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This article presents the results of a trend study investigating what students associate with the term radiation and what ideas they have about this topic. The first part of the interview study was conducted in June 2010 and its results were reported in a previously published article (Neumann & Hopf, 2012). Two years later (June 2012, 15 months after the Fukushima accident), the study was replicated under similar preconditions in order to get an impression about a possible shift in the changes of students' ideas. One result of our comparison study was that, compared to the students interviewed in 2010, a significantly higher percentage of students exclusively associated nuclear radiation with the term radiation and their emotions towards the topic were more negative.

Keywords: Fukushima, interviews, radiation, students' conceptions, trend study

INTRODUCTION

In science education, the enormous impact of students' own ideas on their learning has been recognized for a long time (Wandersee, Mintzes, & Novak, 1994). A large number of research studies have found students' conceptions in many fields of science education that potentially influence students' learning. Also, theoretical models of the structure of these conceptions as well as strategies for conceptual change have been and continue to be published (Treagust & Duit, 2008).

Students are often confronted with the term radiation in their everyday lives. A lot of parents, for instance, are concerned about the potential harm of radiation emitted by mobile phones. Most apartments in the industrialized world are equipped with WiFi. Remote controls and modern video games use infrared radiation to transmit information. Also, the use of nuclear radiation in medicine and technology has often been discussed in the media. A profound understanding of different aspects of radiation, thus, seems to be essential for all citizens. This is why we were interested in examining the students' conceptual understanding regarding this topic.

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Students' conceptions about radiation in general

Studies about students' conceptions about radiation are, compared to research in other fields of science education, rather rare. Most of these studies focus on nuclear radiation. Only very few studies can be found that investigate students' conceptions about the topic radiation in general.

Florbela Rego and Luis Peralta (2006) used questionnaires to find out what students knew about this topic. In the questionnaire, which was administered to 1246 students, the researchers included general questions about radiation (e.g., "*Do all types of radiation produce the same effect in the human body?*") and also asked the students whether or not they had already heard of different kinds of radiation. In the second part of the

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State of the literature

- Research studies about students' ideas in various fields of science (mechanics, electricity, optics …) have contributed and continue to contribute a plethora of findings to science education research.
- Studies about students' conceptions about the topic radiation (nuclear radiation and radiation in general), however, are very rare.
- Only few studies, evidently, have been able to investigate pre/post-effects of nuclear accidents on risk perceptions or on students' conceptions about radiation.

Contribution of this paper to the literature

- This article presents the results of a trend study about students' ideas in the field of radiation which compares two parts of an interview study that were conducted before and after the Fukushima accident, respectively.
- The results show that, in the second part of the study, significantly more students associated nuclear radiation with the term radiation and also their emotions regarding this term tended to be more negative.
- The article also includes suggestions for teaching the topic radiation in the science classroom so that conceptual change might be fostered.

questionnaires, the students were asked to state whether or not they thought that certain statements about radiation were correct. These statements included sentences such as: "Nowadays people are continuously exposed to several types of radiation" or "In some jobs and sports, people are more exposed to radiation". The results revealed that although 87.2% of students in grades 7 to 9 had heard of radiation, very few students were familiar with the term ionizing radiation. Even at university level, this figure turned out to be as low as 27.3%. Also, a minority of the students were able to identify what was meant by the term visible radiation. The second part of the questionnaire demonstrated that, although most students know that radiation has medical applications, they do not know about the differences between various kinds of radiation.

Since so little research could be found about students' conceptions about radiation in general, our workgroup decided to perform an explorative study (Neumann & Hopf, 2012; Neumann & Hopf, 2013) that investigated children's associations with the term radiation at a rather young age (9 to 12 years old). All in all, 1026 students were asked to draw whatever images they associate with this word. Using a self-created and peer-evaluated category system, it turned out that the chosen motifs depended strongly on the age of the children. The vast majority of younger children drew sources of visible radiation (the Sun, flash lights), possibly influenced by the close connection of the German word Strahlung (meaning radiation) and the Sun. Older children in our study tended to include sources of invisible radiation such as mobile phones and nuclear power plants. Short interviews with a sub-set of the students contributed to a larger more detailed picture about general associations with the term radiation and the impression that the picture changes from 'warm and pleasant' to 'dangerous and artificial' was confirmed by the interview results.

Based on these findings, our workgroup carried out an interview study (Neumann & Hopf, 2012) in which we investigated the previous knowledge and conceptions of 9th graders, an age level that corresponds to the end of compulsory education in our country. We included questions about their first associations with the term radiation and about corresponding emotions. The students were also asked to state whether or not they had heard about different kinds of radiation and what they knew about those types. Also, the concept of thermal radiation ("All bodies emit radiation") was tested. One phase of the interview was dedicated to the students speaking freely about their conceptions. This phase was initiated with cards showing different objects from everyday life, such as plants, animals or computers. The students were asked to rate which of these objects they would link to the term radiation and to explain in detail why (or why not). The main results of this study include the fact that the students' associations and emotions regarding the term radiation have very little to do with the scientific definition of the term. A lot of students were of the opinion that radiation is, at any rate, dangerous for the human body and that human beings should try to avoid exposure to radiation by all means. Also, many students thought that radiation is something artificial. The concept that light and heat are also types of radiation that are indubitably conducive to human life, was hardly known to any of the students interviewed. This interview study founded the base for a trend study on which we would like to report in this article.

