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Two concepts of radiation. a case study investigating existing preconceptions

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Abstract
Conceptual Change is a widely accepted theoretical framework for science education. Setting up successful learning and teaching arrangements in this framework necessarily entails including students´ preconceptions into the construction of those arrangements. In order to provide a basis for such arrangements this study investigated and explored preconceptions about radiation in a qualitative case study with seven students (age 17-18). The use of grounded theory allowed the discovery of deep-rooted conceptions and the formulation of a theory to help learners understand the basic concepts of radiation more quickly and more reliably.

The results revealed a new conception „the nature of radiation", which hampers students' understanding and interferes with their explanations of radiation. Additionally, analysis of the data revealed interesting conceptions concerning the danger of different types of radiation. These highly interesting findings about the nature of radiation will be embedded in a broader perspective and suggestions for learning and teaching about radiation will be given.

Keywords: radiation, students' misconceptions, artificial, natural, dangerousness

Introduction

In the last thirty years students' conceptions and misconceptions have been central topics in science education research. Since Strike and Posner (1982) published their seminal model of conceptual change in 1982, the idea of changing misconceptions has come into the focus of the scientific community. In the following years a lot of research was conducted in this area and the theory of conceptual change became widely accepted in science education (e.g. Aufschnaiter and Rogge, 2015; diSessa, 2008; Duit and Treagust, 2003; Duit, Treagustand Widodo, 2008; Parnafes et al., 2008; Vosniadou, 2008). In order to initiate processes of conceptual change it is necessary to know and understand the conceptions students bring to the classroom. A great number of studies have attempted to identify and understand students´ preconceptions. As a consequence there are a lot of well-established and well-documented preconceptions for the fields of mechanics, optics or thermodynamics (Duit, 2009). However, there are other fields (e.g. quantum physics) where little is known about students' preconceptions. One of those fields is invisible electromagnetic radiation (such as infrared or ultraviolet radiation), which is the subject of this study. In this research area significantly fewer studies have been carried out; thus, knowledge of misconceptions concerning radiation is much scarcer.

A second reason why the topic of radiation differs from other topics in physics education is its position in the curricula. While topics of mechanic or optic are self-contained units of the curriculum in different grades (e.g. mechanics in grade 6 and/or 7 in the Austrian curriculum), radiation often spreads across several grades. For example, teachers talk about radiation in the context of heat transfer in grade 7 or 8 and about electromagnetic radiation in the context of radio waves in grade 10. However, in most curricula there is no section that provides the opportunity to link previously taught aspects of electromagnetic radiation or provides comprehensive information about it. Despite the importance of electromagnetic radiation in our everyday life (from mobile phones to microwave ovens) the topic radiation is allocated relatively small importance in curricula and thus in most school teaching.

The aim of this study is to investigate students' conceptions about electromagnetic radiation at the end of their school education. While studies by Neumann and Hopf (2012, 2013) laid the foundation for research in this area, this project will provide further insights by exploring students' deep-rooted conceptions and present first implications for instructional practices at school. The findings are a first step to enable teachers to design better learning settings for the topic of radiation, although further research is necessary to fulfill this objective.

Theoretical framework

Conceptual Change and Students' Conceptions

Over the span of thirty years the theory of conceptual change was developed and investigated by various researchers. It became a thriving field in science education and a huge amount of studies dealt with this subject. The field of conceptual change focused in the beginning heavily on students' pre-instructional conceptions. As a result we find a profound knowledge about students´ preconceptions in the field of mechanics or optics. After this first period the focus broadened to include other conceptions like those about nature of science (Duit and Treagust, 2003, 2012). During the 1990s two drifts emerged in conceptual change studies. On the one side there is the work from di Sessa and his colleagues looking at the process of conceptual change in a fragmented point of view (di Sessa, Gillespie and Esterly, 2004; diSessa, 2002, 2008). On the other hand we got the work of Vosniadou and colleagues who are more bound to a Kuhnian tradition and see a changing framework, when they describe conceptual change (Vosniadou, 1994; Vosniadou, Pagondiotis and Deliyianni, 2005; Vosniadou and Skopeliti, 2013; Vosniadou, Vamvakoussi and Skopeliti, 2008). However, there is a third part in the discussion yielded by Chi and colleagues, explaining conceptual change in an ontological way (Chi, 1992; Chi and Slotta, 1993). All sides of the discussion stretch out the importance of the knowledge about the students´ preconceptions.

Duit and Treagust (2012) mention the importance of affective variables like interest and self-concept in the theory of conceptual change. They argue that we need to understand the conceptions about the content and those affective variables. Notwithstanding, this study will deal with the students´ conceptions on the content and not with conceptual change as a process. Due to that fact we do not investigate affective variables in our study.

The superior goal of the conceptual change theory is to create appropriate learning settings that support conceptual change. In the model of educational reconstruction (Duit, Gropengießer and Kattmann, 2005; Duit, Gropengießer, Kattmann, Komorek and Parchmann, 2012) we get such a theoretical frame that enables a theory-based creation of learning settings. One fundamental part in this model is the student's perspective on the learning content. Therefore it is necessary to know the affective side, but primarily the cognitive difficulties like preconceptions, that contradict the scientific conceptions to different degrees. As we mentioned above there is a lack in the knowledge about conceptions about radiation. In the next paragraph an overview about the known conceptions is given.

