

Context Dependence of Physics Students' Responses to the Term "Radiation"

University of Cape Town



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Mpeli Takane
November 2014

Abstract

For the public to be able to participate meaningfully in debates regarding issues that are related to science and technology it is important that they are properly informed and that their sources of information are reliable. One source of such information are university science students and it is therefore interesting to find out what their views are regarding various scientific concepts. For example such an area of interest is that of using nuclear power for electricity generation, in particular the dangers associated with radiation. A reasonably correct view of radiation would be seen as an important part of having a meaningful debate. The present study aims to find out the views that a group of university students who are studying physics hold about radiation, in particular their immediate response to being asked to clarify what the term radiation means. However, the notion that students simply have conceptions that are unitary and static has been challenged by several Physics Education Researchers. Instead a view summarised as “knowledge in pieces” has been proposed in which it is suggested that much smaller units of ideas are brought together dynamically depending on the situation at hand and that context plays an important role in how students respond to questions. Thus, the thesis explores to what extent context plays a role in their responses by preceding the question with four different scenarios which are suggested as the contexts in which the question is being asked.

In summary, the guiding questions for the present work are: (1) What do students understand by the term radiation and (2) To what extent do student response patterns depend on “textual priming”. The thesis is divided into two parts (1) a pilot study in which the methodology is established and (2) a follow up study (main study) in which the effect of textual priming on the responses is explored.

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1 Introduction

At present moment South Africa is planning to increase their nuclear power production by building more nuclear power stations. Like any other citizens in the world South Africans have different opinions on the building of nuclear power stations. In 2011 Japan was hit by the earthquake, which resulted in the destruction of the Fukushima Daiichi nuclear power station. This incident served to heighten public interest around the issues of radiation and radioactivity. The debate around radiation is often heated if one looks at articles and letters in the newspaper for example. However, for the debate to be meaningful it is necessary that the public are informed correctly about the issues.

University students are well placed to assist the general public with such information and physics students should in principle be able to help with both the terminology and concepts involving radiation and radioactivity. However, in the area of physics education research not much work has been done on students' understanding of radiation as compared to other physics topics. As noted by Millar et al. (1990) that “ Compared with some other science topics, relatively little research has been carried out on children's ideas about radiation and radioactivity”. Similarly McDermott & Redish (1999) provided statistics on the number of published papers per physics topic, *Mechanics (56)*, *Electricity and Magnetism (20)*, *Light and Optics (15)*, *Properties of matter, fluid mechanics and thermal physics (14)*, *Waves and sound (06)*, and *Topics in modern physics (04)* where there is only one published paper in radiation out of the four in the *Topics in modern physics* which is; “*School students' understanding of processes involving radioactive substance and ionising radiation,*” Millar & Gill (1996). A recent search on the www.compadre.org is indicative of this trend in that fewer than 10 relevant papers are listed when searching for terms “radiation and radioactivity”.

1.1 Radiation

For the purposes of discussion in the thesis I provide a brief account of radiation as it is understood by physicists. From Shapiro (1990) we found that radiation can be described as the process in which energy is transferred from one point to another through electromagnetic waves or sub-atomic particles. In electromagnetic radiation energy is spread out as the wave

travels through a medium or space. Electromagnetic radiation can come in the form of any part of the electromagnetic spectrum such as radio waves, microwaves, infra-red, visible light, ultraviolet, X-rays and gamma rays. Sub-atomic particles consist of both charged and neutral particles. Commonly known charged particles are beta and alpha particles while neutral particles are neutrons. Radiation can be found from the natural and man-made sources. Natural sources include cosmic radiation, the solar wind and natural background radiation while man-made sources range from medical x-rays to radiation associated with nuclear power production.

1.2 Understanding of radiation by the public

With regard to public understanding Brown & White (1987) carried out two studies in which they asked the members of the public to define what they meant by the terms radiation and radioactive waste. Of the 223 respondents from their 1984 survey, 7% failed to give any definition of radiation, 18% gave the definition that was coded as accurate by the experts, 37% showed awareness in their responses, while 36% gave responses that were coded as inaccurate. Responses in the latter group included ideas such as, “radiation is light that burns”, and “radiation is poison”. In summary 40 people out of the sample of 223 respondents provided a definition of radiation that was regarded as accurate by experts.

In 2004 Miller published a paper on Public Understanding of various scientific concepts in the United States of America. Among some of the scientific concepts on which Miller did his research on were radiation, plate tectonics, and antibiotics. The graph in Figure 1 shows some of his findings for the years 1988-1999. For example, he found that more than 70% of his samples had an understanding of Plate tectonics which is shown by the graph connecting the solid diamonds. Another example is that of antibiotics, where the graph shows a steady increase from 25% understanding in 1988 to 45% in 1999. But the situation is very different when it comes to radiation where the percentage of people who understood radiation remained steady at low level of 10%.

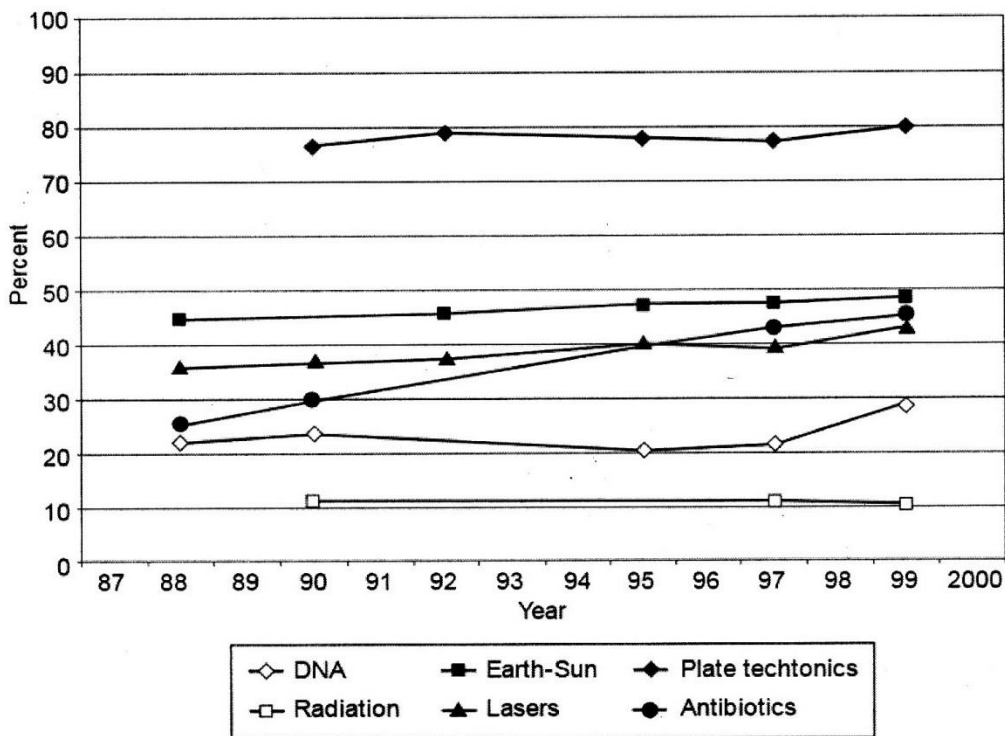


Figure 1 Miller's results on Public understanding of certain scientific concepts

1.3 Understanding of radiation by students

In the same study that was undertaken by Brown & White (1987) there was also another survey that was done in June 1984 on 252 high school students aged between 11 and 16. This group was asked to give the definition of radiation, 21% (which is regarded as highest) of this group gave definitions that were associated with the nuclear weapons; 4% said radiation “makes your hair fall out”; 5% “it gives you radiation sickness”; 16% indicated that “its something that kills you”; 9% thought it was something dangerous but did not really know what it is; 8% defined it as a gas; 13% related radiation to the sun and other natural phenomena; and 10% gave an approximate physics definition of radiation. And most students’ definitions includes things like; “it makes you ill, you lose your hair and throw up”, “it is very hot light that when it gets to you it can kill you”; if you have radiation you might die in a month or two” Brown & White (1987). From this study we can see that it is only 25 students out of 252 who managed to give the response that was considered as an approximate physics definition which then show us that majority of the students in this group did not have “the right” physics definition of radiation but rather still had the same theories and ideas of radiation as the “non-scientists” members of the public Brown & White (1987).

E.K.Henriksen (1996) reported on a survey in which he investigated the “*understanding of radiation phenomena and risk among Norwegians with a reasonable level of general education, but lacking specialisation in physical science*”. The survey was also administered to a group of 270 first year physics students at the University of Oslo. This survey was administered in the form of a questionnaire which was made up of 13 questions, for which 7 of them were testing the “understanding of radioactivity and radiation, and 4 were designed to give information about radiation fear and attitudes” E.K.Henriksen (1996). For the purpose of this study, we will only focus on some of the findings not on all the findings in the survey, E.K.Henriksen (1996) found that “89% of the respondents knew of the three radiation types alpha, beta and gamma, whereas only 34% could correctly state what the radiation is consisted of in each case”. The notion of “absorption of radiation” was also tested in the survey by asking a question regarding the effect of radiation on spice (to kill bacteria). According to the findings of this survey, this question appeared to be difficult as only 55% of the respondents managed to attempt it. “10% of the respondents answered that question by saying, ‘the radiation is taken up by the spice’, and some of these added that the radiation was ‘stored’ in the spice, which gave reason to suspect that they really meant that the spice became radioactive. 12% said explicitly that the radiation made the spice radioactive” E.K.Henriksen (1996).

None of the studies mentioned tried to understand how students had come about their ideas.

Prather (2000) in his thesis titled, “*Investigation into what students think and how they learn about ionising radiation and radioactivity*”, focused on, “(1) the identification of common conceptual and reasoning difficulties that college students have prior to instruction, (2) the development of a framework for understanding the source of these difficulties, and (3) the development of specific instructional strategies and materials to target these difficulties”. In order to achieve these aims, they then “investigated student understanding of radiation sources, the process of irradiation and contamination, the nature of atoms in the radioactive decay process, and radioactive half-life”. The research on students’ understanding of radiation and radioactive is not only for the purposes of increasing numbers in science education research publications, but it is also of public importance in terms of radiation and radioactivity awareness. “Research on students’ understanding of radiation and radioactivity has a tremendous pragmatic value on society” Prather (2000). There are some applications of technology that use ionizing radiation and radioactive materials; these include applications in

medical diagnostic equipment and treatment, electric power generation, and industrial. Apart from the usefulness of radiation in the above mentioned applications, and in other applications not mentioned here, these topics of radiation and radioactivity “are often featured in the media and are typically surrounded by controversy and public debate” Prather (2000).

A study titled, “*Radiation risk and science education*”, which was undertaken by Eijkelhof (1996), in which he focused on finding whether the common approach of teaching the topic of radioactivity would contribute to a better understanding of the risks of ionising radiation; and if the answer is negative, how to explain and improve this situation. In his study, the assumption was made, that the answer on teaching of radioactivity and its effects on understanding of the risks of ionising radiation cannot be given by one single study, and most importantly the knowledge and experience of radiation experts should be used as the bases to improve teaching and learning. But for the purposes of our study, we will only focus on students’ ideas about radioactivity, ionising radiation, and risks in the context of Chernobyl, medical use of radiation, radioactive waste disposal, food irradiation and background radiation. In his study, Eijkelhof (1996) interviewed among his sample the secondary Dutch students and this is the sample of which we are most interested in. Even though the numbers or statistics of the interviewed students were not given, we will only concentrate on the findings. In the interview that was administered to students, among the findings that were recorded was on the meanings of the following terms, radiation, contamination, radiation standards, and radioactivity, and according to Eijkelhof (1996) students gave the meanings that differs from the ones that are scientifically accepted. From these terms, we want to highlight “radiation”, according to these findings as outlined by Eijkelhof (1996) it shows that the interviewed Dutch secondary students were unable to give scientifically accepted meaning of radiation.

1.4 Focus and approach of the present work

The present study focusses on student understanding of radiation at its most basic level, namely, the response to the question, “What is radiation?” However, it has become clear that students do not necessarily “have” one fixed notion regarding a particular concept and that many contextual factors could influence student response. For example Allie et al. (2008) have noted that simply changing the purported audience has a large effect on the sense-

making aspect of an explanation. Thus, it suggested that a term like radiation which often has an emotional aspect could also similarly be affected by context. If this is indeed the case then it is possible that a term such as radiation which has been noted above often engenders emotional responses could in fact be even more so. The approach that will be followed in the present work is therefore based around the notion that students do not have simple fixed unitary mental constructs for complex ideas but that “in the moment explanation” are expressed as a response not only to the question but to one or more contextual factors. In the following section a brief description of a “knowledge in pieces” perspective is presented.

1.4.1 “Knowledge in pieces” and context

According to Smith et al. (1993) there is a strong historical strand of research into student reasoning which had been modelled in terms of conceptions (or misconceptions). Conceptions are viewed as stable, unitary coherent structures that are present in the students’ minds. Incorrect conceptions, namely misconceptions present obstacles to instruction and need to be “rooted out” Clement (1982). Smith et al. (1993) however they argue that this way of dealing with student ideas goes against constructive notions of learning. A similar view is noted by Driver et al. (1985) in which they problematize the nature of student ideas in terms of conceptions which take many factors into account rather than simply labelling the students as having misconceptions. The view that ideas are constructed in the moment based on context and experience rather than as present as large constructs is often termed the “knowledge in pieces” perspective Scherr (2006). This theoretical framework was suggested and elaborated on in detail by DiSessa (1993) in his paper “*Towards an Epistemology of Physics*”. In this view DiSessa (1993) described larger ideas as consisting of smaller fine grained ideas which he called phenomenological primitives (p-prims) were used as the basis of student ideas. Thus for example the table below shows some of the p-prims that DiSessa (1988) noted in his paper. Table 1 shows a list of p-prims together with Key Attributes that, in part, define them, and a Prototypical Circumstances from which the p-prim might be abstracted and to which it applies as taken from DiSessa (1988).

Table 1 some examples of p-prims

<i>Name</i>	<i>Key Attribute</i>	<i>Prototypical Circumstances</i>
Ohm's Law	Agency (also "resistance")	Pushing a box with variable effort on different surfaces
Force as a mover	Violence	A throw
Continuous force	Steady effort	A car engine propelling a car
Dying away	Fading amplitude	Sound of a struck bell
Dynamic balance	Conflict	Equal and opposite competing forces
Overcoming	"Success"	Greater force overcomes weaker

The knowledge in pieces perspective was further broadened to include other "cognitive resources" or simply "resources". Thus resources also included reasoning primitives and epistemic resources that were activated during a situation or to solve the problem in question. "For example, if students are asked why it is hotter in summer than winter, the question may activate for them a p-prim connecting proximity and intensity: *Closer means stronger*. This p-prim is an abstraction by which one may understand a range of phenomena" Hammer (1996). Thus misconceptions for example were not fixed properties that could be attributed to the student's mind but that the resources that were activated were not appropriate for a particular situation. In other circumstances however the activation could be appropriate. One important aspect of this perspective was to try and distinguish carefully between what was observed and what was inferred. Thus, for example in her paper on "*Modeling student thinking: An example from special relativity*" Scherr (2006) notes that, "I characterize student ideas in terms of five observable properties; determinacy, coherence, context-dependence, variability, and malleability and describe how those observable properties correspond to the "misconception" and "pieces" models of student reasoning". But Scherr (2006) further states that, "more recently, some researchers have proposed a model of student thinking in which student ideas are made up of flexibly combinable "knowledge pieces" that can be activated independently or in networks and whose activation may change depending on the situation".