Students' conceptions about specific kinds of radiation

The numbers of studies that have investigated students' conceptions about different kinds of radiation greatly vary, depending on the type of radiation. One of the most explored areas is students' ideas regarding light and optics (cf. Guesne, 1985; Jung, 1987; Smith, 1987; Watts, 1985). As these studies typically focus on students' conceptions about optics (*shadows, mirrors, images,* …) and do not investigate conceptions about

light as a form of radiation, we will omit the results of these studies in this paper.

Research results about students' ideas regarding UV and IR radiation are very scarce. One of the few studies was carried out by Libarkin et al. (2011) who examined 283 students in grades 6 to 12, using questionnaires, in-depth interviews and a panel discussion. One of their results was that students confused ultraviolet radiation with visible light, stating, for instance, that in the presence of UV one can see objects. With IR radiation, the researchers encountered problems investigating the corresponding students' conceptions because only very few students were familiar with this term. In our interview study (Neumann & Hopf, 2012), we also included questions about UV and IR and found out that the students' conceptions about these types of radiation were dependent on the context in which students would place these types of radiation. UV, for instance, was sometimes rated as blue and harmless. This was mainly the case for students who associated UV with disco lights or dentist treatments. Infrared radiation was overwhelmingly linked to the wireless data transfer on mobile phones and thus perceived as invisible and harmless.

More interest has been drawn to students' conceptions about nuclear radiation. Especially in the aftermath of after the reactor accident in Chernobyl, some studies investigating students' ideas about nuclear radiation were conducted. Harrie Eijkelhof published the results of several studies in his doctoral thesis (Eijkelhof, 1990) and together with other researchers, such as Robert Millar, Piet Lijnse and Cees Klaassen, in several articles (e.g. Eijkelhof, Klaassen, Lijnse, & Scholte, 1990; Lijnse, Eijkelhof, Klaassen, & Scholte, 1990; Millar, Klaassen, & Eijkelhof, 1990). After a Delphi study using questionnaires answered by 63 experts on radiation, the workgroup scoured newspapers to detect alternative conceptions about radiation risks. Also, they administered questionnaires to high-school students and conducted in-depth interviews. Using these methods, they found a number of ideas that students and the general public have about nuclear radiation, e.g. the idea that food which is exposed to ionizing radiation stores this radiation or the idea that radiation could accumulate in a human body. Also, they demonstrated that a lot of students have scientifically unacceptable ideas about the transfer of radioactive substances and the process of radiation. For example, many students apparently believed that radiation itself could be spread by the wind or that human beings could be contaminated with radiation.

Edward Boyes and Martin Stanisstreet (1994) investigated students' conceptions about nuclear radiation by analyzing 1365 closed-form questionnaires, followed by interviews with a sub-set of 60 randomly chosen students. One of their major findings was that only very few students knew about natural sources of radioactivity. A lot of students also deemed radioactivity responsible for exacerbating the greenhouse effect and the depletion of the ozone layer.

When doing research about students' ideas about nuclear radiation, the field of risk perception also plays a vital role. Paul Slovic (1996) was able to find factors that influence how the public views the use of nuclear radiation arising from human activities. He showed that whether or not people rate radiation as harmful primarily depends not on the type of radiation but on the context in which the radiation is used. A lot of people, for instance, rated ionizing radiation for medical purposes as harmless whereas in the context of food irradiation it was rated as harmful.

Few studies, evidently, have been able to investigate pre/post-effects of nuclear accidents on risk perceptions or on students' conceptions about radiation. Klingman, Goldstein and Lerner (1991) were interested in how the Chernobyl accident influenced the attitudes of 96 students related to nuclear threat. By administering a questionnaire (the Nuclear Threat Index) before and after the incident, they were able to find that the older the students were, the more pessimistic they became regarding nuclear issues after Chernobyl. The older students did, however, report fewer nuclear-related activities (e.g. talking to their parents or searching for information) than the younger students after Chernobyl. When analyzing the changes before and after Chernobyl, they also found that the number of nuclear-related activities had decreased, a fact that the authors of the study suggested to trace back to a possible saturation of information by the extensive media coverage. Cees Midden and Bas Verplanken (1990) published a study in which they reported how the nuclear attitudes of adults and their perceptions of risks and benefits of nuclear technology changed a certain period after the Chernobyl accident. One of the results was that those people who supported nuclear power turned out to be less stable in their attitudes than those who opposed this technology.

At the beginning of our research related to students' ideas about radiation, our workgroup only aimed to contribute to science education research in the field of students' conceptions. After the tragic events of Fukushima, however, we decided to take this opportunity to start two trend studies that will support and enhance the few existing pre/post-studies about children's associations with the term radiation as well as about older students' attitudes towards nuclear issues.