Previous findings for students' misconceptions on invisible radiation
Most studies in the past focused on ionizing radiation, especially on nuclear radiation. Various studies in the mid-nineties came up with the following findings concerning frequent misconceptions (Eijkelhof, Klaassen, Lijnse and Scholte, 1990; Lijnse, Eijkelhof, Klaassen and Scholte, 1990; Millar, 1994 ; Millar and Gill, 1996). Students struggle with the difference between contamination and irradiation or the concept of activation: an object emits radiation after being exposed to radiation. The idea of linking the effects of nuclear radiation to other environmental issues like the greenhouse effect or the ozone layer was an additional result. According to Sesen and Ince (2010) a lot of misleading information concerning such known misconceptions can be found on the internet today and are therefore a source for students to learn and stabilize their misconceptions.

Looking more closely at invisible electromagnetic radiation as distinct from nuclear radiation there are some important studies and results. Rego and Peralta (2006) conducted a study about the knowledge of Portuguese students (n=1246) at different school levels (age 12-18) and at university. They used a multiple-choice questionnaire asking about general radiation physics, radiology and radiological safety. They found that students were unable to distinguish between non-ionizing and ionizing radiation. The difference between various types of radiation was largely unknown. Libarkin, Asghar, Crockett and Sadler (2011) focused on infrared (IR) and ultraviolet (UV) radiation in their research. They conducted semi-structured interviews and developed a questionnaire with questions about IR, UV and visible light. The students in this study (n=283) were aged between 10 and 16. The majority believed that the sun is the only origin for UV-radiation. Additionally, UV is described as "light," "bright light," "strong rays," "very violet," "a color like red, blue, purple light," or "harmful rays." Asking questions concerning IR-radiation they found a lack of knowledge; scarcely anybody had heard of this kind of radiation. Neumann and Hopf (2011) started research with students' drawings to visualize their associations with the word radiation. More than 500 students (aged between ten and twelve) drew their associations on paper and a smaller sub-group was interviewed afterwards. The results showed a vast majority depicting the sun followed by light bulbs or other artificial light sources. There was also a significant shift in the motifs from the sun (younger) to mobile phones or radioactivity (older). Neumann and Hopf were not able to identify clear misconceptions in this first, exploratory study. They discussed the problem of drawing something invisible and the limits of getting concepts from drawings.

In their following study Neumann and Hopf (2012) conducted semi-structured interviews with fifty students (aged between 14 and 16 years). The results were six general conceptions of radiation (radiation is not natural; light is different from radiation; all electrical devices emit harmful radiation; radiation is responsible for many environmental problems; radiation is the same as radiating particles; radiation is emitted by living creatures and helps us detect feelings). Additional they investigated the conception of risk potentials for different types of radiation. The students had to grade different sorts of radiation from dangerous to harmless.

A lot of the mentioned studies dealt with preconceptions and associations linked with radiation. Overall there is a fractured picture of the students' conceptions about radiation. Hence there is a clear gap in the knowledge about students´ conceptions in the field of radiation. Therefore this study will explore this topic further.

Description of the actual study

This study did not investigate students´ conceptions for the whole spectrum of radiation, but instead focused on four specific parts of the electromagnetic radiation (microwaves, infrared radiation, ultraviolet radiation and X-rays). First of all, these are of interest because by focusing on infrared radiation and ultraviolet radiation this study is connectable to the studies from Libarkin et al. (2011) or Rego and Peralta (2006). Second, since ultraviolet radiation and also X-rays are ionizing and therefore more dangerous, it will be interesting to see students' conceptions of these. Third, microwaves were added because of usage in modern communication technology and gamma rays were excluded to avoid the activation of students' conceptions linked to radioactivity. Fourth, the focus on electromagnetic radiation made it possible to define the object of interest. Radiation is hard to define in a general way. A lot of different concepts are mixed into this term, starting at nonionizing radiation and ending at alpha radiation. By focusing on electromagnetic radiation only one concept is used.

This study is comparable to the study of Neumann and Hopf (2012, 2013)and kind of an extension because the concepts under investigation are similar, although the age of the students is different. The shift to older students gives the opportunity to investigate conceptions at the end of their school education and the possibility to compare them to the documented conceptions from Neumann and Hopf. However, the present study will also contribute to a better understanding of the nature of student conceptions because of the analyzing process through grounded theory.

Method

The study is designed as a case study. A group of seven students (aged between 17 and 18) from different schools in Vienna volunteered to work with the researcher for more than a year. As part of their school-leaving exams Austrian students (in upper secondary schools) have to conduct a small research study. The participants chose to investigate topics linked to radiation. In the beginning of the year a semi-structured interview took place. There were several questions about the participants' perceptions of radiation to stimulate different associations with the term "electromagnetic radiation". The students wrote down their associations with the term on paper notes (e.g. Figure 3 or Figure 4). The advantage using those paper notes was the possibility to move and rearrange them. All associations were noted and no term was excluded. These notes were the centerpieces of the second part of the interview. The students were asked to arrange the words in an order that makes sense to them. Afterwards they explained the map to one author. In the third part of the interview the students had to explain different kinds of radiation (UV-radiation, IR-radiation, X-rays, microwaves) in their own words. The mind map was still in front of them and they often referred to it during the interview. The last two questions addressed the conceptions about danger of radiation. In this last part of the interview radio waves, mobile radiation or α, β and γ-radiation were included. The interview guideline can be found at the end of this paper.

The task of arranging the associated terms enabled us to see if the arranged terms fit the correct order from a physical point of view. We expect the students to have knowledge of the spectrum and therefore to order the terms in the sequence of a spectrum. This assumption is valid because the students were interviewed after electromagnetic radiation and spectrum was taught in their physics classes. They should have learned about electromagnetic radiation and the spectrum.