“Research in cognitive science provides an alternative ontology of multiple, fine-grained cognitive resources that are context sensitive in their activation” Hammer (2004). It is clear that the idea of context plays an important role in the “knowledge in pieces” perspective. The question thus arises as to what is meant by context. This turns out to be a difficult concept as can be seen from the discussion that follows.

From a linguistics point of view context is said to have “several overlapping dimensions; physical, cultural, social, and linguistic. It can also be understood in either a narrow or a broader sense” Langacker (2008). He then uses the following instance; “suppose you yell *The cat is on the mat!* in order to warn me that my beloved Siamese is climbing the valuable decorative mat mounted on my study wall.” For this person yelling who is in the study room, “the physical context includes the actual scene described, where the cat is clinging on the mat with its claws” while on the other hand to the owner of the house and the cat who is on the other room, “this scene is not part of the context”. While the use of *the cat* as opposed to *a cat* shows the cultural context where it shows that person yelling is aware of the pet culture, he or she is not treating a cat as a stranger to be found in the house. In the social context, in as much as socially is not a common practice to yell while visiting, but emergency calls for yelling Langacker (2008).

According to Corbin & Strauss (2008) “Context is the structural conditions that shape the nature of situations, circumstances, or problems to which individuals respond by means of action or interaction or emotions. Contextual conditions range from the most macro to the micro”. Context does the following; “it identifies the sets of conditions in which problems and or situations arise and to which persons respond through some form of action or interaction and emotion (process), and in doing so it brings about consequences that in turn might go back to impact upon conditions but does not determine experience or set the course of action” Corbin & Strauss (2008).

Cole (1996) under the heading “*Context That Which Surrounds*” states that “context is defined as “the whole situation, background, or environment relevant to a particular event”, and “environment” is defined as “something that surrounds.” “The whole situation” and “that surrounds” are mixed together in the same definition”.

In our present work the focus may be thought of as being at a micro-level, namely, the textual surroundings of a written question. The effects of such linguistic context were explored for

example by Tabossi & Johnson-Laird (1980) in a paper “*Linguistic context and the priming of semantic information*”. In the experiments in which Tabossi & Johnson-Laird (1980) carried out they demonstrated that linguistic context (in the form of a sentence) influences the interpretation of unambiguous words as well as priming ideas. “Semantic priming is known to affect the identification of words and the disambiguation; the present study confirms that it also affects the specific interpretation of words” Tabossi & Johnson-Laird (1980). The present work is directly related to the notion that text primes ideas. However, while the instances discussed indicate that such ideas give rise to meaning (interpretation) the effect of priming on the response (synthesis) will be explored.

Based on the notion of knowledge in pieces and that context therefore plays an important role in conceptual construction the present work aims to explore to what extent, if any, responses are sensitive to “textual priming”. The term textual priming is used in the thesis to mean that passages of text are used to depict scenarios that precede the question. From a misconceptions view this should have little or no effect on the responses while knowledge in pieces perspective would appear to indicate that preceding purported scenarios will play a role.

The guiding questions for the present work are:

- (1) What do students understand by the term radiation and
- (2) To what extent do student responses patterns depend on textual priming

The thesis is divided into two parts (1) a pilot study in which the methodology is established and (2) a follow up study (Main Study) in which the effect of textual priming on the responses is explored.

2 Pilot study

In order to establish the methodology that would be used in the main study a pilot study was undertaken. This involved adding a question on radiation to an instrument that was being developed to study student responses to a number of issues in a first year astronomy course at UCT, Introductory Astronomy (AST1001). The instrument in question, the Introductory Astronomy Questionnaire (IAQ), probed students' ideas regarding motivation, beliefs and prior knowledge relevant to astronomy. The question on radiation thus fitted well into the IAQ as part of probing prior knowledge. In general the students in the AST1001 course tend to be more diverse than is usually the case in first year science courses at UCT. One reason for this is that Astronomy is often taken out of interest by students from outside the Science Faculty in addition to those who intend to major in Astronomy.

2.1 Developing a probe

The radiation question was composed following the structure discussed in the paper by Allie et al. (1998) in which the question is presented as a debate between different views on some topic. The respondents are then requested to choose one of the sides presented and then, most importantly, to explain carefully the reasoning for making this choice. It should be noted that, while the original form of the questions in the paper by Allie et al. (1997) used cartoon figures, it was felt that this aspect would not affect the responses. The question that was used in the pilot study was placed at number 6 out of a total of 9 questions. Figure 2 shows the question that was developed for probing radiation.

A group of students is having an argument about radiation.

Student A: “Radiation is a form of electromagnetic waves.”

Student B: “No! Radiation consists of nuclear particles.”

Student C: “I don’t agree with either of you.”

With whom do you mostly agree: student A, B, or C? (Circle only one letter.)

A	B	C
----------	----------	----------

Explain in detail why you chose this option.

Figure 2 Pilot Probe

As can be seen the question suggested that radiation comprises either electromagnetic waves (option A) or nuclear particles (option B) while a third option (C) for all other ideas including a combination A and B to be expressed. As noted earlier the most important part of the probe was the written response that follows the answer choice.

2.2 Student Cohort

The instrument was administered to the total of 79 students undertaking Introductory Astronomy (AST1001) course. The cohort was fairly diverse in terms of their backgrounds and intended career directions as can be seen from Table 2 below. The percentages indicated are calculated relative to the total cohort of 79 students. It is interesting to note that about half of the students were not first year students which is unusual for a first year science course. Only 18% of the group indicated Astrophysics as their major with the majority intending to pursue computer science careers.

Table 2 Summary of student diversity

Category		#N (%)
Gender	Female	20 (25)
	Male	59 (75)
Year of study	1	40 (51)
	2	20 (25)
	3	15 (19)
	4	04 (5)
Intended majors	Applied mathematics	12 (15)
	Astrophysics	14 (18)
	Biology-related major	09 (11)
	Computer science	28 (35)
	Environmental And	
	Geographic related major	11 (14)
	Engineering	7 (9)
	Mathematics	10 (13)
	Other	5 (6)
	Physics	17 (22)

2.3 Protocol

The IAQ was administered to 79 students at the pre-course information lecture in early February 2013 at the start of the academic year. This represented 73% of the total class of 108 students who had registered.

The IAQ was administered immediately after the lecturer in charge of the course had given a short over-view about the course. The information that was provided to the students was confined to the lecture timetable and venues, forms of assessment, etc. All content related matters were avoided by the lecturer as the purpose of the IAQ was to measure pre- and post-course changes. Following this introductory overview a research assistant (who was not in any way associated with the course) handed out the IAQ and requested that the students complete it during the remainder of the session. The following points were emphasized to the students by the research assistant before they responded to the questionnaire; (a) the

questionnaire was to be completed as “honestly and completely as possible”, (b) questions were to be answered in the order in which they appeared, students’ answers would be used to improve the course for future cohorts, (c) there were not necessarily “right or wrong answers” for any of the questions, (d) students’ answers would not count in any toward their grade for the course, (e) and the course lecturer would not be allowed to match individual answers to student identities. In order to introduce some degree of personal accountability on the part of the students it was also mentioned that students might be contacted on an individual basis to explain what they had written should their responses be found to be interesting. No time limit was given to students. Most finished within 20-25 minutes, with none taking longer than 35 minutes.

2.4 Data Analysis

After collecting the completed questionnaires from the students, each script was given a three digit *Respondent Identification Number (RIN)*. Since the questionnaire was made up of several pages, the RIN was copied onto each sheet of the questionnaire for a particular student. Each questionnaire was then separated into loose sheets and the sheets were grouped together by question and bound.

Examples of typical answer sheets for the radiation question are shown below each showing the RIN, a circled answer choice followed by free response writing. The data were analysed both by tallying the various answer choices and more importantly by coding the writing using the approach suggested by Grounded Theory, where the categories were allowed to emerge from the responses. “Grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analysed. Theory evolves during the actual research, and it does this through continuous interplay between analysis and data collection” Strauss & Corbin (1994). Grounded theory was suggested in the 1960s by Glaser and Strauss Glaser et al. (1967). The analysis of the free response writing is presented first followed by a summary of the answer choice tallies.

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Q6. [RWP1]

A group of students is having an argument about *radiation*.

Student A: "Radiation is a form of electromagnetic waves."

Student B: "No! Radiation consists of nuclear particles."

Student C: "I don't agree with either of you!"

With whom do you *most closely* agree: student A, B or C? (Circle only one letter.)

<input checked="" type="radio"/> A	<input type="radio"/> B	<input type="radio"/> C
------------------------------------	-------------------------	-------------------------

Explain in *detail* why you chose this option.

Because even though it consist
of nuclear particles, it is still
a form of electromagnetic waves
since it has those electromagnetic
wave like properties.

Figure 3 Example of student response where student circled "A"

Q6. [RWP1]

A group of students is having an argument about *radiation*.

Student A: "Radiation is a form of electromagnetic waves."

Student B: "No! Radiation consists of nuclear particles."

Student C: "I don't agree with either of you!"

With whom do you *most closely* agree: student A, B or C? (Circle only one letter.)

A	<input checked="" type="radio"/> B	C
---	------------------------------------	---

Explain *in detail* why you chose this option.

Radiation is the ~~ener~~ effect of energised particles
In contact with other ~~sem~~ unenergised particles
causes a molecular disruption. Thus causing Radiation
a Radiated object.

Figure 4 Example of student response where student circled "B"

147

Q6. [RWP1]

A group of students is having an argument about *radiation*.

Student A: "Radiation is a form of electromagnetic waves."
Student B: "No! Radiation consists of nuclear particles."
Student C: "I don't agree with either of you!"

With whom do you *most closely* agree: student A, B or C? (Circle only one letter.)

A	B	C
---	---	---

Explain *in detail* why you chose this option.

Although my knowledge of radiation is limited, I believe it is the result of the decay of radioactive elements, this should consist of nuclear particles which could emit electromagnetic waves.

Figure 5 Example of student response where student circled "C"

2.4.1 Identifying students’ ideas from free writing responses

As seen in Figure 3, Figure 4 and Figure 5 students’ responses comprised two parts; a circled answer choice and a free written response. Thus, each student’s free written response was analysed as follows: the writing was carefully read and then *a short summary of what the student wrote was recorded*. In essence this was a paraphrased sentence that captured as accurately as possible what had been written but without any interpretation. This was followed by attempting to summarise the main idea expressed by the writing. This two-step process was used in order not to conflate what the student had actually written with an interpretation (by the researcher). It was envisaged that while two independent researchers might differ on the latter, they should have close to 100% agreement for the first step. A sample of 30 response sheets was subjected to this two-step process by myself and a research colleague. We achieved close to 100% agreement for the first step. But a greater level of disagreements occurred in step 2, the interpretative phase. These disagreements were subjected to discussion which also included my thesis supervisor and consensus was reached in 98% of the cases. After all the response sheets were subjected to the same treatment, my supervisor selected a random sample response sheets for further group discussion. And after

this the remaining response sheets were analysed by myself. The results of the process were recorded in a spreadsheet which was used as the basis for further analysis.

The results from the two step analysis described above were transferred to the spreadsheet with the following fields per student:

1. Respondent Identification Number (RIN): the three digit number that was assigned to each response set.
2. Choice: the selected answer choice (A, B, or C).
3. Summarised student writing: a summarised version of the student’s free writing response
4. Inferred idea: based on summarised student writing.

Figure 6 shows typical entries in the spreadsheet used to capture the results of the analysis thus far.

RIN	Choice	Summarized student writing	Inferred idea
101	C	Radiation consists of EM waves of light at different frequencies, have different radiation levels.	Consists of EM waves of light at different frequencies
109	C	EM waves are produced differently to radiation. Whilst radiation is partially nuclear particles it also includes gamma rays which are not particles at all.	.EM waves are produced differently to radiation .Partially nuclear particles, but also includes gamma rays which are not particles
113	A	Radiation is a form of EM waves because it is a process where energy is emitted from some source, travelling towards something or object so the space it moves in it uses waves.	.Form of EM waves .Energy emitted from some source which travels in the space that uses waves
129	C	I choose C purely because I don't know much about radiation so that it consists of something I don't know.	Consist of something I don't know
132	B	Radiation is harmful to the body so should consist of nuclear particles.	Consist of nuclear particles
142	A	The option is ambiguous but correct in one way - the 'radiation' that is usually spoken of like that is gamma-rays: a type of electromagnetic waves. However, all electromagnetic waves are 'radiation'.	.Gamma rays is a type of EM waves .EM waves is radiation
144	A	Because the spectrum works with radiation so for someone to detect radiation he/ she needs to understand the forms of electromagnetic waves.	Form of EM waves
163	C	I believe it has been shown that radiation consists of both electromagnetic waves and nuclear particles.	Consists of both nuclear particles and EM waves.
168	B	I'm not sure between A and B but I would think closer to nuclear particles as there are different element in radiation although I do think electromagnetic waves play a part.	Both nuclear particles and EM waves

Figure 6 Portion of spreadsheet showing the results of the two step analysis for the 9 students in the cohort.

As can be seen in some cases the idea that was inferred is almost identical to the summarized wording. For example, [101] indicates ‘Radiation consists of EM waves of light at different frequencies, have different radiation levels’ as the summarized student writing and the inferred idea is ‘consists of EM waves of light at different frequencies’. On the other hand

there are instances where the idea or ideas inferred and the exact wording for the summarized student writing are less close. One of the reasons for carrying the detailed two step procedure in the pilot study was to see how closely the summarized student writing and the expression of the inferred ideas were to each other. If the majority of cases had both columns very similar then it would mean that in future it would be possible to record the inferred main idea directly from summarized writing, thus speeding up the analysis. In about 60% of cases the summarized writing expressed the ideas directly.

2.4.2 Emergent Categories

The third step of the analysis involved looking at the main ideas that were inferred to see if common themes could be identified that could form the basis of a large category. This step also involved a group discussion with myself, research colleague, and my supervisor. Four categories emerged covering most responses with a small fifth category into which responses that were difficult to categorise were placed. The main categories that emerged were thus:

1. Nuclear particles only
2. Electromagnetic waves only
3. Both nuclear particles and electromagnetic waves
4. Heat
5. uncodeable

Each emergent category is briefly described below.