First, we replicated the analysis of children's drawings as described above. Pre/Post-effects relating to the events at Fukushima included the fact that students of all investigated age levels, girls as well as boys, chose more motifs related to nuclear issues. In the interviews, we found that most students had heard of

the events in Fukushima and often referred to this accident when talking about nuclear radiation (Neumann & Hopf, 2013). The design and results of our second trend study (replication of the interview study) will be the focus of this article.

Research Questions

Our trend study had two major aims: First, it was self-evident that we wanted to test whether or not certain students' ideas about radiation, in general, remained the same and would also be shown in a replicative study two years after the original study. In this article, however, we would like to present and discuss the second aim of our trend study: to find out about students' ideas about nuclear radiation. We will therefore omit reporting the stability of conceptions about other types of radiation such as ultraviolet and infrared.

The research questions that we aspired to answer were the following:

How did students' perceptions about radiation (especially nuclear radiation) change in a trend study before and after Fukushima?
Which evidence can be found that these changes originated (at least partially) from the media reports or other sources as a result of the events at Fukushima?

By answering these two research questions, we were hoping to find evidence regarding our assumption that some types of students' perceptions are easily influenced by external events. If this were the case, it would be important for science education to perform trend studies about other ideas that might have changed over time and for teachers to be aware of the development of students' perceptions.

In order to keep the preconditions as similar as possible, we aimed to include students of the same schools as in the first part of the study. From the eight schools which participated in 2010 (all of them in urban areas, but different types of schools from different districts), seven schools agreed to participate again. One school, however, could not take part in the 2012 study. This is why we removed the data of this school from the 2010 database. All in all, in the second part of our study, we conducted interviews with 43 students attending grade 9 with a mean age of m = 15.6 (s = 0.6). The main reason for choosing 9th grade students was the fact that, in Austria, this is the last year of compulsory education and about 30% of all students discontinue their education once they fulfill this requirement. The students selected for the interviews were taught by the same teachers as in 2010. The science curriculum had not been changed in the meantime. However, we were not able to account for changes in the individual teaching methods of the teachers or the specific content of the science lessons that each of the students had already attended. We have to concede that these variables could have changed in the time between the two studies. Though the topic of nuclear radiation is a part of the official science curriculum in Austria (before students complete their compulsory education), the amount of lessons dedicated to the topic and the context in which nuclear radiation is taught, are left to the teachers to decide. We asked the teachers to select students from their classes with diverse school performances so that we would get a mixture of over- as well as underachieving students in each school. Also, the girls-boys ratio was selected to be comparable in the two studies as well as representative of the total student population in Austria. All participating students volunteered to take part in the interviews.

RESEARCH DESIGN

Our study was designed as a trend study based upon

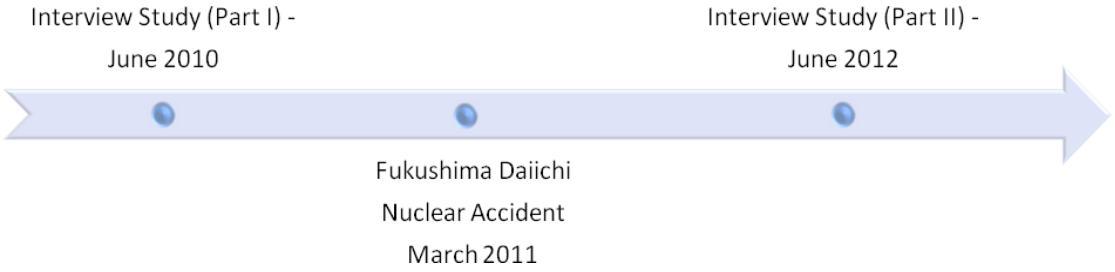

Figure 1. Timeline of Research Design

Table 1. Database 2010 vs. 2012

	male	female	Total
Interview Study (Part I) - 2010	22	21	43
Interview Study (Part II) - 2012	23	20	43

one of our previously published investigations (Neumann & Hopf, 2012; 2013). We chose June 2012 as the date for the second part of our study, exactly two years after the first part and fifteen months after the nuclear events in Fukushima. We selected this date for two reasons: First, the date should not be too close to the tragic incident but approximately one year afterward, in order to excite long-term memories of the interviewed students. Second, the setting of the interviews should be as similar as possible to the first part of the study. Choosing the same month allowed for similar background conditions in the students' private lives and school environment, e.g. no more exams and/or the students' anticipation of the summer break.

The semi-structured interviews followed exactly the same interview guideline as 2010. Based on the literature review and our previous studies, we had found several hypotheses of potential students' conceptions that we wanted to test using our two interview phases. The person conducting the interviews was also the same as in 2010 (table 1). An English translation of the complete interview guideline can be found in the appendix of this article. As the interviews were conducted in German, we also include the original version with some linguistic comments. In our first study, we created the interview guideline and had it peer-evaluated. After three tests runs followed by emendations of the questions and their specific order, the guideline was completed and was not altered again for the 2012 study. Despite the fact that more questions regarding the topic of nuclear radiation would have been interesting to include in the questionnaire, we decided not to alter it at all, in order to get comparable results for the trend study. The interviews were administered directly at the students' schools, usually in separate rooms adjoining the science lab. Although the interviewer presented herself as a university researcher, not mentioning any relationship to science, a potentially perceived proximity to science cannot be excluded, as the introduction of the interviewer took place during the science lessons. All interviews were audio-recorded and partially transcribed. The category system that underlies the analysis of the semi-open questions had already been developed and peer-evaluated during the first part of the study and was re-used in the 2012 study (table 1).

