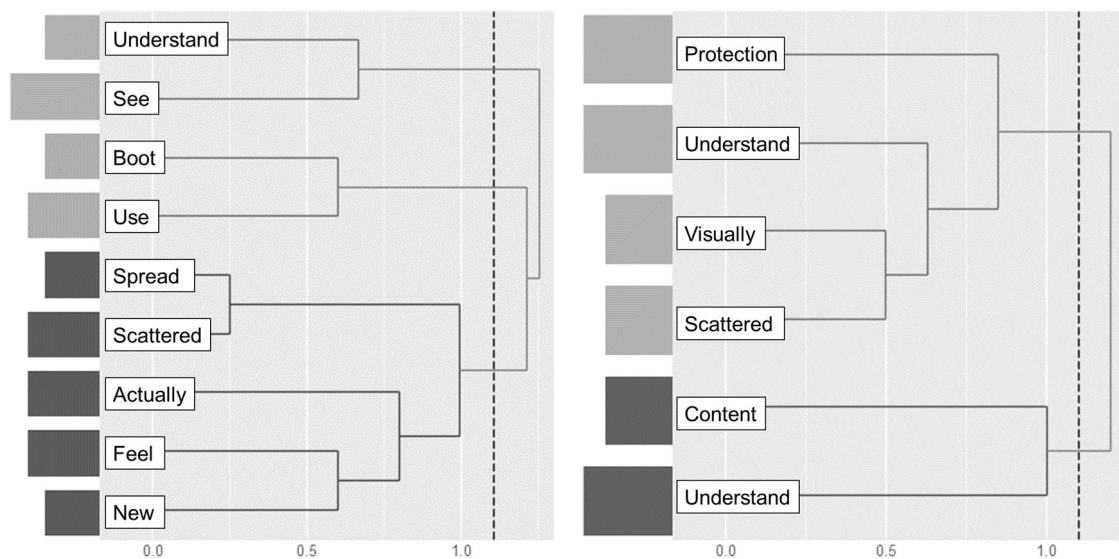


Figure 6: Relationships among the words included in the feedback on classes using WebXR
(Left: WebAR, right: WebVR).

IV. Considerations

IV-1. Exercise scores

The scores of the exercises were high, indicating that the users had gained a high level of understanding. However, the score may have been high because the users were students of the Department of Radiation Technology Science, and had prior knowledge of radiation protection. Therefore, the same survey should be conducted on those who have less knowledge of radiation protection, and the results thus obtained should be compared.

IV-2. The ARCS model

The average score of the evaluation of the ARCS model was high, with a mean value of 4 or higher for all items, indicating that the education materials using WebXR increased interest and motivation of the users in the class. In particular, the high rating of the questionnaire items related to confidence in radiation protection indicated that the materials increased the users' confidence in radiation protection. In addition, the high rating of the item "easy to understand the importance and outline of the educational content" indicates that the use of XR technology deepens user's understanding.

There were two items rated low. First, the item "I was able to learn unexpected things" was rated low, which may have been due to the fact that the users were students of the Department of Radiological Technology and the exercises were basic questions. The next item, "feedback was useful," was rated low, probably due to the fact that the content of the exercise was basic to the users and many of them knew the answers to the questions. To improve the evaluation of these two question items, the exercises and exercise methods should be modified to suit the users and purpose.

As for the two questions where WebAR was rated higher than WebVR, AR was considered to be a more unknown and fresh experience for users than VR, so AR was more likely to attract the interest of users and was rated higher. For the question where WebVR was rated higher, it was rated so, because the observations in VR were more stable and easier to understand and relate to.

IV-3. Results of text mining

As for the words with the highest number of occurrences, "understanding" was included in all the comments, suggesting that the use of the WebXR system had an effect on the understanding the educational content. And since the words "feel" and "see" were included, the WebXR system is considered to be easy to understand visually.

From the relationship diagram of the words in the impressions about the WebXR system in cluster analysis, it could be concluded that students could understand the spread of scattered radiation by actually seeing and feeling it, hence, deepening their understanding on radiation protection. Therefore, the WebXR system helped understand the behavior of scattered radiation visually, and enhanced the understanding of radiation protection.

V. Conclusion

A new method of education for radiation protection using WebXR was developed. WebXR allows the user to visually observe and understand the spread of scattered radiation. We concluded that this method improves the user's interest, understanding, and confidence in radiation protection.