1. Nuclear Particles Only

This category consisted of responses in which only nuclear particles were mentioned as the constituent of radiation. Examples of responses which were placed into this category are;

“Consists of nuclear particles” [141]

“The effect of energised particles in contact with unenergised particles” [106]

2. Electromagnetic waves Only

This category consisted of responses in which only electromagnetic waves were mentioned as the constituent of radiation. Examples of responses which were placed in this category are;

“Form of EM waves” [113]

“Consists of photons (light) that is an EM wave” [155]

3. *Both nuclear particles and electromagnetic waves*

This category comprised of responses which were describing radiation as both nuclear particles and electromagnetic waves. Examples of those responses are;

“Consists of both nuclear particles and EM waves” [163]

“Particle - wave duality” [137]

4. *Heat*

This category comprised of responses which were describing radiation as form of heat. Examples of responses which were placed in this category are;

“Emission of energy of any form, mostly heat” [107]

“Heat energy” [166]

5. *Uncodeable*

This category comprised small numbers of responses that did not fit into the four mentioned categories, thus they were grouped under the umbrella category which we called uncodeable. Examples of responses which were placed in this category are;

“Consist of something I don't know” [129]

“What gives super heroes their powers” [160]

2.4.3 Generation of a numerical coding scheme

One of the purposes of the pilot exercise was to generate a coding scheme that could be used as a starting point for the main study. In addition assigning codes allows for easier manipulation of the data via the spreadsheet and of quantitative analysis. Thus we assigned a three digits integer code of the form NMP to each idea as follows:

The first digit (N) indicated the emergent category to which the response belonged; the second digit (M) indicated a particular idea within the category while the third digit (P) was used to indicate a small variation on the idea expressed in M. Thus the 100 series indicates nuclear particles only, the 200 series electromagnetic waves only, the 300 series both nuclear

particles and electromagnetic waves, and the 400 series to heat. The uncodeable category was assigned the 500 series. Table 3 shows some examples to illustrate the numerical coding scheme. The full coding scheme is detailed in Appendix C.

Table 3 Extract showing numerical coding

codes	Nuclear Particles Category
100	Consists of nuclear particles/ alpha-particles, beta particles and gamma rays/can be nuclear particles (alpha-particles, beta particles)/ can be nuclear particles
110	Effect of energised particles on unenergised particles/ forcing electrons from metal surface
120	Caused by the instability within the nucleus
130	Formed from the rapid acceleration of an electron caused by a gain in energy
140	The result of the decay of radioactive element/ emitted from radioactive particles
150	Can cause cells to create cancerous cells/molecular disruption and radiated object/ harmful to the body.
160	Partially nuclear particles
codes	Electromagnetic waves Category
200	Part / Consists /form /Made/consequence of EM waves
205	Refer to / emission of EM waves
220	EM waves with high/different frequencies/strength
230	EM waves: gamma rays, x-rays, radio, light/wave nature/ consists of photons(light)
240	Sun radiates EM waves/Comes from sun and UV/when light is emitted it radiates/solar radiation is a form of EM wave
250	Travel/propagate through vacuum, space, air etc.
codes	Electromagnetic waves and nuclear particles Category
300	Both EM waves and nuclear particles/nuclear and EM radiation
305	Propagates as both EM waves and nuclear particles
310	Consists of /can be both EM waves and nuclear particles
315	Could be either EM waves and nuclear particles
320	Can be caused by either waves or particles
325	Can consist of either EM waves or nuclear particles
330	Can act as wave and particle, as can all EM-waves
335	Giving off waves, the waves can contain nuclear or just particles and electrons
350	Particle-wave duality
360	Light can act as both wave and particle

Some examples of using the numerical coding scheme are shown in Table 4. The examples chosen also illustrate cases where students' responses expressed more than one idea. It should be noted that no attempt was made to identify a single idea with a single respondent and thus in subsequent quantitative analysis the number of ideas exceeds the number of students. 15 students (20% of the cohort) expressed more than one idea, some from the same emergent category while others are from different categories.

Table 4 Numerical Coding of inferred ideas

Respondent Identification Number	Inferred Main ideas	Code
101	<ul style="list-style-type: none"> • Consists of EM waves • EM waves with different frequencies and different radiation levels. 	200 & 220
109	<ul style="list-style-type: none"> • EM waves are produced differently to radiation • Partially nuclear particles 	160 & 230
115	<ul style="list-style-type: none"> • Radiation is when something e.g. heat is transported through air as a medium • Radiation is the act of waves travelling through air, space, vacuum, etc. 	250 & 405
154	<ul style="list-style-type: none"> • Consist of either EM waves or • Consist nuclear particles • Alpha and beta particles consist of nuclear particles, and x-rays and gamma radiation are electromagnetic wave 	100, 230 & 325

Due to the categories that emerged during the analysis of the free writing responses, we then felt a need to do further analysis whereby we are now considering the answer choices (circled options) together with the given reasons supporting the answer choices.

2.5 Results

2.5.1 Frequency of ideas

Figure 7 below shows the frequency of main ideas grouped per emergent category in the form of a histogram. The main emergent categories are indicated on the horizontal axis while the number of ideas per category is indicated on the vertical axis. The total number of ideas shown is 83. This includes 15 students out of 79 (19% of the cohort) who had ideas spread over more than one emergent category as well as 14 students who did not provide reasons that could be coded as an idea while others did not respond at all. Percentages calculated below are with respect to the total number of ideas (83).

From this distribution it is clear that the lowest frequency of 8 out of 83 (10%) is indicated for the category associated with heat. It is interesting to note at this stage that no ideas explicitly associated with energy transfer were expressed other than those implying heat. There are two further features that are of interest, the first being that the majority of ideas 52% are associated with waves which are spread over two categories [waves only (24)+ particles and waves (19)] followed by the 44% of ideas which regard radiation as associated with particles [particles only (18) + particles and waves(19)].

In the following section we present the results from the forced choice responses bearing in mind that this part of the instrument is meant to be a focussing step toward the free writing response and that no major conclusions about the nature of the student responses regarding the question itself will be drawn from this.

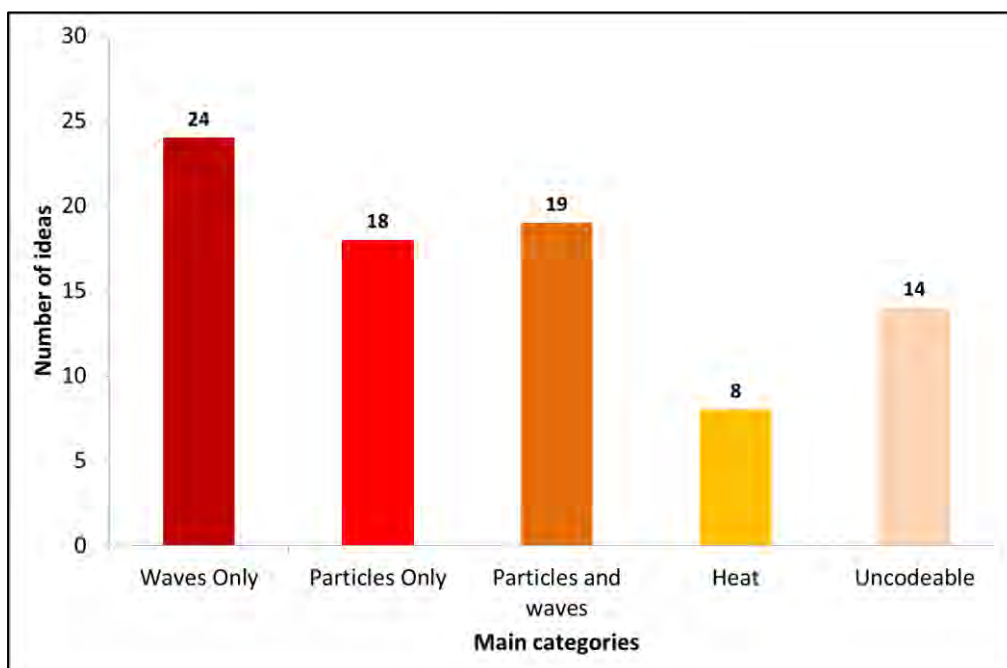


Figure 7 Shows the categories which emerged from students' responses and the number of ideas in each category.

2.5.2 Relationship between forced choice responses and analysis of free writing

Figure 8 shows the results of tallying the forced choice responses that were circled on the response sheet. The horizontal axis indicates the option chosen while the vertical axis shows the number of students who selected a particular option (A, B or C).

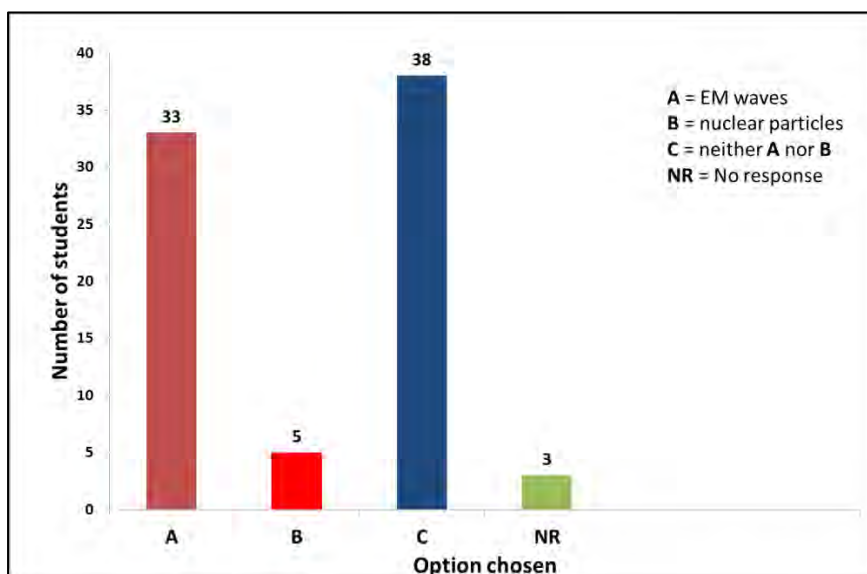


Figure 8 Results of the forced choice responses.

The main purpose of providing the tallies is to be able to answer the question as to how good a proxy the forced choice is for representing the reasoning that followed in the free writing of a particular student. This was done by looking over the student main ideas then selecting the appropriate forced choice option post hoc. The process is described in more detail as follows:

Each free writing response was then assigned a code (A, B or C) based on the inferred ideas that emerged from it. Students who did not mention any idea related to the forced response choice were assigned as uncodeable (U). However, a new category corresponding to A+B was created that catered for students who considered radiation to consist of electromagnetic waves and nuclear particles. The results of this exercise are shown in Figure 9 from which it is clear that had the choice (A+B) been offered it would have been the most popular response compared with Figure 8 where category A is the most selected response.

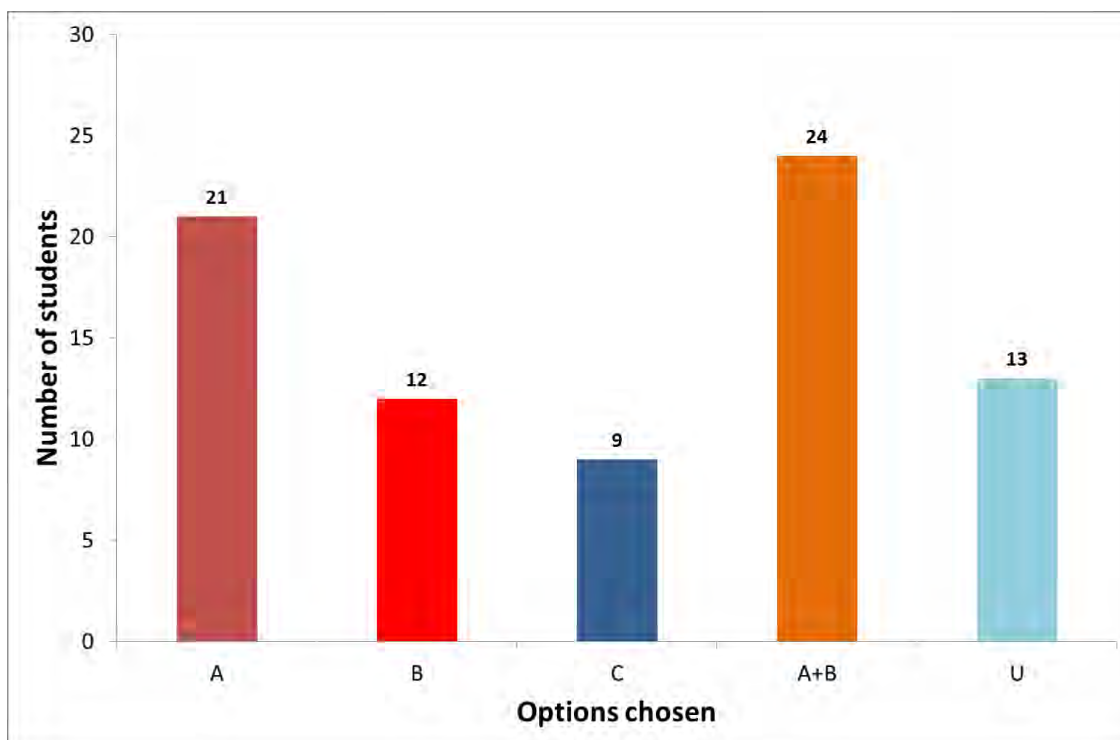


Figure 9 Result showing post hoc assignment of most appropriate forced choice response based on the free response writing in which a new category A+B (waves + particles) has been added.

2.6 Discussion

The difference between Figure 8 and Figure 9 show that relying only on the forced choice response as offered in the pilot instrument would have led to incorrect conclusions regarding what students thought about radiation. One of the reasons for not offering a choice of A+B in the instrument was that it was felt that many students might simply choose this as the safe, all inclusive option. Thus, instead of offering A+B as an explicit option, option C was offered which allowed students who genuinely wanted to choose A+B a way of doing so. However, it is clear there are other reasons for students choosing option C in addition to A+B. The pilot study was aimed at establishing the methodology to be used when undertaking the main study. In the methodology establishment we aimed at finding among other things the appropriate instrument to use in probing students' understanding of radiation and also to develop the coding scheme that could be used in the analysis of data for the main study. This pilot study was done on a diverse group, which is the introductory astronomy class. This course is taken by the students from different faculties; humanities, science, engineering. At the time when the IAQ was administered to the AST1001 class no material had been covered

related to radiation; thus the findings presented here are from the pre- instruction questionnaire. The students showed diverse understanding of radiation as about four main categories emerged during the analysis where in each category students showed different ideas in which they associate radiation with.

It was also observed that in many cases students' forced choices responses did not appear to be consistent with the ensuing written explanation. From this observation it was clear that relying only on the forced choice responses was not possible in order to obtain an accurate picture of student views. In short, the pilot study revealed the short comings of our choice of instrument. Apart from the considerations above there was no way to be certain that students were actually choosing an option that the matched their thinking rather than simply choosing the most attractive option and then providing reasoning to support this choice.

Based on the difficulties of relating the forced choice responses to the free writing responses it was decided to abandon the aspect of forced choice responses only for the main study where it was possible that even more subtle effects might be present when the question was allocated within different contexts. While it was possible to include a larger number of options this could lead students to be primed for ideas that they would not have thought about in the first place.

However, there are few interesting findings from the pilot study that are noted. In the first place the results showed up wider differences of understanding of the term radiation in terms of waves and particles than might have been expected. Few students had an understanding of radiation as consisting of nuclear particles only, as is clear from both Figure 8 and Figure 9. The majority of students seem to view radiation as involving waves only or as both waves and particles. However, it is surprising that the notion of energy transfer did not feature in any way other than via heat as noted above.

In summary, the methodology for the main study has been established both in terms of reframing the question to be less suggestive about the nature of radiation and more open-ended and also in terms of having established the basis for a coding scheme that could be used as the starting point. From a practical point of view the pilot study also helped to establish both protocol for the study as well as the analysis tools required for capturing the results of the analysis.

3 Main Study

The main study followed on from the Pilot Study in which the methodology was established. However, the Pilot Study showed that the question needed to be reformulated in order not to limit the responses of the students as discussed in more detail below.

3.1 Structure of question

The development of the question was guided by the findings from the Pilot study from which it was apparent that the one used in the Pilot Study was not phrased in a manner that allowed students to express themselves freely as they were confined to a small number of choices.