RESULTS

As an opening question in the interviews, we asked the students to simply list some words that spontaneously came to their mind when they heard the term radiation. For this part of the study it was especially interesting to analyze how many students listed words that were related to nuclear radiation and how many listed words exclusively in this category. In order to get an impression of the variety of words that we classified into this category, we list some frequently mentioned words in fig. 2. For an overview of the frequency of these words please refer to fig.4.

The analysis (see fig. 3) showed that in the second part of our study, 90.7 % of the students spontaneously associated words related to nuclear radiation with the term radiation. The difference between the two parts of the study was even stronger when we compared the number of students who only associated words related to nuclear radiation and did not list other words (unlike, for instance, students who listed nuclear power plants and UV-radiation). Testing the significance of these

Nuclear power plant, Fukushima, Chernobyl, radioactivity, half-life, alpha/beta/gamma radiation, atomic bomb, radiation sickness, irradiation, nuclear meltdown …

Figure 1: Sample of Words from Category "Nuclear Radiation"

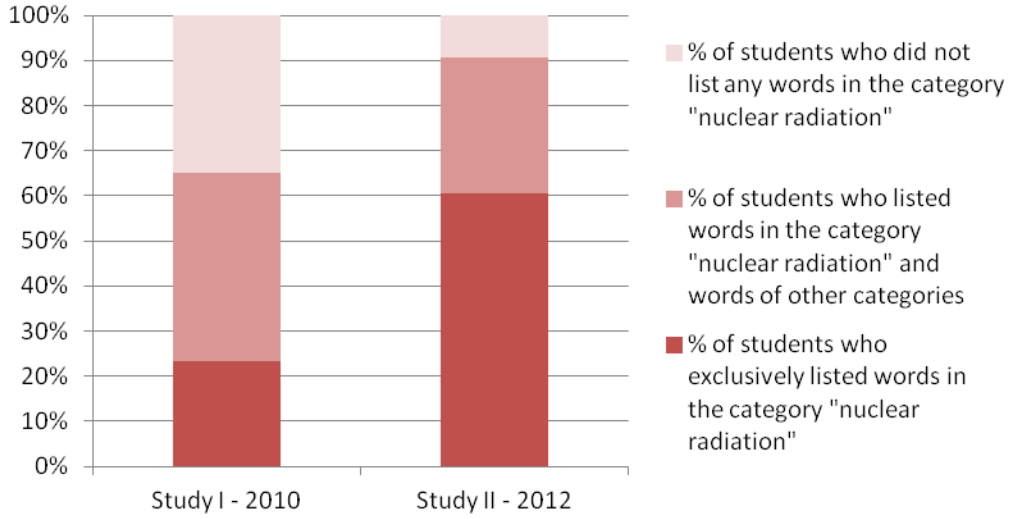

Figure 2. How Many Students Associated Words Related to Nuclear Radiation?

values, we used a 2x3-contingency table, where the χ^2-test revealed a high significance in the changes ($\chi^2 = 14.29$; $df = 2$; $p < 0.001$).

We also analyzed the frequency of specific words that were listed in both studies. Fig. 4 cites the ten most frequently associated words in study I and study II, respectively. It can be seen how the absolute frequency of (nearly all) words related to nuclear radiation increased in the 2012 study and the frequency of words related to other aspects of radiation (the Sun, UV, mobile phones) decreased.

In order to find out more about the students' spontaneous associations, we then asked them to tell us about the feelings they have when confronted with the term radiation and to give reasons why. Fig. 5 shows that a difference between the two parts of the studies could be found. In 2012, 11.6 % more students reported that they associated negative feelings with the term radiation, while 11.6 % fewer students reported to have mixed feelings. These differences, however, were not found to be significant and, thus, only show a trend in our sample.

The interview guideline also included a section where the students were asked whether or not they had heard of different types of radiation, e.g. infrared, ultraviolet, X-rays and nuclear radiation. Then, the students were asked to rate the risk potential of those types of radiation. As there were no substantial differences detected between the 2010- and the 2012-study, we would like to refer the reader to our previous article (Neumann & Hopf, 2012) in order to find out about students' ideas about risk potential. In this article, we would like to report only one finding related to the students' perception of risk potential. In this context, we present the findings based on the combined sample of 2010 and 2012 (although the same idea can also be found in both samples independently).

The interviewed students demonstrated a very different reaction pattern when asked to rate the risk potential of X-rays and nuclear radiation, respectively (see also fig. 6). Although 38.4 % of the students characterized X-rays as harmless for the human body, none of the 86 students suggested that about nuclear radiation. For the vast majority of students (92.4 %) there was no doubt about the hazardous nature of nuclear radiation, while only 32.6 % considered X-rays to be unrestrictedly harmful.