At the end of the year the students had to fulfill the task from the first interview again. Within this year the students worked on their research and wrote the final report. In the second interview they also wrote down their associations and arranged the terms. There were several interesting changes in the arrangements. However, these are not the focus of this paper.

The interviews were coded and analyzed with methods from Grounded Theory (open coding; axial coding; constant comparison) to get well-described categories for the perceptions of the students (Charmaz, 1995; Glaser and Strauss, 1967). Additionally this method enables us to draft a theory for the understanding of radiation in the end. This theory is grounded in the data and valid for this dataset. However, it is a draft and should be tested on other data.

In the beginning two interviews were open coded to get the first codes. These codes were then checked against the other interviews to establish their validity. In addition, the open coding process continued. Next the connections between the codes were investigated further, so that in the end a lot of codes were grouped into categories. Finally, we carefully constructed our theory based on these categories. During the whole coding process the authors worked together. The first author has done the initial coding. These codes were discussed between the two authors. The different categories and the drafting of the theory were accompanied by a group of science education researcher (called Forschungswerkstatt) at the university of Vienna. Following this procedure led to new results, which again needed to be compared to the existing body of literature. This review took place during data analysis and is therefore part of the discussion.

Categories and codes

The following section gives an impression of the process of analysis. As an example the category "radiation is natural" and linked codes will be described. In the first round of the coding process the interviews were coded in a descriptive way. There were a lot of different codes like *"describes phenomenon"*, *"the sun"*, or *"radiation flows"* that are linked with parts of the interview. Every code is directly grounded in the interviews. Taking for example the code "Radiation can be found in the nature" there are statements like

"I think it [radiation] is part of nature." student 1

"I think every radiation occurs in nature" student 2

The translations of the quotes were made from German by the first author. The next step following the grounded theory method was to analyze and rewrite the codes. Simultaneously, we looked for pieces that fit together and created categories. Table 1 displays the codes that lead to the category "**radiation is natural**". Additionally, a second category "**radiation is artificial**" emerged from the codes. When inspecting the categories more closely, a connection between the two categories became visible and the two categories were thus merged to the final core category "**the nature of radiation**".

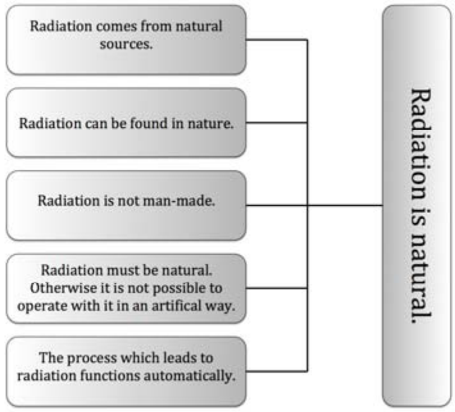

Table 1. Building a category

During the coding it was not clear if there is a definition of the term 'natural' for the researchers. In order to build the category it was not yet necessary to define this term. At this point in the process first pieces of a theory started to form, which is presented in the results sections in its current form.

Findings

The nature of radiation

In most interviews students introduced the question: "Is radiation artificial or natural?" This question was not a part of the interview guideline, but the topic was important for the students in one way or the other. They had great troubles to decide and often couldn´t explain the difference between natural and artificial. Most commonly, the students started their argumentation with a decision for one side (natural or artificial) and then argued using logic strategies depending on the initial assumption. Usually, the argumentation process didn´t stop at this point, as the students often switched to the other side and started their argumentation again. This leads them to a kind of decision-dilemma. On the one hand they argue in a logical, correct way "All radiation is natural". On the other hand they support the argument "Radiation is artificial". During the interviews the students were not capable of solving this dilemma.

The source of this dilemma is the law of the excluded middle. In logic, the law of the excluded middle (or the principle of excluded middle) is the third of the so-called three classic laws of thought. It states that for any proposition, either that proposition is true, or its negation is.Between the characteristics artificial and natural no other trait is possible. A characteristic like "half-artificial" makes no sense within this context. Following this assumption it is clear, that everything must be part of either side.

The category "Radiation is natural." is explained by the students in two slightly different ways. Both have in common, that they are based on the assumption, that everything that comes from nature is natural. The first way refers to the connection between natural radiation and the natural source. Especially the sun is mentioned very often as a source of radiation. Natural sources of radiation exist in nature therefore the radiation emitted is also natural.

„For example, there is a lot of cosmic radiation from space […] and also from the sun, the radiation…" student 3

This argumentation line leads to the problem of defining a natural source and distinguishing it from artificial sources of radiation. An interesting fact is that the definition of a natural source is not clear for the students. This leads to the same problem they had at the beginning. How can you decide between an artificial and a natural source?

The main argument of the second student explanation is that radiation must be natural because physicists were able to discover it. Scientists are not able to invent radiation; therefore all kind of radiation is natural.

"I think that every kind of radiation occurs in nature." student 2

"… everything we have in physics comes from nature" student 2

The second strategy focuses on the assumption "Radiation is artificial". The foundation of this argumentation is the connection between radiation and technical artifacts. Machines that are built are declared as artificial, so the radiation used in the machines or generated by the machines is artificial too. Especially when the topic is microwaves there is a big confusion between the machine and the radiation since the words in German for both are equal.

"I connected every type of radiation with a machine so nothing natural is on that radiation" student 1

"Radiation, which is produced more than it exists in nature like the radiation used by mobile phones." student 4

The students used both lines of argumentation for and against naturalness. In some cases these lines were interwoven and condensed into one sentence.