Data on understanding or ideas may be collected by either conducting one-on-one interviews or using questionnaires. These two methods of collecting data can both be used in undertaking any research study. Even though it is not easy to choose which method is better than the other, but in some cases one method will somehow out compete the other depending on the factors such as sample size, time frame for the research work to be completed, financially constrains and many others. “The interview is a conversation with a purpose” Bingham & Moore (1931). This conversation is between the interviewer (the person collecting data) and the interviewee (the person whom the data is collected from); the purpose of this conversation is mainly to collect data through a series of questions. The questionnaire in this study refers to the research instrument where respondents are expected to answer questions in writing, either given as multiple choice or open-ended or structured open-ended questions.

Having looked at two main methods of collecting data; interview and questionnaire, we then decided to use a questionnaire that required a written response. We preferred a written question over interview for practical reasons such as not requiring as much of the time for the respondents and the resources needed to administer were also easily accessible because only paper and pen were needed. In as much as the questions exist in different types such as multiple choice, open-ended or structured open-ended questions; we chose open-ended (free-writing) format of which the choice was motivated and guided by the findings of the Pilot Study.

In addition a prompting free writing response we also paid attention to other factors in posing the question. For example, Allie et al. (2008) have noted that the way in which questions are formulated in terms of the audience that is perceived, has a direct bearing on the way in which the questions are answered. Based on their “knowledge flow model” described in the paper we therefore formulated the question such that the audience was specified as a friend who knows less than the questioner. Of particular interest was the extent to which responses would change given the same question but different textual surroundings. Thus, the same question was posed with four different posited scenarios (the beach, the dentist, a nuclear power station and a physics class). Each respondent, who only answered the question for one of the scenarios, was requested to explain to a friend what they understood by radiation. We chose these four scenarios because it was believed that each one would be familiar but would trigger very different associations. We used the beach scenario as a relaxed situation usually associated with heat and the sun. The dentist scenario was used because it was thought to be an uncomfortable situation but often associated with x-rays. The nuclear power station (Koeberg) scenario was chosen because it represented the situation which is most often associated with radiation in the public mind while the physics class scenario represented the formal situation. The resulting questions are shown below. In order that the heading on the question received by the students did not trigger any associations the question was simply labelled Physics First Year Questionnaire (PFYQ).

<p>Student number: <input type="text"/></p>
<p>Physics First Year Questionnaire (PFYQ)</p> <p>Department of Physics University of Cape Town May 2013</p>
<p>Q1.</p> <p>While sitting at the beach with your friend, your friend turns to you and asks, “What is radiation?”</p> <p>How would you explain to your friend what radiation is?</p> <hr/>

Figure 10 Sample of the question on the beach scenario

Student number: _____

Physics First Year Questionnaire (PFYQ)

Department of Physics
University of Cape Town
May 2013

Q1.

While sitting on the bench at the dentist with your friend, your friend turns to you and asks, "What is radiation?"

How would you explain to your friend what radiation is?

Figure 11 Sample of the question on the dentist scenario

Student number: _____

Physics First Year Questionnaire (PFYQ)

Department of Physics
University of Cape Town
May 2013

Q1.

While visiting the nuclear power station at Koeberg with your friend, your friend turns to you and asks, "What is radiation?"

How would you explain to your friend what radiation is?

Figure 12 Sample of the question on the nuclear power station (Koeberg) scenario

Student number:

Physics First Year Questionnaire (PFYQ)

Department of Physics
University of Cape Town
May 2013

Q1.

While sitting in the Physics class waiting for a lecture to start, your friend sitting next to you turns to you and asks, "What is radiation?"

How would you explain to your friend what radiation is?

Figure 13 Sample of the question on the physics class scenario

3.2 Cohort

The question was administered to 140 first year medical students, who are doing PHY1025F which is the physics course for the medical students. All the students in this group have graduated from their high school with physical science (combination of physics and chemistry). Among the topics that they have covered in their grade 12 physical science is electromagnetic radiation which covers; dual (particle or wave) nature of EM radiation, nature of an EM waves as mutual induction of oscillating magnetic or electric fields, EM spectrum, nature of EM as particle energy of a photon related to frequency and wavelength, and penetrating ability. By the time the instrument was administered to the students, they had not yet taught any topic in radiation. Hence the knowledge outlined by the students in their responses is mainly from their high school learning and other non-formal learning. This was a good group of students mainly because at some stage they will use radiation application in their work place, or even before that they will get a chance to learn about applications of radiation.

3.3 Protocol

The PFYQ was administered to 140 students during the last day of lectures of first semester or term in end of May 2013. This was 54% of the total class of 260 students who had registered for the course.

The PFYQ was administered before the lecturer in charge of the course delivered his lecture of the day. He introduced me to his students as a masters student in physics education. From this brief introduction, the following points were then emphasised to the student before the question papers were handed out; (a) the questionnaire is intended to help in developing and improving teaching of certain topics in the department of physics, (b) the responses provided in this questionnaire will not in anyhow affect their grades for the course, (c) the findings of this questionnaire will not be discussed with the course lecturer nor match them with individual performance in the course, (d) there are no right or wrong answers, so answer as honestly as possible, (e) and do not discuss the answers with your neighbour or friend. In order to introduce some personal accountability on the part of students, a non-threatening accountability was stated to students that they might be contacted for further one on one interviewing to explain what they have written in case their answers are found to be interesting. The question papers were then distributed to the students who were then told to

answer the questionnaire immediately when they get it. No time limit was given and most of them finished within 10 minutes, with none taking 15 minutes or more.

3.4 Analysis

After collecting the completed question papers from students, the scripts were grouped into the four scenarios (beach, dentist, Koeberg and physics class). This was followed by giving each script a three digit *Respondent Identification Number (RIN)* where the first group to be allocated *RIN* was the one for beach scenario, followed by dentist, then Koeberg (nuclear power station) and lastly physics class. The beach scenario scripts occupied the *RIN* from 101 to 133, dentist from 134 to 168, nuclear power plant 169 to 208 and physics class from 209 to 240. The data were analysed in two main phases. The first phase can be described as a **coarse-grained analysis** and the second phase involved **coding of the written responses using the approach suggested by Grounded Theory** where categories were allowed to emerge from the written responses as for the Pilot Study.

The **coarse-grained analysis** involved the following: *word-count of the total number of words used in the responses, analysis of the non-technical terms or words, and a marking scheme analysis*. The main purpose of this analysis was to see if there are any simple markers that characterised differences in the nature of responses to the different scenarios. Each of these measures is described in details below.

3.4.1 Word count

This stage of analysis involved counting of the number of words used by each student in their writing. We counted the number of words in the summarized student writing for each student in all the four scenarios by copying the summarized student writing into blank word document where the number of words was shown at the end of the document by the word counter. This was done for all students, and the total words used by each student were recorded in the column that was added next to the one for ‘the summarized student writing’. The total number of words written by all students in each scenario was then added and the sum was divided by the total number of students in that scenario to find the average words used in a particular scenario. Table 5 shows how the analysis results were recorded, showing

the scenarios, number of students in each scenario, the total words used in each scenario and finally the average words used.

Table 5 Average words used per Scenario

Scenarios	Number of students	Total words used	Average words used
Beach	33	857	26
Dentist	35	732	21
Koeberg (Nuclear power station)	40	1294	32
Physics Class	32	718	22

3.4.2 Use of non-technical terms

In this stage of analysis we focused on the specific words that were used in the students' responses and we looked for the words and expressions which were considered to be non-technical. As a practical way of doing it the students' responses were analysed by changing the font colour using different colours based on the type of words or expression used. For example, for the words or expressions mentioning biological effects of radiation red was used to highlight the text while purple was used to mark allusions to harm in general (see figure 14). A colour count was then carried out.

<i>Student 114:</i> Emission of absorbed energy to the external environment, e.g. terrestrial radiation, electromagnetic radiation etc. This energy can be propagated in either shortwave or long wave; radiation can alter the structural composition of matter, e.g. cell deterioration, mutations, etc.
<i>Student 152:</i> Radiation is a form of waves which have the potential to be harmful to living organisms
<i>Student 176:</i> Form of energy moving from one object to another. Energy is emitted in forms of waves. It is harmful to living organisms. Causes biological defects to infants if mother of an infant was exposed to radiation while they were pregnant. Kills people. It's dangerous.
<i>Student 220:</i> Transfer of energy, can cause and abnormal growth.

Figure 14 Example showing students' responses and the different effects of radiation

The non-technical expressions which were used by the students in their responses were then grouped into two groups (1) specific biological effects and (2) general harmful effects of radiation. Examples of specific biological effects were expressions such as “radiation has potential to damage human DNA” while “radiation is very dangerous” was placed into the harmful effects category is for an example”. Some further examples of the expressions on both biological and other effects of radiation as mentioned by the students in their responses are then shown in Table 6 below.

Table 6 Examples of expressions regarding the effects of radiation

Specific Biological Effects	General harmful effects
causes cell mutations	have the potential to be harmful to living organism
causes damage to cells and tissues	Radiation is very dangerous
causes cancer	silent killer
causes biological defects to infants if a mother of an infant can get exposed to radiation while pregnant	emits dangerous gases.

The summary showing the number of times biological and other effects of radiation were mentioned across all the four scenarios is shown Table 7. Column 3 shows the percentage of students represented per scenario. For example 15% of group who were presented with the Physics Class scenario mentioned biological or harmful effects while this percentage was 38% for the Koeberg scenario.

Table 7 Number of students who mentioned effects of radiation per scenario

Scenarios	Biological Effects	Other effects	(%)of total for specific scenario
Beach	3	3	18
Dentist	3	3	17
Koeberg	11	4	38
Physics Class	2	3	15

3.4.3 Scoring the quality of the explanation

In order to obtain a more quantitative measure regarding the nature and quality of the explanations that could be used for comparative purposes we devised a scoring scheme based on the following definition of radiation:

Radiation is a process in which energy is transferred through a vacuum or a medium by electromagnetic waves (e.g. gamma rays, x-rays, microwaves, infra-red, ultra-violet) or, particles (e.g. electrons, positrons, protons, alpha particles, heavy ions). This includes thermal radiation (heat / infra red)

A scorecard was designed in which the presence of key elements were identified and scored as detailed in Table 8. Thus, each response was marked out of five according to the following scheme: If energy transfer was mentioned this was assigned two points as this was felt to be a central concept underlying an understanding of radiation. If the transfer of heat only was mentioned this was assigned a single point as while it is not incorrect it is a small subset of the broader concept of radiation. If energy transfer through electromagnetic waves or just waves an extra one point was awarded but with heat an extra point was awarded for heat transfer through vacuum or no medium. If energy transfer through particles was mentioned an extra point was awarded but there was no extra point awarded for heat transfer through particles as that would now be referring to other methods of heat transfer such as conduction or convection. The overall written response was awarded one point if it was making sense or the given extra details were making sense, and this extra point was not awarded to people who mentioned heat transfer even if their response had all the points, such as heat transfer through vacuum or no medium, because heat transfer is part of the explanation of radiation. The maximum points that a student could obtain was five. Students who did not write down anything related to the main points mentioned were awarded zero.

Table 8 Marking Scheme Score Card showing how points were distributed

Element	Score
Energy transfer [Heat transfer only]	2 [1]
(Electromagnetic) waves [Heat: vacuum or no medium]	1 [1]
Particles [Heat:]	1 [0]
Makes sense / extra detail	1 [0]

Examples of student responses and the way in which marks were allocated is shown in Table 9 below.

Table 9 Sample of students' responses and the scores obtained

Respondent Identification Number	Students' explanation	Marks/Points scored
107	An electromagnetic wave	1
137	Radiation is form of heat transfer without a medium, so it is through a vacuum	2
179	Radiation is a type of energy transfer. It is a wave and is electromagnetic. This means the wave can be propagated through a vacuum or through a medium.	3
168	Radiation is the passing of energy from one thing as electromagnetic waves or as moving subatomic particles	4
N/A	N/A	5

Table 10 below summarizes the marks awarded for each written explanation grouped per scenario. .

Table 10 Summary of scored points per scenario posited in the question

Scored points	Beach N=33 (100%)	Dentist N=35 (100%)	Koeberg N=40 (100%)	Physics class N=32 (100%)	Total N=140 (100%)
0	0 (0)	0 (0)	1 (3)	1 (3)	2 (1)
1	5 (15)	13 (37)	6 (15)	8 (25)	32 (23)
2	14 (42)	12 (34)	15 (38)	13 (41)	54 (39)
3	13 (39)	9 (26)	16 (40)	10 (31)	48 (34)
4	1 (3)	1 (3)	2 (5)	0 (0)	4 (3)
5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

3.4.4 Identification of ideas from the written responses

Following the approach carried out in the Pilot Study, each student's response was analysed as follows: the writing was carefully read and then a *short summary of what the student wrote was recorded*. In essence this was a paraphrased sentence that captured as accurately as possible what had been written but without any interpretation. This was followed by attempting to summarise the main idea expressed by the writing. This two-step process was used in order not to conflate what the student had actually written with an interpretation (by the researcher). Due to the experience gained on working with data from pilot study, only the researcher herself was involved in this phase but with the guidance from the supervisor. A sample of 40 response sheets (10 from each scenario) was subjected to this two-step process by myself and discussed it with my supervisor. Since no major disagreements were found I analysed the remaining responses on my own. After all the response sheets were subjected to the same treatment, my supervisor selected a random sample of response sheets for further discussion. Here too no significant disagreements were found. The final results of the process were recorded in a spreadsheet which was used as the basis for further analysis.

The results from the two step analysis described above were transferred to the spreadsheet with the following fields per student:

1. Respondent Identification Number (RIN): the three digit number that was assigned to each response set.
2. Summarized student writing: a summarized version of the student's response.
3. Inferred idea: based on summarized student response.

Each written response was analysed as described in the Pilot Study where both the summarized student writing and the inferred ideas were recorded as shown below. These inferred ideas were then grouped together into similar themes which were used the basis of a three digit numerical coding scheme that was assigned to each inferred idea as shown in detail in the following section. The themes were finally used to form larger categories leading to a total of four categories emerging from the process.

Table 11 shows the typical entries of the spread sheet used to capture the results.