To get an impression of the arguments that the interviewed students used, we would like to present some typical comments from those students who rated X-rays as harmless:

"I don't think that X-rays are harmful. If they were, we would not use them in medicine." (I 35, Study 2010)

"Of course, they are not harmful. I have done it a million times and it's perfectly okay." (I 36, Study 2010).

"X-rays? No, they are not dangerous." – "Why don't you think so?" – "Why should they be? What you do, is only taking pictures, pictures of your bones." (I 12, Study 2012)

In our interviews, we also asked the students if they could remember any topics related to radiation that had been discussed previously in school. In the Austrian science curriculum the topic of radioactivity is explicitly planned for grade 8, so we could expect the majority of our interviewees (all of them attending grade 9) to have heard about nuclear radiation in school. The fact that the accident in Fukushima had happened a year previously, when the interviewed students were attending grade 8, could have given the teachers an opportunity to connect the curricular topic to current events. What we found was that 37 out of the 43 interviewed students remembered that they had discussed the topic radioactivity in science lessons, 13 of these students explicitly mentioned that the accident of Fukushima had been a specific theme in science lessons. Some of the students even told us about cross-curricular activities and projects centered around the incident at Fukushima, which also involved subjects other than science. As teacher interviews were not part of this study, we cannot provide any data about how often and how in depth the teachers really discussed the topic in their science lessons. Also, no figures can be given about the period of time during which the Fukushima accident was extensively covered in Austria and through what kinds of media.

The major aim of the interviews, in both parts of the study, was to detect students' conceptions about radiation. This is why we also included open questions (see questionnaire in the appendix) that would give the students the chance to talk freely about their ideas related to the topic. When we analyzed the answers of those questions we also discovered several ideas about nuclear radiation that we find worth reporting. For students' conceptions about radiation in general and types of radiation other than nuclear, we would like to refer the reader to the analysis of our first study (Neumann & Hopf, 2012). All students' ideas presented in the previously cited article, for instance, the idea that radiation is always something harmful and artificial or the idea that light is not a type of radiation, were discovered again in the 2012-interviews. Therefore we are now only going to present those students' conceptions that relate to nuclear radiation. All of the following students' conceptions could be found in the 2010- as well as in the 2012-study.

There are no positive aspects of nuclear radiation

A very remarkable result of our interviews was the fact that, when students talked about nuclear radiation, most of them only mentioned its negative aspects.

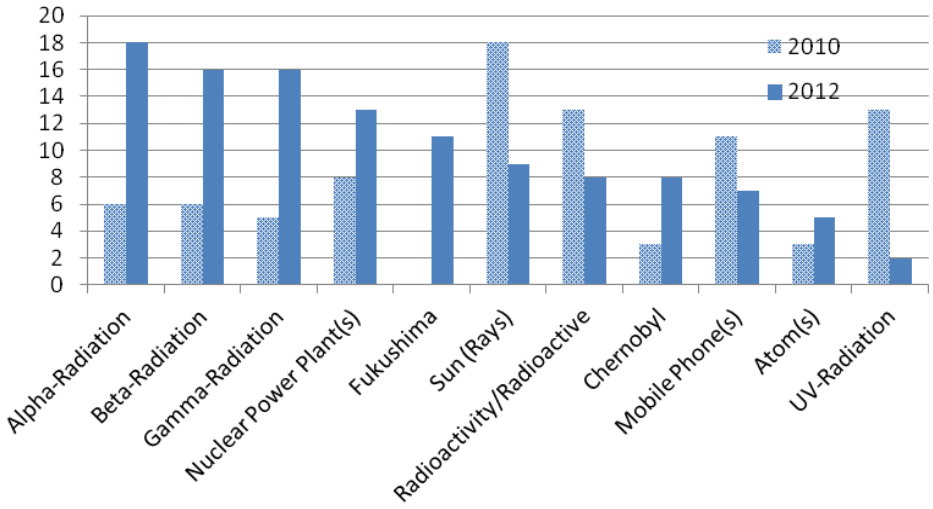

Figure 3. Specific Words Associated With "Radiation"

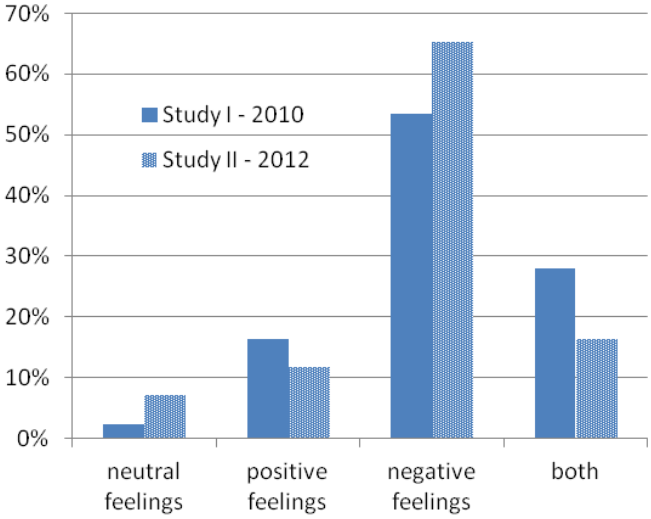

Figure 4. What Feelings Do Students Have When Confronted with the Term Radiation?