"…all (radiation) can be generated artificially, but they also occur in nature…" student 1

Overall we assume the existence of an underlying construct (What is the definition of natural?) that is activated by the question "Is radiation artificial or natural?" This concept seems to be deeply rooted in the students´ mind and part of their personal belief system. We assume that this concept acts as a p-prim for the students.

Based on those findings a first theory can be drafted. The understanding of radiation is founded on the understanding for the terms natural und artificial. However, a sound understanding of the two terms cannot be expected from most students. Therefore it is necessary to incorporate a clear definition of those terms into the learning instructions to avoid this difficulty. Understanding the two terms enables the students to think about radiation without questioning the nature of radiation.

Radiation is dangerous

Neumann and Hopf (2012) found some interesting facts in the answers to the question "How do students estimate the risk potential of various kinds of radiation?". The most important fact is that different types of radiation have different levels of harmful potential (see Figure 1). According to their design, it is not possible to order the types of radiation suitable to their level of dangerousness. You cannot compare for example infrared radiation to ultraviolet radiation. It is clear, that more students sense ultraviolet radiation as harmful then infrared radiation. However, it is not possible to rank the different kinds of radiation (i.g. ultraviolet radiation is more harmful than infrared radiation.).

To find a solution to this matter the students were asked to order the different types of radiation from the most to the least harmful. Additionally, they had to put radiation in order from the most to the least useful. Due to this specific task it is possible to rank the different kinds of radiation.

Keeping the question "Is radiation artificial or natural?" in mind, the task of ordering the cards is related to the pair harmful and useful. Again there is a kind of excluded middle. The separation between these two terms is not that strict as it is with the terms natural and artificial. There is a possibility that a radiation can be seen as harmful and also useful in another way. Notwithstanding it is reasonable to suggest the hypothesis, that the order is mirrored: radiation labeled as harmful may be seen as useless and vice versa.

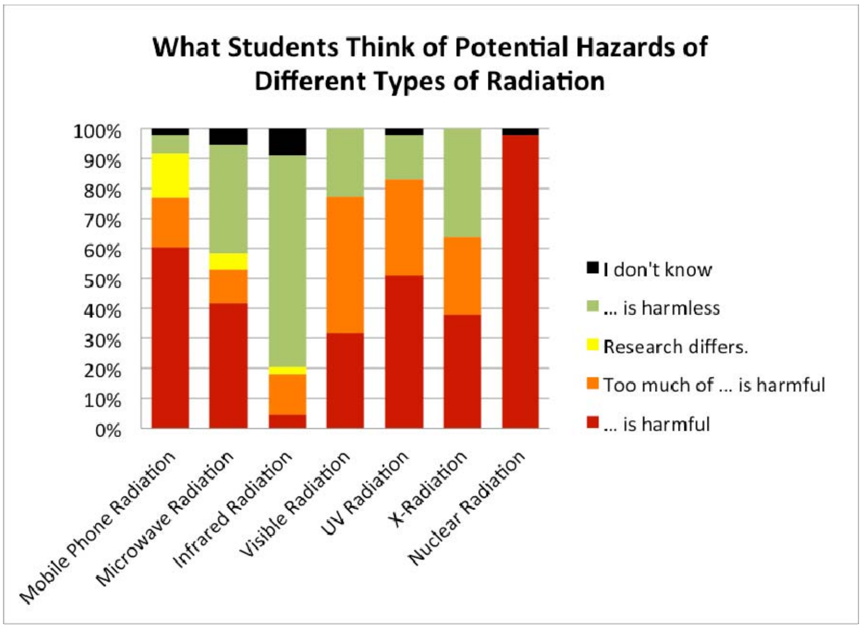

Figure 1. Potential danger of different radiations

The first result to be mentioned is the harmfulness of nuclear radiation (alpha-, beta- and/or gamma-radiation). All students see this type as the most harmful radiation. This result corresponds with previous findings from Neumann and Hopf (2012). They pointed out that nearly 100% of the students in their study classified nuclear radiation as harmful. Our students also classify nuclear radiation as not useful. So for this particular radiation the hypothesis seems true.

The second result is that almost every student ranked UV-radiation and X-rays after nuclear radiation. These two types appear in different order, but are always named as second and third. The students often connect the harmfulness to the possibility of getting cancer when exposed to radiation. Yet, they are not able to explain a mechanism including dose or stochastic reasons. There are clues in the answers pointing to a misconception related to this point.

The third result refers to the way students explain the mechanism of dangerousness. There are different ways the students tried to explain what makes a radiation more or less dangerous. Some students explain hazardousness of radiation in terms of a threshold. The human body has a certain resistance to radiation. There is a threshold that defines the dose of radiation that can be handled by the human body without damage (see Figure 2). In radiology these two models have been vigorously debated in the last years. There are studies in favor of the linear model (e.g. Martin, 2014; Preston, 2008) and others supporting the threshold model (e.g. Hooker et al., 2004; Tubiana, Feinendegen, Yang and Kaminski, 2009). Nevertheless the linear model is widely used in the explanation of the relation between low radiation dose and cancer.