Table 11 Sample of the spreadsheet showing the results of the two step analysis

RIN	Summarized student writing	Inferred idea
103	It is the heat energy transferred through the sun, rays to the environment e.g. human and the sun. Therefore this type of heat transfer is not due to molecules moving and passing the energy to the next molecule. I would tell them that it is the reason they feel warm while sitting on the beach.	Heat energy transferred through the sun, rays to the environment
107	An electromagnetic wave.	An EM wave
110	Energy from the sun in the form of waves. Radiation can travel in a vacuum as we can see when the sun emits radiation. We end up getting some radiation on earth in the form of gamma, UV etc.	Energy from the sun in the form of waves
111	Radiation is small particles emitted in the form of rays as the atoms change from the unstable states to the more stable state. The energy contained by these emitted particles differs in energy levels, some are extremely dangerous (gamma rays) can penetrate almost everything.	Small particles emitted in the form of rays as the atoms change from the unstable to the more stable state
135	It is a type of heat transfer	A type of heat transfer
138	Radiation consists of waves that cannot be seen, it's often a form of heat transfer. Radiation is also a carcinogen.	<ul style="list-style-type: none"> • Consists of waves that cannot be seen • A form of heat transfer
148	It is the transfer of energy via electromagnetic waves, mate.	The transfer of energy through electromagnetic waves
150	It is the transfer of heat particles.	The transfer of heat particles
175	Basically, you get waves that are electrical and also magnetic (which exists between magnets and electron) and they act at 90° angles to one another. Radiation has waves like these and by means of these waves; energy is transferred over a specific distance. The trick in it, is that the waves don't need a medium to travel through. An example would be the sun, in	Electromagnetic waves

	space there is nothing, so no medium, yet we are able to feel the heat of the sun on earth.	
177	Charged particles emitted in nuclear reactions which have the potential to damage human DNA.	Charged particles emitted in nuclear reactions
191	Radiation is the transfer of heat (energy) through space or a vacuum. It is an electromagnetic wave which propagates in a vacuum at a high frequency (UV light). It can cause a lot of damage because of the high energy it transfers due to the high frequency.	<ul style="list-style-type: none"> • The transfer of heat through space or a vacuum • The transfer of energy through space or a vacuum • An electromagnetic wave which propagates in a vacuum at a high frequency (UV light)
208	Radiation is a form of energy; it is also a way in which energy can be transferred.	<ul style="list-style-type: none"> • A form of energy • A way in which energy can be transferred
228	I would say: "Radiation is the gradual dissipation of energy from a molecule. It is the transfer of energy involving no contact."	<ul style="list-style-type: none"> • The gradual dissipation of energy from a molecule • The transfer of energy involving no contact
232	It is an electromagnetic wave that doesn't need a medium. It is a form of heat.	<ul style="list-style-type: none"> • An electromagnetic wave that doesn't need a medium • A form of heat

233	The process of radiation is when particles or energy is transmitted without a medium. There is therefore no contact between the source and the receiver. That's why you can, for example feel the heat from an object when you stand close by, but you're not in contact with it.	<ul style="list-style-type: none"> • When particles are transmitted without a medium • When energy is transmitted without a medium.
237	Imagine a vacuum, for example space. Nothing makes up space. There is no medium. Just imagine. Now consider the fact that you can see stars. This is electromagnetic radiation, or light rays. They radiate through space (no medium). One can view radiation in terms of heat which passes from object to object without direct contact. So, which radiation are you asking me about?	<ul style="list-style-type: none"> • Electromagnetic radiation, or light rays • Heat which passes from one object to the other without direct contact

As can be seen in some cases the idea that was inferred is almost identical to the summarized wording. For example, [135] indicates ‘It is a type of heat transfer’ as the summarized student writing and the inferred is ‘A type of heat transfer’. While on the other there are instances where the summarized student writing involved a lot more of complex writing and the inferred ideas and summarized student are less close in such cases. Hence that shows the significance of undertaking the two step procedure analysis.

3.4.5 Identification of main themes (emergent categories)

The third step of the analysis involved looking at the main ideas that were inferred to see if common themes could be identified that could form the basis of a large category. This step also involved a discussion between myself, and my supervisor. Four categories emerged covering most responses; the main categories that emerged were thus:

1. Heat
2. Waves
3. Particles
4. Energy

Each emergent category is briefly described below;

1. Heat

This category consisted of responses in which heat was mentioned as the constituent of radiation. Examples of responses which were placed into this category are;

“It is the heat energy transferred through the sun, rays to the environment...” [103]

“It is a type of heat transfer” [135]

“Radiation is the transfer of heat (energy) through space or a vacuum” [191]

“One can view radiation in terms of heat which passes from object to object without direct contact” [237]

2. Waves

This category consisted of responses in which electromagnetic waves were mentioned as the constituent of radiation. Examples of responses which were placed into this category are;

“An electromagnetic wave” [107]

“Radiation consists of waves that cannot be seen” [138]

“Waves that are electrical and also magnetic (which exists between magnets and electron) and they act at 90^0 angles to one another” [175]

“It is an electromagnetic wave that doesn't need a medium” [232]

3. Particles

This category consisted of responses in which nuclear particles were mentioned as the constituent of radiation. Examples of responses which were placed into this category are;

“Radiation is small particles emitted in the form of rays as the atoms change from the unstable states to the more stable state” [111]

“It is the transfer of heat particles” [150]

“Charged particles emitted in nuclear reactions” [177]

“The process of radiation is when particles or energy is transmitted without a medium” [233]

4. Energy

This category consisted of responses in which energy was mentioned as the constituent of radiation. Examples of responses which were placed into this category are;

“Energy from the sun in the form of waves” [110]

“It is the transfer of energy via electromagnetic waves” [148]

“Radiation is a form of energy; it is also a way in which energy can be transferred” [208]

“Radiation is the gradual dissipation of energy from a molecule” [228]

3.4.6 Numerical coding scheme

For easier manipulation of the data on the spreadsheet for the quantitative analysis we assigned a response code of the form CNMP where the (C) is the letter and (N), (M), and (P) are digits to each idea as follows:

The letter (C) indicated the beginning letter in the emergent category which the response belonged; first digit (N) indicated the emergent category to which the response belonged; the second digit (M) indicated a particular idea within the category while the third digit (P) was used to indicate a small variation on the idea expressed in M. Thus the H100 series indicates heat, the W200 series waves, the P300 series particles, and the E400 series to energy. Figure 15 shows some examples to illustrate the numerical coding scheme. The full coding scheme is detailed in Appendix F

	Main Categories
CNMP	Heat
H100	Heat from the sun/stars
H101	Emission of heat
H102	Heat transported through air as medium
H103	transfer/transmission of heat through vacuum/no medium
H104	movement of heat through space
CNMP	Waves
W200	Electromagnetic wave
W201	Electromagnetic waves that are transmitted/emitted from the sun
W202	consists of waves
W203	Movement of waves in space/vacuum/no medium
W204	Transmission of EM waves
CNMP	Particles
P300	Particles from decaying atoms
P301	Particles of energy
P302	Electromagnetic particles
P303	Transfer of heat particles

Figure 15 Shows a portion of the coding scheme generated and used for analysis.

Figure 16 shows examples of how the ideas were coded and assigned to particular students. The examples have also been chosen to illustrate cases where students expressed more than one idea. It should be noted that no attempt was made to force a single idea with a single respondent and thus in subsequent quantitative analysis the number of ideas exceeds the number of students. However, in practice only 16 students (11% of the cohort) were assigned more than one code.

Respondent Identification Number	Inferred Main Ideas	CNMP
130	<ul style="list-style-type: none"> • Electromagnetic waves propagating through air • Energy from the sun 	W208 & E401
138	<ul style="list-style-type: none"> • Consists of waves that cannot be seen • A form of heat transfer 	W202 & H112
174	<ul style="list-style-type: none"> • The process in which energetic particles travel through a vacuum, or through matter-containing media that are not required for their propagation • The process in which energetic waves travel through a vacuum, or through matter-containing media that are not required for their propagation 	P305 & W208
204	<ul style="list-style-type: none"> • The transfer of energy using electromagnetic waves, that doesn't require a medium • Made up of small charged particles of atoms 	E406 & P307

Figure 16 Examples showing the use of the coding scheme where more than one idea was expressed.

4 Results and Discussion

The results from the various types of analyses that were described in Chapter 3 are presented in the following sections together with brief discussions.

4.1 Word count

Figure 17 shows the average number of words used scenario in the form of a histogram. The four scenarios are indicated on the horizontal axis while the average number of words per scenario is indicated on the vertical axis.

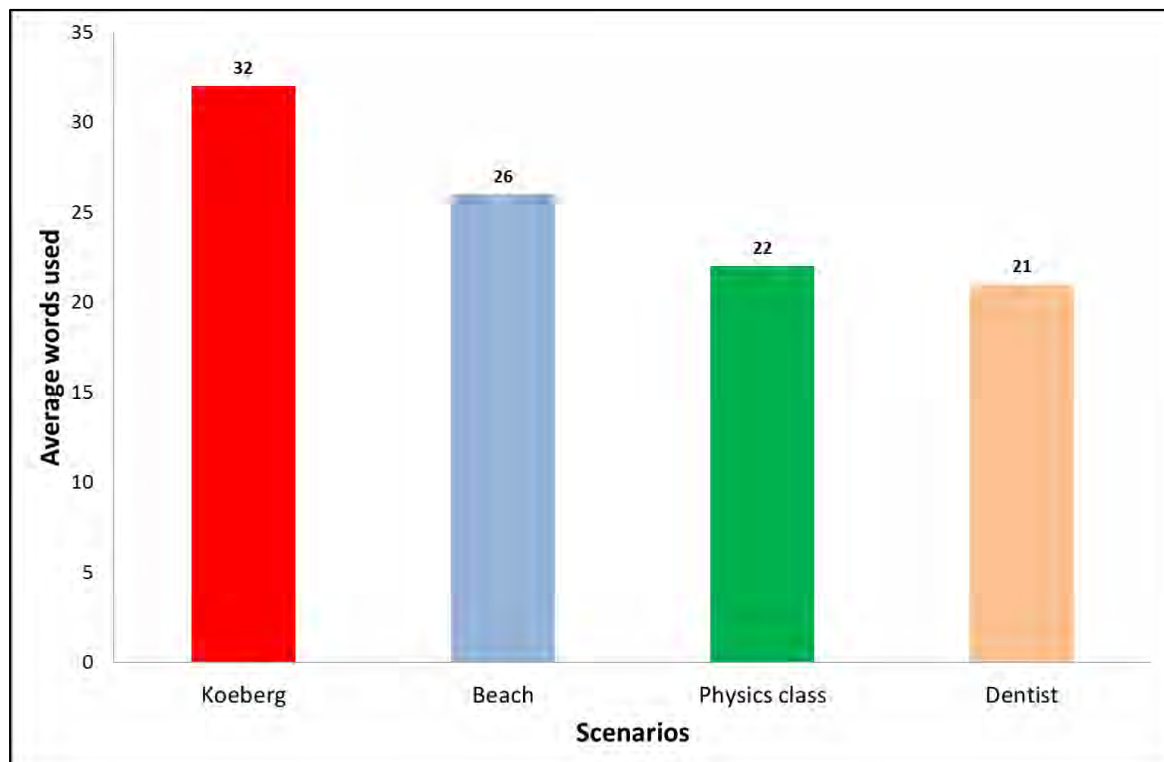


Figure 17 Average words used per scenario placed in descending order.

From this distribution we see that all the average words used in all the four scenarios are less than 35 but also greater than 20 and also the difference between the respective scenarios are less than 10. From the histogram it is clear that in the Koeberg scenario students had lengthy responses and that is shown by the highest average words used, 32. While on the other side it can be observed that the other two scenarios physics class and dentist had almost the same average words used which then makes them to be the scenarios with the least lengthy responses, with average word used as 22 and 21 respectively.

4.2 Frequency of non-technical words or expressions

Figure 18 below shows the percentage of the number of responses per scenario where non-technical words or expressions were used in the responses. After finding the number of responses where biological effects and also other effects were mentioned, we added the two numbers and found the total number of responses in that scenario with the non-technical expressions and then calculated their percentage out of the total number of responses in each scenario. It should be noted that the number of responses in each scenario is equivalent to the number of students in that particular scenario. For the beach scenario, biological effects and other effects gave a total of six (3+3 from each), then took the total of responses (33) in the beach scenario to get the percentage as 18%. We did the same for all the other three scenarios.

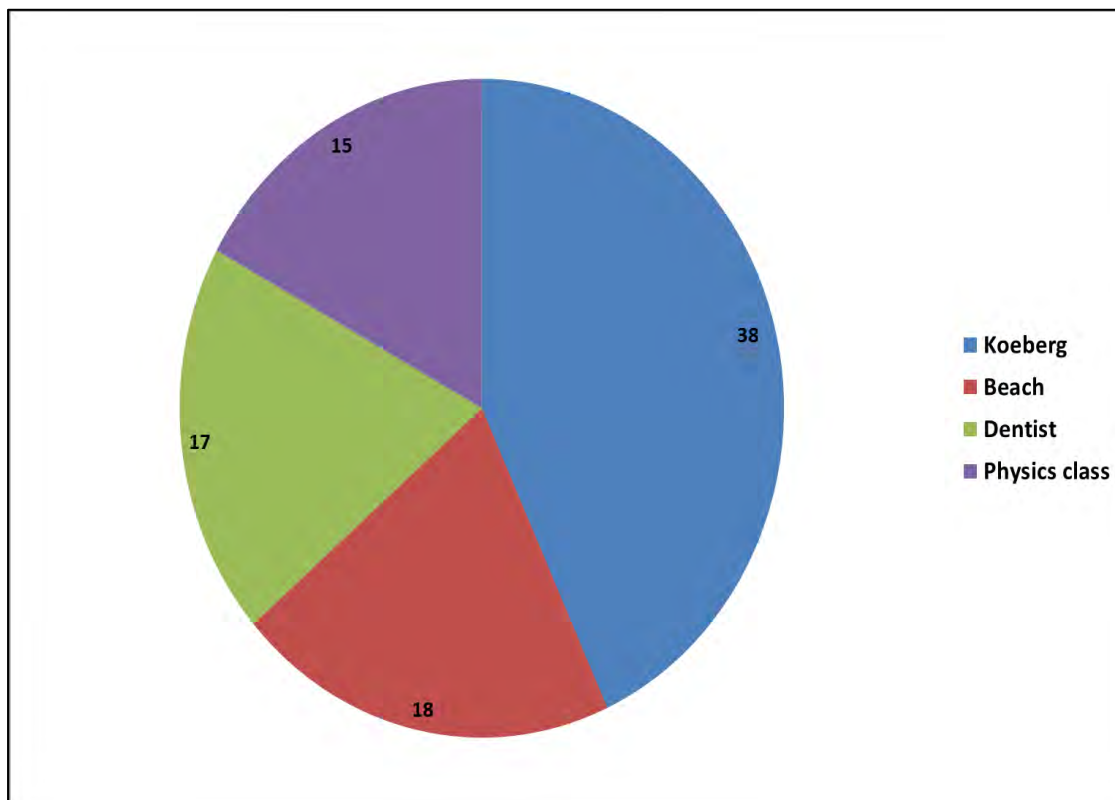


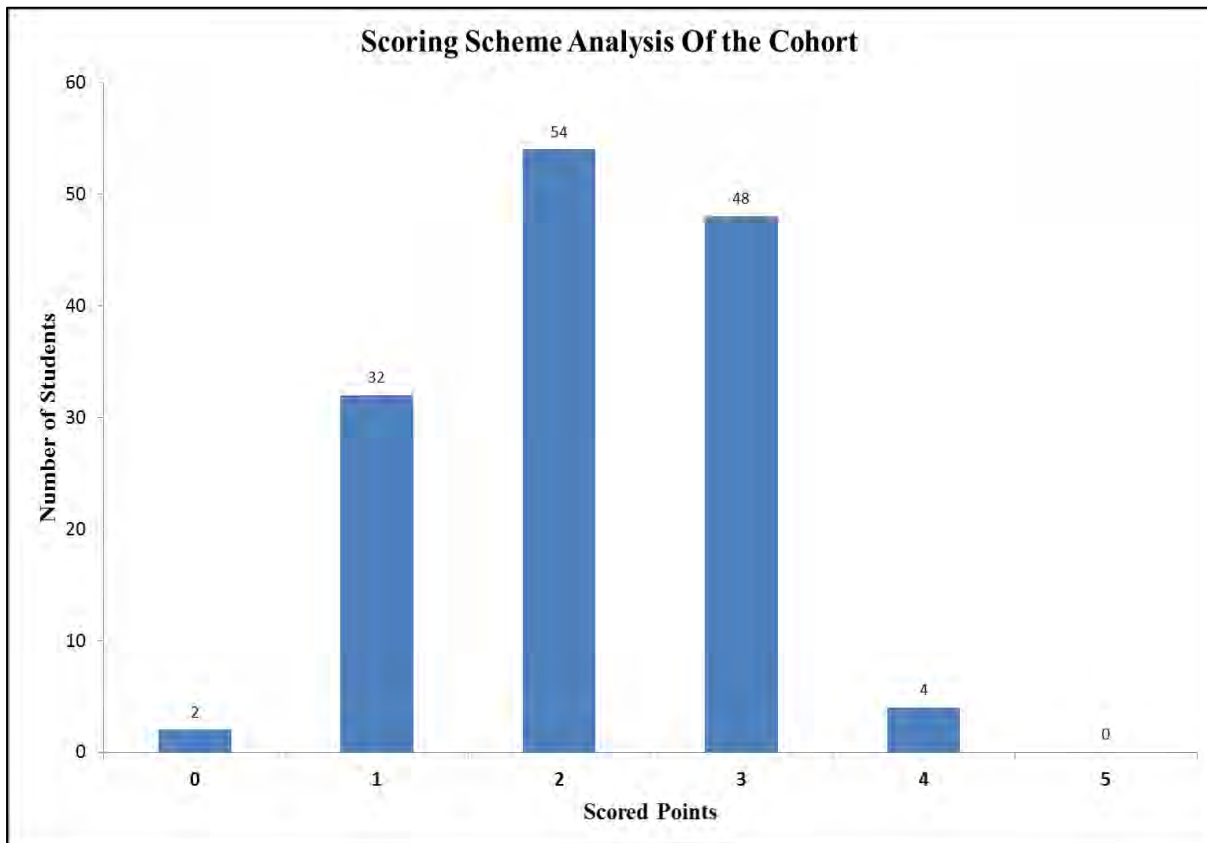
Figure 18 Distribution of the non-technical terms used per scenario