Overall, there was only one student who argued that nuclear radiation is also used in medicine (although in the same statement, she confused it with chemotherapy). All of the other interviewees only talked about the hazardous aspects, usually illustrating their point by listing accidents in nuclear power plants (Chernobyl, Fukushima). It cannot be ignored, however, that all of the reported students' comments are only statements that they delivered unsolicitedly because the interview guideline did not contain specific questions about positive aspects of nuclear radiation.

Radiation is confused with radioactive substances

This students' idea, which has also been identified in previous studies (Boyes & Stanisstreet, 1994; Eijkelhof, 1990) cannot only be explained by a technically incorrect use of the words but several comments from the interviewed students show that the scientific concepts behind these words were not understood. A lot of students, for instance, were able to remember that gamma radiation can penetrate thick walls. However, their confusing the differences between radiation and radioactive particles made it impossible for them to explain why the wearing of raincoats is recommended after a nuclear accident.

> *"I've heard that there are those plastic suits you should wear, but to be honest I think this is a lie because nuclear radiation goes through that material anyway."(I 23, Study 2010)*
> *"If I eat, let's say, mushrooms [after a nuclear breakdown], I would have the radiation inside of me."(I 4, Study 2012)*
> *"On the news I saw that the workers in Fukushima were wearing those masks so that they would not inhale the radiation." (I 41, Study 2012)*

The statement "All objects emit radiation." is true because nowadays everything is contaminated with nuclear radiation.

Although our purpose for testing this statement was to find out whether or not students consider thermal radiation plausible, we discovered that some students affirm this statement not because they had a profound understanding of thermal radiation, but rather because they attributed it to nuclear radiation.

"Why should I not believe that the table, for instance, emits radiation? It is made of wood and that's definitely contaminated with a little bit of radioactive radiation." (I 20, Study 2010)

"I think that has changed over time. A Hundred years ago, of course, there was not so much radiation. But nowadays everything contains radiation. A little bit at least." (I 8, Study 2012)

"I also think that flowers emit a little bit of radiation, especially if they grow in the neighborhood of Fukushima." (I 25, Study 2012)

Gamma radiation consists of waves, every other type of radiation travels in a straight line

One question included in our interview guideline requested that the students draw an object that emits radiation. We were not only interested in the objects that students would choose to depict, but also in the way that students would use to illustrate the process of emitting radiation. What we found was that most students used sun-ray like straight lines for picturing the process of emitting radiation independent from the object they drew (e.g. mobile phones, nuclear power plants, nuclear waste), see fig. 7.

Some students, however, included waves in their drawings. If this was the case, we asked them why they chose this way of illustrating radiation. None of the interviewed students could give a scientifically satisfactory answer.

"Of course this radiation wants to go in a straight line. But there are molecules in the air and so the radiation is bent around them like this (showing a wavy motion with his hand)." (I 5, Study 2010)

"It depends on the kind of radiation. It's only gamma radiation that travels up and down like a wave. Everything else spreads out in straight lines." (I 41, Study 2010)

"I really have no idea why I drew a wave. I think I've seen it in my physics text book that gamma travels up and down and has a wavelength, right? And alpha radiation goes straight, just like light coming from a laser." (I 14, Study 2012)

The analysis of the open questions also made it possible to investigate whether or not the interviewed students in the 2012 study would refer to the accident in Fukushima when talking about nuclear radiation. We already showed in this chapter that 11 out of the 43 interviewed students included the word Fukushima in their spontaneous associations with the term radiation. Also, 13 students (7 of which had not listed Fukushima as one of their associations) mentioned Fukushima after having been asked about radiation topics discussed in