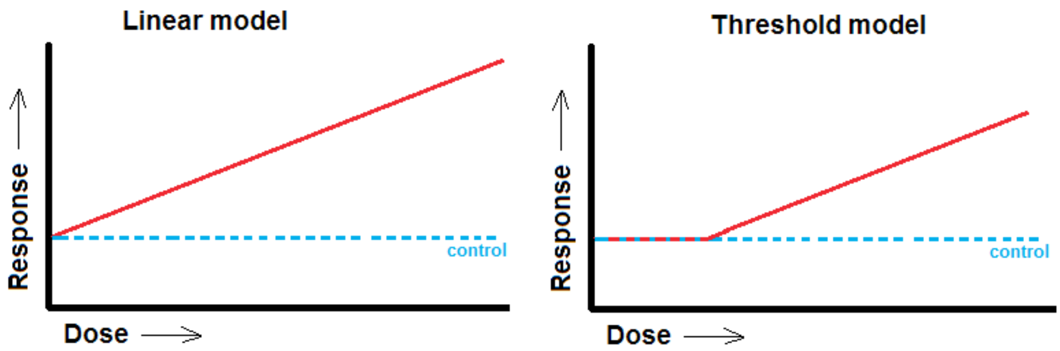

Figure 2. Two models of reaction

Another student argues using the quote from Paracelsus "All things are poisons, for there is nothing without poisonous qualities. It is only the dose which makes a thing poison." (Paracelsus, 1965, p. p. 510) talking about dose and response.

"I mean, the dose makes the poison, clearly,…" student 5

Student 5 argues that ultraviolet radiation is much more dangerous than radiation from wireless LAN. She underpins the argument with the sentence from Paracelsus in the way that we are much more exposed to ultraviolet radiation than wireless LAN. The interesting fact is the word "clearly" at the end of the sentence. For the student it is a fact that the sentence is true for the topics of radiation and hazard. The term clearly also points to a sort of assumed common knowledge. The quote from Paracelsus and its implications are a part of this common knowledge for this particular student.

Another interesting way of argumentation is shown in the following quote.

"[…] there is no proof that mobile radiation influences the human body. Therefore this radiation is harmless." student 2

Student 2 qualifies radiation as harmless, because there is no scientific proof that humans are affected by the radiation. The problem in this quote is, that we do not know, what a scientific proof is for this student. So it is very difficult to qualify, when the student grades a radiation as harmful.

We cannot say that the students perceive harmfulness and usefulness similarly. According to the data the students do not see the most harmful as the most useless radiation. One student argues that

"X-Rays are in my opinion the most useful radiation. […] it is a pity, that they are so harmful for the body." student 6

Student 6 also states that harmful radiation is radiation with high energy. The student is able to identify the energy of the radiation as the key component for harmfulness. In Figure 3 we see the picture taken at this interview. On the top student 2 listed radioactivity, x-rays and gamma rays, the types of radiation with the most energy. It is interesting, that this student splits the energy level of nuclear radiation. The energy level of alpha radiation is in his opinion as low as the level of infrared radiation.

In comparison to the rather complex analysis of danger in Figure 3, Figure 4 shows a more simplistic model provided by student 7. All types of radiation except nuclear radiation, x-rays and ultraviolet radiation were put at the same level of danger. Student 7 showed no concept of energy connected to radiation.