From the distribution in Figure 18 it is clear that the Koeberg scenario generated the most responses where a non-technical explanation of radiation was provided with 38% of the respondents in that scenario mentioning the (adverse) biological effects and other harmful effects of radiation. In contrast the physics class scenario generated the least responses (15%) where a non-technical explanation was provided.

4.3 Marking scheme

Figure 20 below shows the overall results obtained from the marking scheme analysis provided in Table 10 in the form of a histogram while Figure 19 shows the same data separately for each scenario. From the distributions it is clear that none of the responses provided by the students was found to be on the level worthy of maximum points. For three scenarios the explanations clustered in the 2-3 range: for the beach scenario 81% (27 / 33) were in this range, for Koeberg scenario 78% (31/ 40) and for the physics class 72% (23 / 32). However, the dentist scenario had the highest number of students 71% (25 /35) in 1-2 range.

Figure 19 marking scheme scores showing the number of students in each score



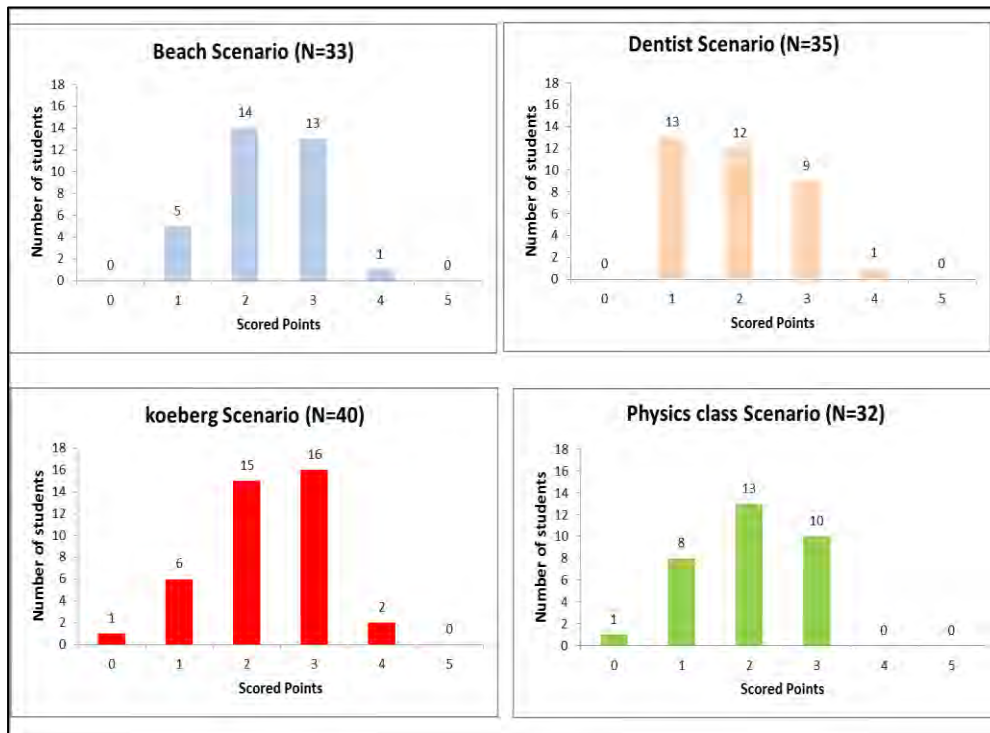


Figure 20 The Marking scheme results for the four scenarios

Because the marking scheme is somewhat subjective at this fine level, we grouped the results into two categories *adequate* (3-5) and *less adequate* (0-2). Figure 21 below shows the results of this exercise. The grouped scored points are indicated on the horizontal axis while the number of students is indicated on the vertical axis. Thus, it can be seen that the majority of the cohort across all the scenarios, around two thirds of the students, 63% [88 / 140], scored two or lower thus implying that on the whole the explanations offered were not very adequate. Thus, only a third of the students, 37% (52 out of 140) could be regarded as having provided explanations that were adequate.

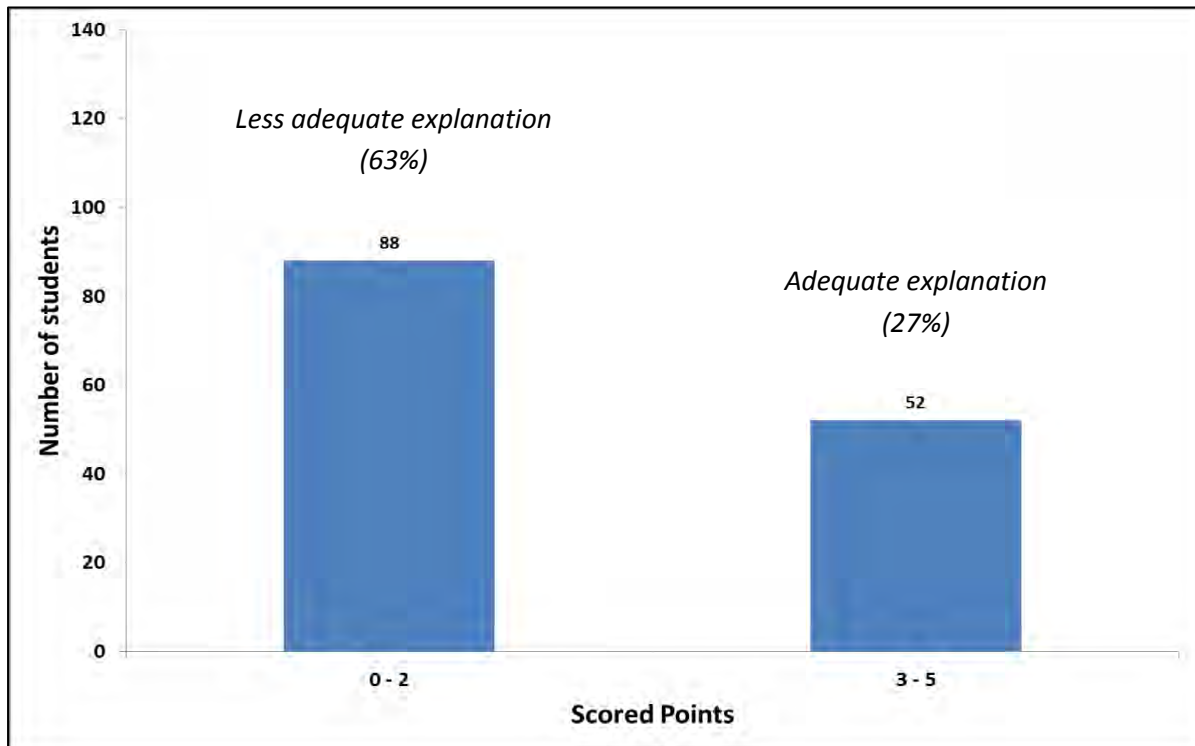


Figure 21 Number of students grouped into Less Adequate and Adequate categories.

However, since each scenario appeared to trigger different type of responses on average the results shown in Figure 21 were disaggregated by scenario (Table 12 and Figure 22).

Table 12 Disaggregated scores per scenario

Posited Scenario	Less adequate (0 – 2)	Adequate (3 – 5)	Total (%)
Beach	58%	42%	100
Dentist	71%	29%	100
Koeberg	55%	45%	100
Physics class	69%	31%	100

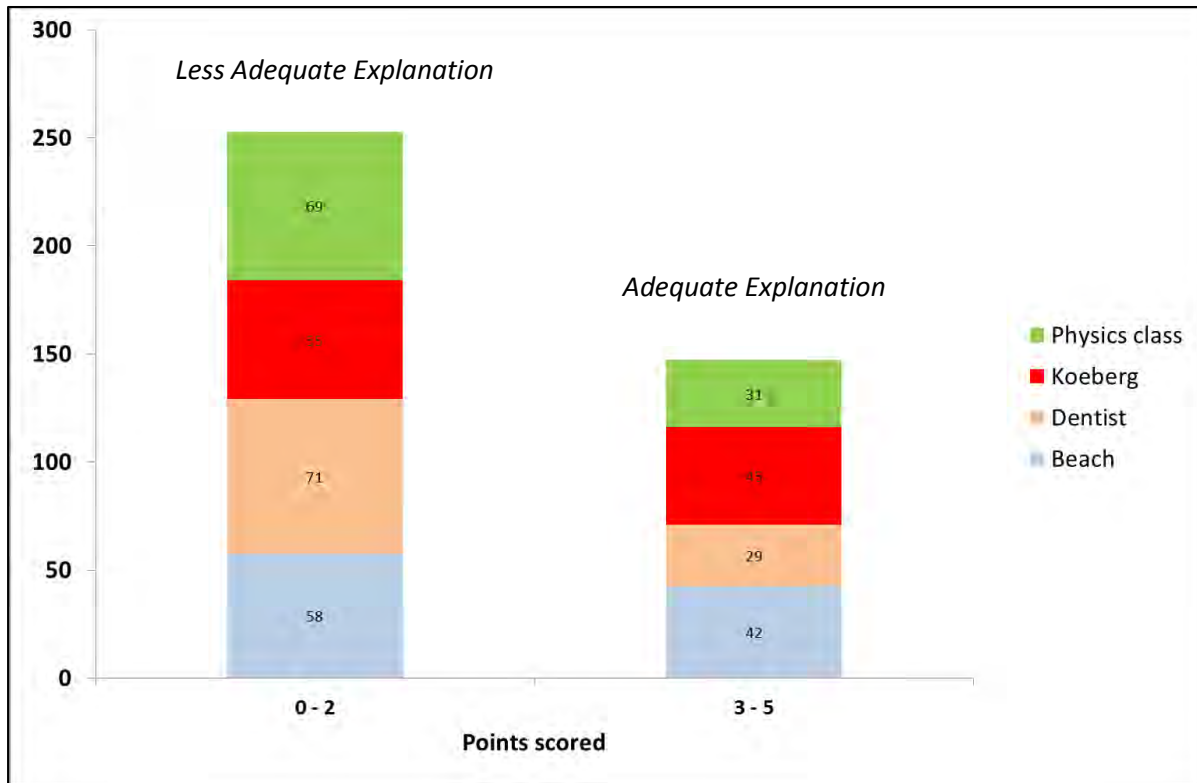


Figure 22 Disaggregated scores per scenario

Figure 22 shows the summarized the results; where the grouped scored points are indicated on the horizontal axis and in this case the vertical axis is not significant as the comparison is between the bars of the different scenarios which are labelled on them. While it is not possible to make definitive statements due to the size of the samples it is certainly suggestive that the Beach and Koeberg scenarios give rise to better explanations on average. Thus, for the Koeberg scenario 45% of the sample was classified as adequate and in the Beach scenario 42% fell into this category. On the other hand both sets of responses from the Physics and Dentist scenarios respectively were seen to be of lower quality on average with 31% and 29% respectively falling into the adequate category.

Another indication that the scenarios were engage with differently is that the word count appears to be associated with the quality of the explanation. Thus the average number of words used in the explanation are as follows: Koeberg had the highest average words used with an average of 32 followed by the Beach scenario with 26 average words. The two lower word counts were the Physics class (22) and the Dentist (21)

A more detailed analysis of the actual words used in the explanation showed that certain words were used more extensively in the Koeberg scenario than in the other scenarios. For example the use of the word “*dangerous*” is much more prevalent in many of the explanations or the negative effects of radiation are mentioned. For example, this is how another student who scored four points from the Koeberg scenario responded, “*It's the transfer of energy using electromagnetic waves, that doesn't require a medium. Some of it is like radio waves, not tangible but still travels through space. Some radiation is made of small charged particles-bits of atoms-which disrupt tissues. It can't be seen, but it adds energy to other objects. The different types can penetrate-go through certain materials.*”

While at first sight it might be argued that more words would “obviously” lead to better explanations one might equally have expected that a more short but technically correct explanation would be prompted by the word “Physics”. It would seem therefore that students do not simply have a single idea concerning radiation but that the idea is connected to other ideas and concepts as suggested by the “knowledge in pieces” perspective discussed in Chapter 1. Another possibility is that there is an emotive aspect that comes into play due to negative publicity over nuclear power generation.

4.4 Main ideas and emergent categories

Figure 23 shows four sets of histograms. Each set corresponds to one of the four scenarios with the horizontal axis showing the four categories that emerged from the analysis of the written responses while the number of ideas per category is indicated on the vertical axis. The number of ideas for each scenario is: beach (40), dentist (39), Koeberg (51) and physics class (36). Note that the number of ideas (N) exceeds the number of students.

In the beach scenario, there were 33 respondents and seven of them had ideas spread over more than one category. From this distribution we see that the lowest frequency of (2/40) or (5%) is indicated for the categories associated with waves and particles while the highest frequency of 18/40 (45%) is indicated for the categories associated with heat and energy. It is worth noting that in this scenario that almost all the responses are spread over only two of the categories.

In the dentist scenario, there were 35 respondents and four of them had ideas spread over more than one category. From this distribution we see that the lowest frequency of three out

of 39 (8%) is indicated for the category associated with particles while the highest frequency of 16 out of 39 (41%) is in indicated for the category associated with heat.