VI. References

- 1: Brun A, Mor RA, Bourrelly M, Dalivoust G, Gazazian G, Boufercha R, Lehucher-Michel MP, Sari-Minodier I. Radiation protection for surgeons and anesthetists: practices and knowledge before and after training. *J Radiol Prot* 2018 Mar; 38(1): 175-188.
- 2: Fujibuchi T. Radiation protection education using virtual reality by visualization of scatter distribution in radiological examination. *J Radiol Prot* 2021 Jul.
- 3: Fujibuchi T, Ueda K, Kadayanagi S, Ueno D, Nakamura C. Examination of Application to Radiation Protection Education by Four-dimensional Visualization of Scatter Distribution in Radiological Examination Using Virtual Reality. *J. Radiol. Technol* 2019; 75(11): 1297-1307.
- 4: J. Kilian-Meneghin, Z. Xiong, C. Guo, S. Rudin, and D. R. Bednarek. Evaluation of Methods of Displaying the Real-Time Scattered Radiation Distribution during Fluoroscopically-Guided Interventions for Staff Dose Reduction. *Proc SPIE Int Soc Opt Eng* 2018 February.
- 5: Matthias Sünksen, Oliver Johannes Bott, Klaus Dresing, Michael Teistler. Simulation of scattered radiation during intraoperative imaging in a virtual reality learning environment. *International Journal of Computer Assisted Radiology and Surgery* 2020; 15: 691-702.
- 6: Yuh-Shihng Chang, Kuo-Jui Hu, Cheng-Wei Chiang, Artur Lugmayr. Applying Mobile Augmented Reality (AR) to Teach Interior Design Students in Layout Plans. Evaluation of Learning Effectiveness Based on the ARCS Model of Learning Motivation Theory. *Sensors* 2019 Dec; 20(1): 105.
- 7: Yi Guo, Li Mao, Gongsen Zhang, Zhi Chen, Xi Pei, X George Xu. Conceptual Design and Preliminary Results of a VR-based Radiation Safety Training System for Interventional Radiologists. *Radiation Protection Dosimetry* 2020 June; 190: 58-65.
- 8: Takeshi Takata, Susumu Nakabayashi, Hiroshi Kondo, Masayoshi Yamamoto, Shigeru Furui, Kenshiro Shiraishi, Takenori Kobayashi, Hiroshi Oba, Takahide Okamoto, Jun'ichi Kotoku. Mixed Reality Visualization of Radiation Dose for Health Professionals and Patients in Interventional Radiology. *Journal of Medical Systems* 2021 Feb; 45(4): 38.
- 9: Chin-Pang Benu Yiu, Yu Wai Chen. Molecular Data Visualization with Augmented Reality (AR) on Mobile Devices. *Structural Genomics* 2020 Oct; 2199: 347-356.
- 10: Žiga Kokelj, Ciril Bohak, Matija Marolt. A web-based virtual reality environment for medical visualization. *IEEE* 2018 May.
- 11: Tatsuhiko Sato, Yosuke Iwamoto, Shintaro Hashimoto, Tatsuhiko Ogawa, Takuya Furuta, Shin-ichiro Abe, Takeshi Kai, Pi-En Tsai, Norihiro Matsuda, Hiroshi Iwase, Nobuhiro Shigyo, Lembit Sihver and Koji Niita. Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02. *J. Nucl. Sci. Technol* 2018; 55(5-6): 684-690.
- 12: Takaki T, Fujibuchi T, Murakami S, Aoki T and Ohki M. The clinical significance of modifying X-ray tube current-time product based on prior image deviation index for digital radiography. *Phys. Med* 2019; 63: 35.

- 13: Kazuki Nishi, Toshioh Fujibuchi, Takashi Yoshinaga. Development of an application to visualize the spread of scattered radiation in radiography using augmented reality. J. Radiol. Prot 2020 Nov; 40: 1299–1310.
- 14: Paraview, <https://www.paraview.org/>; 2021 [Accessed 10 August 2021].
15: A-Frame, <https://aframe.io/>; 2021 [Accessed 10 August 2021].
- 16: AR-js-org, <https://github.com/AR-js-org/AR.js>; [Accessed 10 August 2021].
- 17: Nishi K, Fujibuchi T, Yoshinaga T. Development of scattered radiation distribution visualization system using WebAR. Journal of Physics: Conference Series 2021; 1943.
- 18: Keller, J. M. Motivation, Learning, and Technology: Applying the ARCS-V Motivation Model. Participatory Educational Research (PER) 2016 Aug; 3(2): 1-13.
19: Yuko Kawakami, Chiharu Kogo. Making an Evaluation of the Japanese Edition of Course Interest Survey Scale Based on ARCS Motivational Model. Psychology 2013.
- 20: Kanda Y. Investigation of the freely available easy-to-use software ‘EZR’ for medical statistics. Bone Marrow Transplantation 2013; 48: 452-458.
- 21: KH Coder, <https://kncoder.net/en/>; 2021 [Accessed 10 August 2021].
- 22: Higuchi K. A two-step approach to quantitative content analysis: KH Coder tutorial using Anne of Green gables (part I). Ritsumeikan Social Sci Rev 2016; 52: 77–91.
- 23: Higuchi K. A two-step approach to quantitative content analysis: KH Coder tutorial using Anne of Green gables (part II). Ritsumeikan Social Sci Rev 2017; 53:137–147.