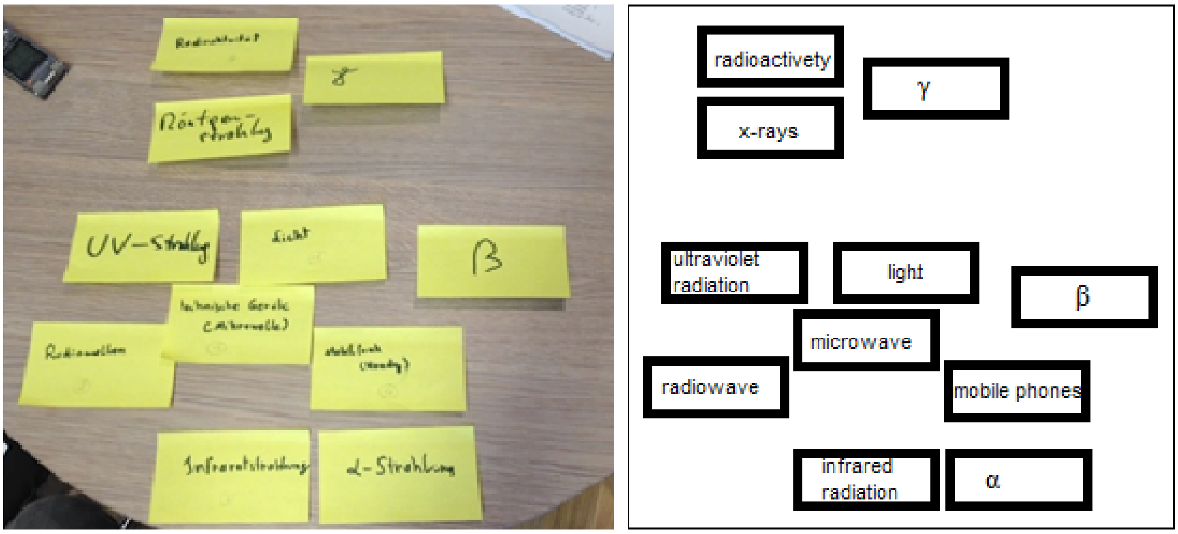

Figure 3. Order of danger by student 2

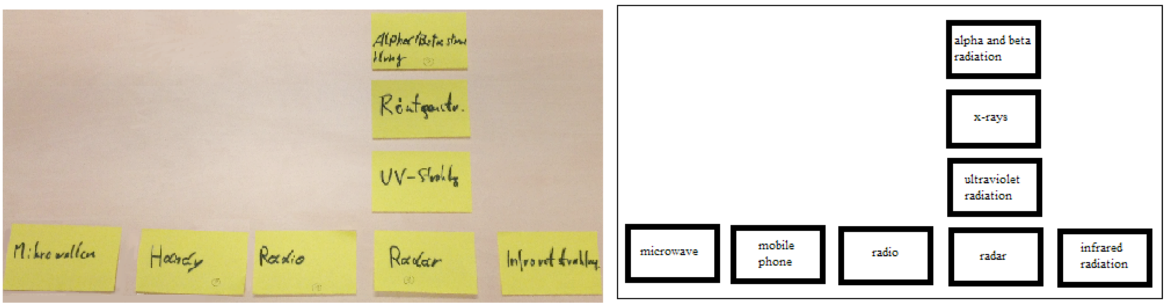

Figure 4. Order of danger by student 7

Based on these results we are able to draft some conclusions. Most students classify nuclear radiation, X-rays and ultraviolet radiation as dangerous. They connect the danger of those radiations to the high possibility of getting cancer. The mechanism why some kinds of radiation are more dangerous than others is not clear. The students talk about dose and a threshold, but also about energy. A big variation and complexity seems to be in this construct.

Discussion

The term natural

The results concerning "The nature of radiation" raised the question whether the students have a clear concept of the term 'natural' or 'nature'. Therefore we searched for studies that focus on the term natural or nature and the perception of those terms by students. Turning to the existing literature we found some helpful studies to answer this question.

First of all the term 'natural' or 'nature' is not easy to define. Schramme (2002) describes five different dimensions for the term ‚natural'. Two are relevant in the context of radiation. The first dimension is related to a biological conception. In this logical construct everything is natural. Phenomena like water running up the hill are classified as supernatural. There is no artificiality in this dimension. In a second dimension he distinguishes between natural and artificial, classifying artificial objects as made by humans. In other words, a garden is not natural, because human beings transformed it in a cultural way. Other dimensions lead for example to a cultural context. Most students in our study argue in the second dimension. Although, the border between human and nature are not equal for al the students.

Second there are studies investigating students' associations to the word ‘nature’. The results vary with the age of the students. Children (n=23) between 7 and 9 years refer to the living world around human beings (Meske, 2011). Meske mentions that children have difficulties deciding whether humans are part of nature. There are three different points of view (Humans belong to nature; humans are part of nature; humans don’t belong to nature) documented in the study.

Margadant-van Arcken (1997) found adolescents (aged 13 to 18) in her study had a limited picture of what nature is: “Nature is the living, untouched and self-regulated nature without human beings.”. Trommer (1990) conducted a study with adults (n=98), which partly yielded similar results (nature is without human beings), but also provided different findings (nonliving things such as mountains are mentioned less). Wenzel and Gerhardt (1998) also found a separation between nature and human beings and no links to scientific knowledge. In addition, the participants often connected positive feelings with the term nature.

DiYanni and Kelemen (2005) tried to understand why and how children distinguish between artificial and natural. They found that young children (aged 5-6) do not make a difference between artificial and natural things by function. Young children respond to the question “would you get it fixed/repaired?” when things cannot fulfill their purpose with “yes”. That was surprising because the children labeled natural phenomena like clouds or mountains also as repairable.

All of these studies deal with the terms ‘nature’, ‘natural’ or ‘artificial’ in a more or less biological context. In the context of physics little is known about those concepts. Only Watts and Taber (1996) framed the term ‘natural’ in a physical context. They defined it in the following way:

> “`It´s natural´ is a term used in many contexts so that, in some cases, it has a quality of being `obviously-the-case´ (the natural state of affairs), and of the `essence of things´ (a natural tendency).”
> (Watts and Taber, 1996, p. p. 940)

In their article they show, that the term “It´s natural” is used by students as a final justification and synonymous to the term “It´s common knowledge and needs no further explanation.” They close their article with the sentence: “…, there is considerably more work to be done.” (p. p. 952). Looking at the results above, the question is which conclusions can be drawn.

The question if radiation is artificial or natural is not important in the world of physics; thus, it may be concluded the result is worthless from a professional physicist point of view. Keeping however in mind that students constantly struggle with this question we propose that teaching radiation, as a topic should avoid this problem. Teachers often introduce radiation in the context of technical things. They assume the topic is interesting for students when it is linked to their everyday life. This focus on technology leads to the problem of understanding. Most students struggle with ideas such as “The flower is a source of radiation.” or “There is a great amount of radiation that surrounds us.”, because they connect radiation only with machines or other technical equipment. The theory drafted above has to be included in teaching instructions to test the validity of the theory.

The Danger of Radiation

Comparing the results for the second question concerning harmfulness to previous findings we can assume that there is a good understanding that nuclear radiation is dangerous for the human body. This prediction is found in student drawings from 4-th to 6-th grade (Neumann and Hopf, 2013), in the interviews with students from 9-th grade (Neumann and Hopf, 2012) and in the recent study with 11-th grade students. It seems clear, that the danger of nuclear radiation is taught at various occasions during education. An interesting fact is the link between danger and the cause of cancer that emerged in this study. This link is new, has not been documented yet and is a little obvious. But there is no good or reliable explanation for this link in the analyzed data and we cannot claim that we know, if it is the only explanation for this concept of danger. In further studies this will be a point to investigate.

The evaluation whether radiation is dangerous or not, is highly contextual. From an experts point of view there are some obvious facts. Ionizing radiation contains more energy per photon than non ionizing radiation. Hence ionizing radiation has a bigger potential to create damage in human cells.