In the Koeberg scenario, there were 40 respondents and 11 of them had ideas spread over more than one emergent category. From this distribution we see that the lowest frequency of 1 out of 51 (2%) is indicated for the category associated with heat while the highest frequency of 40 out of 51 (78%) is in indicated for the category associated with energy.

In the physics class scenario, there were 32 respondents and four of them had ideas spread over more than one emergent category. From this distribution it is clear that the lowest frequency of 2/36 (6%) is indicated for the category associated with particles. All three remaining frequencies are roughly the same with 12/36 (33%) for the category associated with energy and heat and waves both with the frequency of 11 out of 36 (30%).

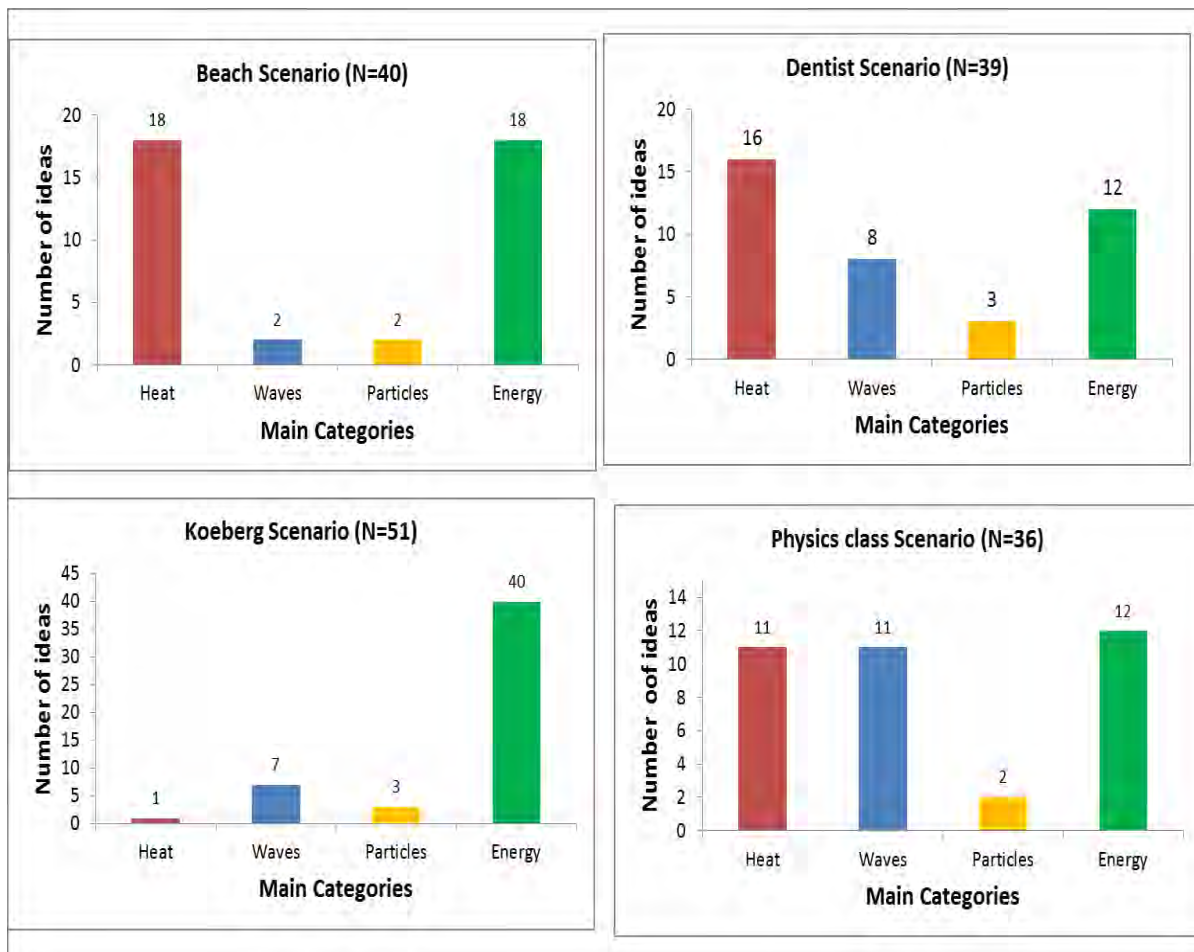


Figure 23 Frequency of ideas per category. Note that N = number of ideas (not students).

Figure 24 shows the percentage distribution of the emergent categories from the data per scenario; where the horizontal axis indicates the emergent categories and the vertical axis indicates the percentage of number of ideas per emergent category in each scenario.

From this distribution we see that “particles” is the smallest category for three of the four scenarios (beach 5%, dentist 8%, and physics class 6%) with the only exception being the Koeberg scenario where the smallest category is “heat” (2%). For three of the scenarios “energy” emerges as the largest category: beach (45%), Koeberg (78%), and physics class (33%) with the exception being the dentist scenario where heat (41%) is the largest category.

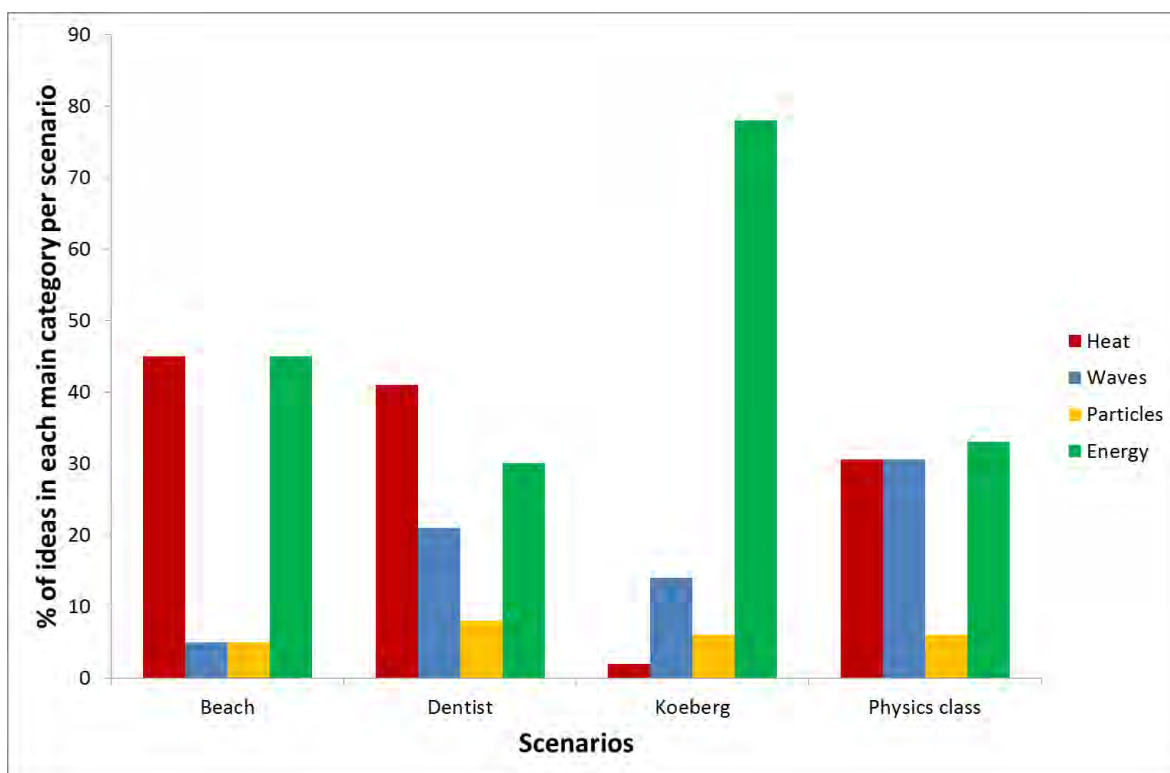


Figure 24 Distributions of the main ideas in each emergent category per scenario (%).

Out of the 166 total ideas that were inferred from students’ responses from all the four scenarios a total of 82 ideas fell into the energy category: beach (18), dentist (12), Koeberg (40) and physics class (12) making the “energy” the largest of the four emergent categories. In contrast there are a total of 10 ideas in the particles category: beach (2), dentist (3), Koeberg (3) and physics class (2) which makes the particles category the smallest of the four. The numbers of ideas per category per scenario are summarized in Table 13.

Table 13 Distribution of student ideas per scenario across the four emergent categories

Category	Scenario			
	Beach N=40 (100%)	Dentist N=39 (100%)	Koeberg N=51 (100%)	Physics class N= 36 (100%)
Heat	18 (45)	16 (41)	1 (2)	11 (31)
Waves	2 (5)	8 (21)	7 (14)	11 (31)
Particles	2 (5)	3 (8)	3 (6)	2 (6)
Energy	18 (45)	12 (30)	40 (78)	12 (33)

4.5 Discussion

The following was noticed, the word count in the Koeberg scenario appeared to be bigger than the word count in all the other three scenarios, but the sample size is too small to make any definitive statement with the data at hand. However, it is suggestive that the Koeberg scenario appeared to activate more ideas about radiation which resulted in more writing that say the responses for the dentist scenario. In addition stronger emotions appeared to be present as for example the response “radiation kills” illustrates. Now this shows that indeed the context (purported scenarios) played part in the way in which students responded as they had written much in others while they had written less in others. And also the familiarity to the context (purported scenarios) played a part when it comes to writing; where students are familiar with the context and radiation they wrote a lot, while where they are not familiar they wrote less. For example, Koeberg (nuclear power station) has the highest average word count, and it does make sense that students wrote a lot on it because there is so much reporting on radiation since the Fukushima incident. While on the other hand they might have less or non-existing information on dentist and radiation, to them relating dentist and radiation might be something new, hence there was not much to write about. When looking at two scenarios which their relationship with radiation is believed to be familiar to the students; the beach happened to have got a higher average than the physics class. Now in this case we may hypothesise that the audience played a role in determining how much the students can write; in beach the audience is a friend, but for physics class the student might have considered audience as a lecturer which then somehow resulted in less writing. Thus it may be the case that different audience had affected the responses, that is, in the case of beach and

physics class context, the difference in the average word used is due to audience dependence whereby the flow of information is easy when it flows from top to bottom (friend to friend, where the friend receiving the information is regarded as novice at the field in question) than when it goes from bottom to top (that is from student to lecturer). This effect was observed by Allie et al. (2008).

From different scenarios we have observed that students mentioned some effects of radiation even though the question just said “explain to your friend what radiation is”. For example in the Koeberg (nuclear power station) scenario 38% of the respondents in that scenario mentioned the biological effects and other effects of radiation; while in other scenarios the percentages are 18% (beach scenario), 17% (dentist) and 15% (physics class), so with these results it shows that these scenarios (which can also be considered as textual priming) primed different ideas in students. Some students when they saw the term ‘nuclear power station’ so many ideas came into their heads (effect of radiation, how dangerous radiation is) and felt they have to share with their friends as asked by the question. While on the other hand we can see that with the physics class scenario about half as many respondents mentioned the effects of radiation as compared with the Koeberg scenario. This shows that the used context played a role in activating students’ ideas about radiation. We can see that with the physics class scenario what triggered the students was technical explanation of radiation, the science behind radiation not the other effects as much as it did to the Koeberg. On the other hand when we look at both beach and dentist scenarios we see that close to 20% of the respondents in those scenarios also mentioned other effects of radiation. In overall when comparing the findings from all the four scenarios; we have discovered that three students used the word danger, saying statements such as ‘radiation is dangerous’ , ‘nuclear power stations produce dangerous gases’. About 17 students mentioned the negative effects of radiation, mentioning statements such as; ‘radiation is a silent killer’ , ‘it causes mutations’ , ‘it causes cancer’ , ‘it destroys DNA’ , and many others; which then shows how broad our cohort’s knowledge is when it comes to radiation. But in their writing, there is no student who mentioned how useful radiation is, none of them mentioned that radiation can be used to cure cancer as one of the example of application of radiation.

Different categories from different scenarios had emerged and showed that the purported scenarios primed different ideas in students’ minds. From the categories that emerged during the analysis of students’ responses as suggested by grounded theory we had found that

radiation had several definitions being expressed by the students, among the most written definitions given are expressing radiation in terms of heat, wave, particle and energy.

As indicated by Stewart et al. (2007) that “students are using “bits and pieces of knowledge” to understand the forces. In this case, the pieces of knowledge may depend on how familiar the student is with the context of the question”. In our study, we have also discovered that students used their “bits and pieces of knowledge” of the contexts in which the questions were asked to state the definition of radiation; this is seen by the frequent use of certain terms in different scenarios. For example; the beach scenario had the most responses where students mentioned sun rays in their responses, while the biological effects and other effects of radiation were mostly mentioned in the Koeberg (nuclear power station) scenario.

The difference in the frequency of the following; categories that emerged, the average number of words used, the non-technical terms used across the four purported scenarios “shows that people represent certain properties quite differently in different contexts” as indicated by Raymond W. Gibbs (2005). And this also shows that the concept of radiation is understood differently in specific contexts.

As stated by Redish (2003) that “long term memory is context dependent. By context-dependent, I mean that cognitive response to a mental stimulus depends on both (1) the external situation and the way in which the stimulus is presented and (2) the state of the respondent’s mind when the stimulus is presented.” Now, when taking the first point for example, we find that in our study the categories which emerged from the data, even though they were the same across the four scenarios, but the differing frequency of each emergent category per scenario showed that the students’ responses were affected by the scenarios which we can call them external situation and also the manner in which the question was asked can be called the way in which the stimulus is presented. In the beach scenario, heat and energy categories had highest frequency, which shows the relationship with the beach scenario as the external situation and also the way in which the stimulus is presented. In the dentist scenario, heat category had highest frequency, which shows the relationship with the dentist scenario as the external situation and also the way in which the stimulus is presented. In the Koeberg (nuclear power station) scenario, energy category had highest frequency, which shows the relationship with the nuclear power station scenario as the external situation and also the way in which the stimulus is presented. In the physics class scenario, heat and

waves categories had highest frequency, which shows the relationship with the physics class scenario as the external situation and also the way in which the stimulus is presented.

Redish (2003) stated that “what people construct depends on context – including their mental states”. And this is seen in how students gave radiation explanations; the students in the beach scenario mostly mentioned heat, sun rays, energy from the sun which shows they constructed the radiation explanation based on the beach context. While on the other hand this was also seen in the Koeberg (nuclear power station), where most responses included the effects and dangers of radiation; which then shows in that scenario students constructed their understanding of radiation in line with how dangerous it is. This is then believed to be influenced by the recent nuclear power stations incident which is much talked about in media. And also in physics class scenario we saw a response where students mentioned that there is an equation associated with radiation, which then shows that the response was constructed depending on the physics context where there are equations in most of the concepts, so mentioning the idea of equation student felt like that is what physics is all about hence worth mentioning.

On the importance of knowledge for the public this is what Brown & White (1987) had to say after their survey on “*The public understanding of radiation and nuclear waste*”, “However, whilst knowledge per se is unlikely to decrease public concern there clearly is a demand for information. Nuclear Agencies receive many thousands of requests for leaflets, films and talks every year and large numbers of the public telephoned for the advice or reassurance following the Chernobyl accident. The reassurance strategy has its problems though. For anxious people it may, in the short term, have the desired effect, but can in the long term confirm the reality of the individual’s anxiety leading them to seek further reassurance” Brown & White (1987, page 70).