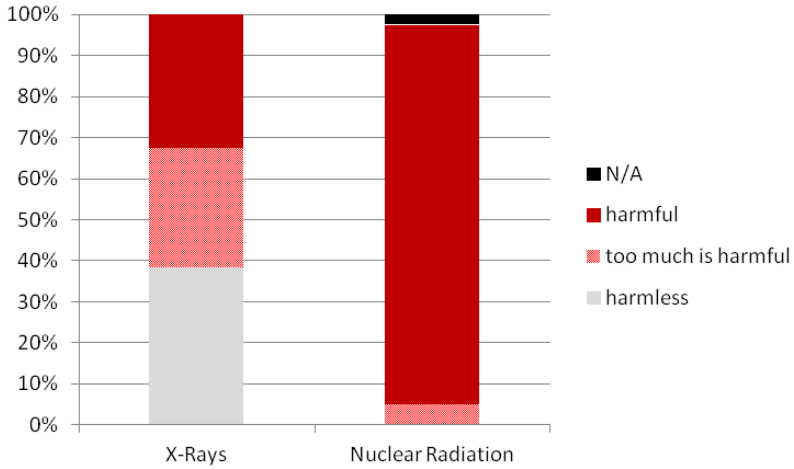

Figure 5. How Students Rated the Risk Potential of Specific Types of Radiation

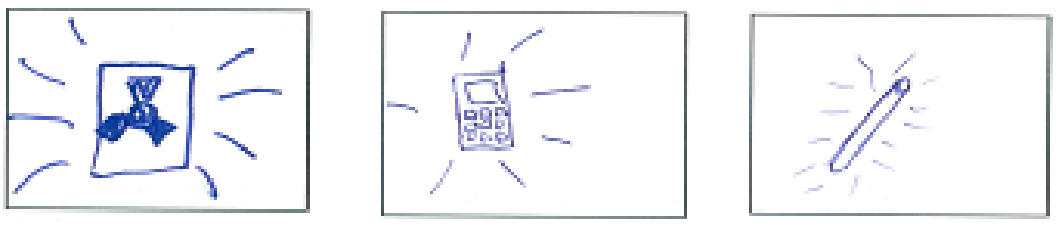

Figure 6. How Students Depicted the Process of Emitting Radiation

school. In addition to that, we also found evidence in the open questions for the hypothesis that students referred to the Fukushima accident when talking about nuclear radiation. They told us about media reports, discussions with their parents and documentaries they watched about the event. It seems noteworthy to mention that a lot of students used Fukushima to illustrate their specific ideas and conceptions about nuclear radiation described above.

"It's clear that nuclear radiation is a bad thing. Everybody knows about this thing that happened in Fukushima." (I 3, Study 2012)

"Radiation is something we cannot see with our eyes. That makes it so difficult to detect it. Just like in Fukushima when the workers needed measuring devices." (I 37, Study 2012)

"On the news, I saw that the workers in Fukushima were wearing those masks so that they would not inhale the radiation." (I 41, Study 2012)

DISCUSSION

From the results described above, it seems to be conclusive that students tend to equate the term radiation with nuclear radiation. The results also show that this correlation is even more prevalent in the second part of the study. We have to concede, however, that due to the design of the interview study, a direct causality between the increase in the students equating the term radiation with nuclear radiation and the events in Fukushima cannot be clearly demonstrated.

The outcomes of our study demonstrate that the term (nuclear) radiation seems to be nearly exclusively associated with negative emotions. Students in our interview associated accidents in nuclear power plants and hazards of nuclear waste with the term. In our opinion, however, students should also be familiar with applications of nuclear radiation that are beneficial to mankind so that their feelings will not solely tend to the negative side. From the interviews, it seems to be apparent that the risk perception of the students was closely related to the students' knowledge about applications in technology and medicine. X-rays were rated much less hazardous than nuclear radiation because students associated benefits for mankind with this kind of radiation. This result is consistent with the outcomes of Slovic's study (1996) which found that the general public's attitude about ionizing radiation is largely dependent on the context.

The interviews also revealed how large the impact of media reports on students' perceptions is. Nearly all of the students reported that they had heard about the Fukushima incident in the media. Also, the families and friend circles seemed to be a major source of students' knowledge. It should not be concealed, however, that a lot of students also stated that they had discussed this topic in school. This demonstrates that a lot of teachers were able to successfully implement current issues into their science teaching.

In spite of the fact that a large number of science teachers had obviously included Fukushima in their lessons, it seems disturbing to see how many students showed major difficulties when trying to align the facts about nuclear radiation (which they apparently had learned in school) with facts they heard from various media reports. This inconsistency could result from the way teachers used the news reports: If they only implemented the Fukushima incident as an impulse for their teaching and did not thoroughly draw relationships between the news reports and the scientific background, this could have led to the learning difficulties found among the interviewed students.

CONCLUSIONS AND IMPLICATIONS

Both our previous interview study (Neumann & Hopf, 2012; 2013) as well as the current study show how biased the majority of students are regarding the term radiation. For most of the students interviewed, the term radiation was equivalent with what scientists call nuclear radiation. This leads to the results that could be shown in both interview studies, in 2010 as well as in 2012: A lot of students are convinced that radiation is, under any circumstances, harmful and should be avoided by any means. Radiation is also seen as something artificial that could not occur without man-made technology. From a science education perspective, these results appear to be problematic as one aim in science learning should be to perceive radiation as a neutral term. Besides nuclear radiation, students should be aware of other types of radiation (such as light, infrared radiation, …) and of the natural occurrence of different types of radiation. Considering these wide-spread students' ideas, the topic radiation should be addressed in detail in the science classroom. Teachers should be aware of the associations and the pre-existing knowledge that students bring with them. General suggestions for effectively introducing and explaining the topic radiation can already be found in (Neumann & Hopf, 2012; 2013). In this article, we would like to add some ideas for teaching nuclear radiation in the science classroom. Some aspects that teachers should focus on are the following:

Nuclear radiation is only one of many different types of radiation

Since the majority of the students in our study equated radiation with nuclear radiation, it seems to be absolutely necessary to introduce and discuss other types of radiation when talking about nuclear radiation.