As a physicist one can compute the numbers and label the different parts of the spectrum as more or less dangerous. You also understand the stochastic process determining the potential to create cancer. Looking at the same situation from a non-expert point of view, the evaluation is based on the context. If the context is medical (X-rays, radiation therapy…) most people underestimate the risk and the danger of the used form of radiation. The patient is able to identify the need of the medical treatment despite the risk that comes along with it and values this as needed more. On the other hand there are a lot of theories about mobile radiation and the possible risks that are referenced by students (Plotz, 2016). There are thousands of homepages, so called experts and scientific questionable studies trying to find a proof for the risk to the human body when being exposed to non-ionizing radiation. However, there is no clear indication if there is a link between those non-ionized radiations (microwaves) and the risk to get cancer.

Neumann and Hopf investigated the potential hazards of different types of radiation. Due to their design it is hard to compare the hazardousness of different types. In the findings of our study this comparison is now possible. We see similarities (e.g. the danger of nuclear radiation) in the results and differences (e.g. the structure of hazardousness for different types of radiation). Overall the conception of danger is more complex than we thought. In the results we see different pieces of the construct, but there are a lot of missing links between them.

The limitations of the study are obvious. The small sample prohibits a generalization of the results. Notwithstanding the found conceptions are worth to be investigated further. Due to the results it is possible to design and construct a questionnaire to validate the results in a further study.

Keeping this limitation in mind, it is possible to make some implications for teaching about radiation based on the results of this study. According to our results it could be better to introduce the topic with sources of radiation that are classified as natural (e.g. sun; cosmic radiation or animals as source of infrared radiation) and not with technical applications. This may avoid the natural/artificial dilemma mentioned above. The difficulty in the decision between artificial and natural may be a very basic problem in various topics. To investigate these connections further studies ought to be conducted. Looking to the discussion of the danger of radiation, teachers should mention and explain the relation between radiation and cancer. Two points are important: First to clarify the link between the energy of the radiation and the effect on humans and second to explain the concept of dose to the students. It is clear to us, that there is a need to find a place in the curriculum to tie the knowledge about electromagnetic radiation together. It will be easier for the students to understand the topic, when they get a brief overview to link the separate parts of the spectrum. Overall, conceptions of radiation are not fully explored, thus a lot of future work is required.

References

Aufschnaiter, C. v., and Rogge, C. (2015). Conceptual Change in Learning. In R. Gunstone (Ed.), Encyclopedia of Science Education (pp. 209–218). Dordrecht; Heidelberg; New Yorl; London: Springer Netherlands.

Charmaz, K. (1995). Grounded Theory. In J. A. Smith, R. Harré, and L. van Langenhove (Eds.), Rethinking methods in psychology (pp. 27–49): Sage.

Chi, M. T. H. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science.

Chi, M. T. H., and Slotta, J. D. (1993). The Ontological Coherence of Intuitive Physics. *Cognition and Instruction*, **10**(2/3), p 249-260.

di Sessa, A., Gillespie, N., and Esterly, J. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science*, **28**(6), 843–900. doi:10.1016/j.cogsci.2004.05.003

diSessa, A. A. (2002). Why “conceptual ecology” is a good idea. In M. Limón and L. Mason (Eds.), Reconsidering conceptual change (pp. 28–60). Dordrecht; Boston: Kluwer Academic Publishers.

diSessa, A. A. (2008). A bird's-eye view of the "pieces" vs. "coherence" controversy (from the "pieces" side of the fence). In S. Vosniadou (Ed.), International handbook of research on conceptual change (pp. 35–60). New York: Routledge.

DiYanni, C., and Kelemen, D. (2005). Time to get a new mountain? The role of function in children's conceptions of natural kinds. *Cognition*, **97**(3), 327–335. doi:10.1016/j.cognition.2004.10.002

Duit, R. (2009). Bibliography - Students' Alternative Frameworks and Science Education.

Duit, R., Gropengießer, H., and Kattmann, U. (2005). Towards science education research that is relevant for improving practice: The model of educational reconstruction. *Developing standards in research on science education*, 1-9.

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., and Parchmann, I. (2012). The Model of Educational Reconstruction–a Framework for Improving Teaching and Learning Science*Science education research and practice in Europe* (pp. 13-37): Springer.

Duit, R. and Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education,* **25**(6), 671-688.

Duit, R. and Treagust, D. F. (2012). Conceptual change: Still a powerful framework for improving the practice of science instruction. In K. C. T. Tan and M. Kim (Eds.), Issues and Challenges in Science Education Research (pp. 43–54). Heidelberg: Springer.

Duit, R., Treagust, D. F., and Widodo, A. (2008). Teaching science for conceptual change: Theory and practice. *International handbook of research on conceptual change*, 629–646.

Eijkelhof, H. M. C., Klaassen, C. W. J. M., Lijnse, P. L., and Scholte, R. L. J. (1990). Perceived incidence and importance of lay-ideas on ionizing radiation: Results of a delphi-study among radiation-experts. *Science Education,* **74**(2), 183–195. doi:10.1002/sce.3730740205

Glaser, B. and Strauss, A. (1967). *The discovery of grounded theory.* London: Weidenfeld and Nicholson.

Hooker, A. M., Bhat, M., Day, T. K., Lane, J. M., Swinburne, S. J., Morley, A. A., and Sykes, P. J. (2004). The linear no-threshold model does not hold for low-dose ionizing radiation. *Radiation research,* **162**(4), 447-452.