This will make it easier for students to broaden their associations with the word radiation. Introducing light and thermal radiation as part of the electromagnetic spectrum will help the students to understand that radiation is not necessarily harmful nor invisible.

The sources of nuclear radiation are, to a very large extent, of natural origin

Most of the students have already heard something about nuclear radiation, mostly in the context of nuclear power plants or nuclear weapons. However, it is highly probably that they are completely oblivious to nuclear background radiation which comes from natural sources like from the soil and from space. As this is the major source of nuclear radiation that people on Earth are exposed to, it is very important for teachers to make their students familiar with those natural sources. Having discussed nuclear background radiation, students will find it easier to not exclusively perceive nuclear radiation as something artificial and man-made.

In technology and medicine, the use of nuclear radiation is beneficial to human beings

In our study, the majority of students reported their negative emotions regarding the term radiation. Also, when discussing nuclear radiation, they almost always mentioned negative aspects of nuclear radiation, for instance (e.g. accidents that happened in nuclear power plants). We assume that these biased emotions towards nuclear radiation stem not only from media reports but are also generated and/or reinforced in the science classrooms. Beneficial applications of nuclear radiation seem to take up very little time, if any, in science lessons.

Apart from finding out about students' conceptions about (nuclear) radiation, the trend aspect in our study also allowed us to investigate how these ideas changed over time. Our results, thus, contribute to the knowledge gained from other pre/post-studies that investigated the change in people's attitudes towards nuclear radiation before and after nuclear accidents (cf. Klingman et al., 1991). In this context, it also seems striking how much students' conceptions can be influenced by current events and media reports. Evidently, the topic radiation might easily be assumed to be one of the science topics where students' associations and conceptions change rapidly due to the prominent role of this term in the students' everyday lives. We suggest, however, that this is not the only topic in which students' ideas might vary over time and it could be interesting to see more trend studies in various fields of research on students' conceptions.

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Appendix

Interview Guideline – English Translation

Question 1: Please list some words that spontaneously come to your mind when you hear the term 'radiation'?

Question 2: When confronted with the term ‚radiation', what feelings do you have? Why?

Question 3: I am going to show you pictures of different objects. Which of these objects do you associate with the term 'radiation'? Why?
The pictures associated with this question showed the following motifs (due to copyright, these pictures cannot be published but can be sent upon request): an X-ray photograph of a foot, a mobile phone, a computer screen with keyboard and mouse, a factory, windmills, a flower, a dog, a campfire, a nuclear power plant, stars in the night sky, a beach with a sunshade, an I-Pod, a TV-set and a child watching TV, a man, a woman in a tanning booth, kids playing a video game console, a mobile phone tower, a laser pointer

Question 4: I am going to list some specific types of radiation (mobile phone radiation, microwave radiation, infrared radiation, visible radiation, UV radiation, X-radiation, nuclear radiation). Please tell me whether or not you have heard of them, in what context you have heard of them, and if you think these types of radiation are harmful. Can they be detected by the human eye?

Question 5: Have you already discussed 'radiation' in physics class or in any other subject? Tell me what you have discussed.

Question 6: Do you think you should protect yourself against radiation? Why (not)? How can you do that?

Question 7: On this sheet of paper, please draw an object that emits radiation.

Question 8: You read in a magazine that all objects emit radiation. Do you think this could be true? Why (not)?

Interview Guideline – Original German Version (with Linguistic Comments)

Frage 1: Nenne mir bitte einige Begriffe, die dir spontan zum Begriff ‚Strahlung' einfallen. *(The German term "Strahlung" is also used in everyday language, especially in compound words such as "Sonnenstrahlung" = "sunshine" or phrases like "Die Sonne strahlt." – "The sun is shining.")*

Frage 2: Wenn ich dir das Wort „Strahlung" sage, welche Gefühle verbindest du damit? Warum? *(see above)*

Frage 3: Wenn ich dir die Kärtchen zeige, welche Dinge, die auf den Kärtchen abgebildet sind, verbindest du mit dem Wort „Strahlung"? Warum? *(see above)*

Frage 4: Ich nenne dir jetzt ein paar Strahlungsarten (Handystrahlung, Mikrowellenstrahlung, Infrarot-Strahlung, sichtbare Strahlung, UV-Strahlung, Röntgenstrahlung, radioaktive Strahlung). Bitte sag mir, ob du von ihnen schon einmal gehört hast und in welchem Zusammenhang. Von welchen glaubst du, dass sie gefährlich sind für den Menschen und warum? Kann man diese Strahlungsarten sehen?

Frage 5: Hast du im Physikunterricht oder in anderen Fächern schon einmal etwas über Strahlung gehört? Erzähle mir, was du davon gehört hast.

Frage 6: Soll man sich vor Strahlung schützen? Warum (nicht)? Wie kann man das tun?

Frage 7: Ein Gegenstand sendet Strahlung aus. Bitte fertige eine kleine Skizze an, wie du das aufzeichnen könntest.

Frage 8: In einer Zeitschrift liest du, dass „jeder Gegenstand strahlt". Kann das stimmen? Begründe bitte.