Libarkin, J. C., Asghar, A., Crockett, C., and Sadler, P. (2011). Invisible Misconceptions: Student Understanding of Ultraviolet and Infrared Radiation. *Astronomy Education Review,* **10**(1), 10105. doi:10.3847/aer2011022

Lijnse, P. L., Eijkelhof, H. M. C., Klaassen, C. W. J. M., and Scholte, R. L. J. (1990). Pupils' and mass-media ideas about radioactivity. *International Journal of Science Education,* **12**(1), 67–78. doi:10.1080/0950069900120106

Margadant-van Arcken, M. (1997). Nationalparkpädagogik aus erster Hand. Naturbilder, Erlebnisse und Lernwünsche 13-bis 18-jähriger Jugendlicher. *Arge Umwelterziehung: Bildungspanorama Nationalparke. Wien*, 47–52.

Martin, C. (2014). The LNT model provides the best approach for practical implementation of radiation protection. *The British journal of radiology*.

Meske, M. (2011). *Natur ist für mich die Welt.Lebensweltlich geprägte Naturbilder von Kindern.* Germany: VS Verlag für Sozialwissenschaften.

Millar, R. (1994). School students' understanding of key ideas about radioactivity and ionizing radiation. *Public Understanding of Science, 3*(1), 53–70. doi:10.1088/0963-6625/3/1/004

Millar, R. and Gill, J. S. (1996). School students' understanding of processes involving radioactive substances and ionizing radiation. *Physics Education,* **31**(1), 27–33.

Neumann, S. and Hopf, M. (2011). Was verbinden Schülerinnen und Schüler mit dem Begriff 'Strahlung'. *Zeitschrift für Didaktik der Naturwissenschaften,* **17**, 157–176.

Neumann, S. and Hopf, M. (2012). Students' Conceptions About 'Radiation': Results from an Explorative Interview Study of 9th Grade Students. *Journal of Science Education and Technology,* **21**(6), 826–834. doi:10.1007/s10956-012-9369-9

Neumann, S. and Hopf, M. (2013). Children's Drawings About "Radiation"—Before and After Fukushima. *Research in Science Education*, **43**(4), 1535–1549. doi:10.1007/s11165-012-9320-3

Paracelsus, T. (1965). Die dritte Defension wegen des Schreibens der neuen Rezepte. *Septem Defensiones 1538.* (Vol. Werke). Darmstadt.

Parnafes, O., Hammer, D., Louca, L., Sherin, B., Lee, V., Krakowski, M., . . . Edelson, D. (2008). How to study learning processes? Reflection on methods for fine-grain data analysis. Paper presented at the Proceedings of the 8th international conference on International conference for the learning sciences-Volume 3.

Plotz, T. (2016). Handystrahlung. Wie gefährlich ist die jetzt wirklich?: Evidenzen und Interpretationen. *Praxis der Naturwissenschaften - Physik in der Schule,* **65**(2).

Preston, R. J. (2008). Update on linear non-threshold dose-response model and implications for diagnostic radiology procedures. *Health physics,* **95**(5), 541-546.

Rego, F., and Peralta, L. (2006). Portuguese students' knowledge of radiation physics. *Physics Education,* **41**(3), 259–262.

Schramme, T. (2002). Natürlichkeit Als Wert. *Analyse and Kritik,* **24**(2002), 249–271.

Sesen, B. A., and Ince, E. (2010). Internet as A Source of Misconception:"Radiation and Radioactivity,". *TOJET,* **9**(4).

Strike, K. A. and Posner, G. J. (1982). Conceptual change and science teaching. *European Journal of Science Education,* **4**(3), 231–240.

Trommer, G. (1990). *Natur im Kopf: die Geschichte ökologisch bedeutsamer Naturvorstellungen in deutschen Bildungskonzepten*. Weinheim: Deutscher Studien Verlag.

Tubiana, M., Feinendegen, L. E., Yang, C. and Kaminski, J. M. (2009). The linear no-threshold relationship is inconsistent with radiation biologic and experimental data 1. *Radiology,* **251**(1), 13-22.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction,* **4**(1), 45-69.

Vosniadou, S. (Ed.) (2008). *International handbook of research on conceptual change*. New York: Routledge.

Vosniadou, S., Pagondiotis, C. and Deliyianni, M. (2005). From the Pragmatics of Classification Systems to the Metaphysics of Concepts. *Journal of the Learning Sciences,* **14**(1), 115–125. doi:10.1207/s15327809jls1401_6

Vosniadou, S., and Skopeliti, I. (2013). Conceptual Change from the Framework Theory Side of the Fence. *Science & Education,* **23**(7), 1427-1445. doi:10.1007/s11191-013-9640-3

Vosniadou, S., Vamvakoussi, X., and Skopeliti, I. (2008). The framework theory approach to the problem of conceptual change. In S. Vosniadou (Ed.), International handbook of research on conceptual change. New York: Routledge.

Watts, M., and Taber, K. S. (1996). An explanatory gestalt of essence: students' conceptions of the 'natural'in physical phenomena. *International Journal of Science Education,* **18**(8), 939–954.

Wenzel, E., and Gerhardt, A. (1998). Empirische Untersuchungen an Schülern und Studenten über ihr Naturbewußtsein und ihr Grundlagenwissen zur Thematik "Ökosystem Stadt". *Zeitschrift für Didaktik der Naturwissenschaften*, **3**, 75–85.

Appendix

Interview Guideline

1.) Can you tell me everything you associate with the term electromagnetic radiation?
2.) Please bring the note in an order. The order should fit your perception.
3.) If they talked about the sun, they were asked how the sun is connected to the term radiation.
4.) Can you tell me something, you know about UV-radiation (IR-radiation, X-rays, microwaves)? Try to explain this radiation to your little brother/sister.
5.) Can you describe situations where radiation is useful for you?
6.) Can you describe situations where radiation is harmful for you?