With this statement, it shows how important it is for our physics students to have a clear understanding of radiation, because in cases like this, they will be of help in their communities, and also people might not need reassurance as they will already know what radiation is and what it does. At times authorities can give the public information they want to hear, not the real story, hence educating the public about radiation is very crucial, not waiting until there is a radiation related accident, but it should be the knowledge the public and students have at their disposal all the time. The importance of teaching both school

children and even adults about radiation and radioactivity is well outlined by Millar et al. (1990) in his study where they were developing an alternative approach to teaching about radiation and radioactivity; they showed that the two main reasons for them to teach about radiation and radioactivity were; the everyday use of applications of ionising radiation in places such as hospitals, dentists which of course are used by both the experts and novice of radiation and radioactivity; the second reason was that the issues regarding radiation are usually seen in the news media which on the other express the radiation in the context of controversy and public debate.

In this thesis, two studies were undertaken; one was a pilot study which was aimed at establishing the methodology to be used for the main study and the other was this main study which is the core of this work. But when we looked at the two groups of students (pilot study and main study cohorts) we have noticed that the students had demonstrated the understanding of radiation in a diverse way; where other students were only stating their radiation understanding based on what we can call scientific definition, others based on what we can call 'what radiation does' that is effects and dangers of radiation.

Radiation is the term that happens to have different meanings depending on who is using it, particle physicists define it from the nuclear particle point of view, the astrophysicists define it from electromagnetic waves, yet the two are still talking about one thing.

4.6 Conclusion

The aim of this study was to probe students' understanding of the term radiation using different contexts in the form of purported scenarios. Inasmuch as the question was formulated using different contexts the explanations of radiation given by students largely overlapped across the contexts. Thus, when looking at the emergent categories, no specific category emerged from only one context and all the categories that emerged were distributed across all the contexts. When looking at the results from the marking scheme analysis, we found 43% of the students who took part in the study gave the radiation definitions which we considered adequate. However, at a more fine grained level differences in response patterns appeared to emerge although in many cases the sample sizes were too small to make claims of significance.

Thus, with regard to the second aim, to see how “understanding: of radiation might depend on the contexts used in the study; there were strong hints that context indeed played a role in how students answered the questionnaire. Most students in their responses gave a response which can be divided into two parts; “what radiation is” and “information supporting the given definition”. It is from the “information supporting the given definition” where the impact of context was observed as students appeared to use words in line with the context in which the question was asked. For example more students from the beach context mentioned “sun” than in any other scenario. A more striking example was that, in the case of the nuclear power station it appeared that a stronger emotional response was evoked and that lead to longer explanations as well as to explanations in which words like “dangerous” were used. This was in contrast to the other scenarios where there was less indication of such a type of response. .

One rather disturbing aspect was that despite the fact that the cohort comprised students who were starting out to do medical degrees hardly any of them mentioned the benefits of radiation, focussing instead on the negative aspects. In the book titled, “*what is radiation and what you need to know*”, Gale & Lax (2013) pointed that in movies and other media the impacts of radiation is blown out of proportion, so much that other people think nuclear power facilities can just explode at any given time as if it is an atomic bomb. In support of that claim they state, “Certainly there have been explosion within nuclear power plants, but they were not nuclear, and they had nowhere near effect of an explosion caused by nuclear fission. The Chernobyl reactor building was destroyed by a steam explosion, and part of the Fukushima reactor building was destroyed by an explosion of highly flammable hydrogen gas”. However, it is likely that the Fukushima incident may have played a specific role in the students’ perceptions.

In summary, the present work was guided by the following two questions

- (1) What do students understand by the term radiation and
- (2) To what extent do student responses patterns depend on textual priming

The results showed that the answers to the two questions were strongly linked to each other. Firstly, it is clear that the context plays a role and that students do not appear to have a single notion of radiation that is independent of the context, in this case the textual surroundings that appear to activate different response networks. This is in keeping with a “knowledge in

pieces” perspective as discussed in Chapter 1. In turn this has an impact on the quality of explanation that is provided by students. There is some evidence that certain contexts might evoke a more emotional response than others which in turn seems to generate a better quality of explanation but at the same time focussing on the negative aspects of radiation. In summary, though, despite the role that context appears to be playing it seems that on average students did not have adequate notions of radiation such that a physicist would feel comfortable with this level of understanding being imparted to the public at large.

4.7 Future work

While the present work has shown clear signs of context dependence insofar as locating the same question within a different textual scenario this has only been demonstrated at a cohort level. Thus, it would be interesting to see if a single student would respond differently when provided with different scenarios. At the other end of the spectrum the cohort was not large enough so that statistical tests could be done on individual aspects in order to see there are indeed significant differences between specific items. It would therefore be of interest to pursue some of these aspects by large enough sample sizes. Perhaps using only two scenarios such as Koeberg and the Physics Class might be able to highlight such differences. A more systematic study on trying to understand the effect of emotional triggers on students’ responses to what are seen to be pure physics concepts would be also be of interest more broadly as this could have implications for the way in which physics problems are approached at an unconscious level.

One interesting aspect that we noted but did not pursue in detail was the fact that many textbooks used the word radiation in a context specific manner but without necessarily noting that the word had a broader meaning. For example, in many first year textbooks the first time radiation is encountered is in relation to the section on Heat where radiation is used together with conduction and convection. In a similar manner radiation is often only used in terms of electromagnetic radiation, for example:

“Radiation is the flow of energy away from the source carried by electromagnetic waves as they propagate through vacuum to “infinity”. Griffiths (2008)

“Radiation refers to the electromagnetic energy emitted by all objects, the amount increasing with increasing temperature”. Halliday & Resnick (1988)

The question thus arises as to where students in fact learn about radiation as a general term as used in the present thesis. This may be an interesting avenue to pursue and address if we wish our students to be able to inform the public in a meaningful manner.

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6 Appendices

6.1 Appendix A

The following sections; *sources of radiation*, *interaction of radiation with matter*, *interaction of radiation with tissue* and *detecting radiation* are mainly the extracts from the research work that was undertaken by the student herself (Mpeli) while still a student at the African Institute for Mathematical Sciences. In 2012, I (I, here mean the student herself, Mpeli), undertook a research project while I was a student at the African Institute for Mathematical Sciences, and its title was “*Interaction of radiation with matter*”, in that project I looked at the most technical level (equations and graphs) of radiation interaction with matter.

Sources of radiation

Sources of radiation “are the substances that are able to emit radiation. They are classified into natural background radiation and man-made radiation. Natural background radiation is the naturally existing sources of radiation. There are some materials that give off radioactive substances naturally; these include rocks, soil of the earth’s crust and drinking water. The natural background radiation sources include; cosmic radiation, terrestrial, food and drink. The main source of cosmic radiation is the galaxies. It is characterised by the highly charged particles that are given off during explosions of supernova, these are hydrogen nuclei (protons) and helium nuclei (alpha particles). We are and protected by the atmosphere from cosmic radiation and also air that is between our outer space us is also preventing the cosmic radiation from reaching us. But when a flight is at its high altitude its passengers are exposed to this cosmic radiation because there is no enough air between the flight and other outer space. And also people staying in high altitudes they are exposed to more cosmic radiation due to insufficient air between the outer space their buildings. From the food that we eat, some have radioactive substances in them due to the soil they were planted on. And some drinking water is coming from the source that is surrounded by the rocks and soil emitting radioactive substances. Terrestrial radiation, some naturally existing radioactive substances emitted by the soil and rocks include uranium-238 and its decay products (thorium-232 and others) and also radon-222. As for uranium and thorium they can be ingested from water that we drink and from vegetation we eat while radon is inhaled. Radon is a gas, it cannot be seen, smelled or touched, but it is a source of natural occurring radiation and it decays after some

time, hence emitting radiation while already inhaled and then depositing radiation in the lungs. Man-made radiation, these are the radioactive materials created by man, not naturally existing. Man-made materials that emit radiation include television and computer screen, smoke detectors, lantern mantels, building materials, medical X-rays, and nuclear medicine. Some man-made radioactive substances are basically produced by nuclear reactors, these include the following; americium-241, cobalt-60, caesium-137. These radioactive substances emit radiation when used in different ways". (Mpeli 2012)

Interaction of radiation with tissue

"We are constantly exposed to radiation, both natural and man-made. When our tissue is exposed to radiation, there are physical or chemical changes that take place. When radiation interacts with living tissue the same basic interactions take place as described in the *interaction of radiation with matter* above. The living tissue contains mainly carbon, hydrogen and oxygen. Just like in the case of matter, radiation interacts with tissue based on the nature and energy of radiation. Heavy charged particles interact directly with the tissue, just like it does with matter; it deposits energy as it travels through the tissue as well. The heavy charged particles emit their maximum energy within a short range, and that range is called *Bragg peak* which is 2.8cm . So, this range shows that heavy charged particles can cause serious damage when ingested as they emit their maximum energy while in the body. Due to this short range, for shielding the heavy charged particles can be stopped by thin material such as a sheet of paper. Likewise, when light charged particles interact with the tissue, they also lose energy as they travel through the tissue, but their loss per distance travelled is less than that of the heavy charged particles, which means the light charged particles travel more distance in the tissue. Hence for shielding a thicker material like few millimetre of a metal would be needed to stop 1Mev of beta particles. And another is, at times electrons also lose energy by emitting bremsstrahlung radiation as photons which then can be absorbed by the other part of the tissue. So, energy is then being distributed across a large volume of the tissue, though ionisation is still less than that of the heavy charged particles. Neutrons interact with the tissue without ionising. Neutrons at energy of $0.025 - 100\text{eV}$ interact with the tissue mainly through (n,γ) capture reactions. But the main capture process is $n+p \rightarrow d + \gamma$, because the tissue is made up of hydrogen atoms in the form of water and the energy of emitted photon is 2.2MeV . High energy neutrons interact with tissue through elastic collision. Since the tissue is having a high content of hydrogen, then elastic scattering would dominate. During the

collision of and neutron, the neutron would lose more of its energy to proton, and then the recoiling proton would produce ionisation as it slows down. Since the tissue is made up of carbon and oxygen, then neutrons also interact with nuclei resulting in greater ionisation density in short interval (range). For shielding against neutrons a thicker material is needed, because 2Mev neutron travels 6cm before they start depositing their energy. Photons with energy above 40eV and tissue which contains low atomic number of elements, C,H,O interact mainly by Compton scattering. Then the scattered photon can again interact with the tissue by photoelectric effect or Compton scattering depending on how much energy it has. As a result, the energy is deposited in a large area of the tissue. So, few centimetres of lead is needed for shielding against gamma rays, since they are more penetrating” (Mpeli 2012).

6.2 Appendix B

Table 14 Typical Entries in the Spreadsheet used to capture the results of the analysis

RIN	Choice	Summarized student writing	Inferred Main idea
101	C	Radiation consists of EM waves of light at different frequencies, have different radiation levels.	Consists of EM waves of light at different different frequencies with different radiation levels.
102	A	Gamma rays and other types of radiation are EM waves. The idea of a particle is a result of the duality in behaviour.	<ul style="list-style-type: none"> Gamma rays and other types of radiation are EM waves Idea of particle result of duality in behavior
103	A	Radiation can travel through a vacuum.	Can travel through a vacuum
104	A	Radiation has something to do with waves that can cause your cells to create cancerous cells.	<ul style="list-style-type: none"> Something to do with the waves Can cause cells to create cancerous cells
105	A	Remember reading something of the sort. From my understanding radiation is a form of conduction.	Form of conduction
106	B	Radiation is the effect of energised particles in contact with unenergised particles, and causes a molecular disruption. Thus causing a radiated object.	<ul style="list-style-type: none"> Effect of energised particles on unenergised particles Causes molecular disruption and a radiated object
107	A	Radiation is an emission of a certain energy of any form, mostly in terms of heat. And EM waves give forms of radiation from radio --> gamma etc.	<ul style="list-style-type: none"> Emission of energy of any form, mostly heat EM waves e.g. radio to gamma are forms of radiation
108	C	It is both, isn't it; it can act as both a wave and particle as all EM-waves can (like light). It is an EM wave in that it can propagate through a	Can act as wave and particle, as can all EM-waves/ EM wave -propagate through

		vacuum. But it can also interact with matter; as when it forces electrons from the surface of a metal.	vacuum/nuclear particle - can interact with matter, e.g. when forcing electrons from metal surface
109	C	EM waves are produced differently to radiation. Whilst radiation is partially nuclear particles it also includes gamma rays which are not particles at all.	<ul style="list-style-type: none"> • EM waves are produced differently to radiation • Partially nuclear particles, but also includes gamma rays which are not particles
110	A	[No answer]	No idea
111	C	Radiation is a word used to describe multiple phenomena. Some types of radiation, e.g. light, can act as a wave and particle, being deviated by gravity like a particle but acting as a wave in other situations.	<ul style="list-style-type: none"> • Light is the type of radiation • Can act as both wave and particle
112	A	Heard something similar to that [EM waves] on some or other documentary.	EM waves
113	A	Radiation is a form of EM waves because it is a process where energy is emitted from some source, travelling towards something/object so the space it moves in it uses waves.	<ul style="list-style-type: none"> • Form of EM waves • Energy is emitted from some source, travelling towards something/object so the space it moves in it uses waves
114	C	Radiation can be both EM waves (like gamma-rays, X-rays, heat-waves and light) and nuclear particles like alpha- and beta-radiation	Can be both EM waves (e.g. gamma rays, x- rays, heat waves and light) and nuclear particles (e.g. alpha and beta radiation)
115	C	Radiation is a form of which something e.g. heat is transported through air as a medium, and	<ul style="list-style-type: none"> • Radiation is when something e.g. heat

		could be a number of different types of waves, i.e. radiation is the act of waves travelling through air/space/vacuum (where air etc. is the medium)	<p>is transported through air as a medium</p> <ul style="list-style-type: none"> • Radiation is the act of waves travelling through air, space, vacuum, etc.
116	A	[No answer]	No idea
117	C	Am not familiar with what constitutes radiation	Don't know what constitutes radiation
118	C	Don't understand/know much about radiation, but have heard of nuclear and electromagnetic radiation	Nuclear and EM radiation.
119	A	Once learnt in physics that radiation is the release of heating	Release of heating.
120	C	It consists of both EM waves, nuclear particles, but not solely of those two things	Consists of both EM waves and nuclear particles, but not solely of those two things.
121	N	[No response]	[No answer]
122	C	Radiation is just the giving off waves, the waves can contain nuclear or just particles and electrons	Giving off waves, the waves can contain nuclear or just particles and electrons
123	C	It can be both	Can be both EM waves and nuclear particles.
124	A	Light is an example of radiation and light is an EM wave	Light is an example of radiation which is an EM wave.
125	C	Radiation is the emission of waves	Emission of waves.
126	A	EM waves are a form of radiation. But radiation can also consist of nuclear particles that have escaped from atoms such as alpha or beta particles.	<ul style="list-style-type: none"> • EM waves • Consist of nuclear particles (alpha particles, beta particles) which escaped from atoms.

127	C	Radiation is when something is emitted from a focal point	Emission from a focal point
128	A	Radiation can propagate both as electromagnetic waves and nuclear particles. So, both student A and student B are partly right.	EM waves and nuclear particles.
129	C	I choose C purely because I don't know much about radiation so that it consists of something I don't know.	consist of something I don't know
130	A	Radiation is a consequence of certain electromagnetic waves and although it is not a form, it does relate closely.	Not a form of EM wave but a consequence.
131	A	Radiation is a wave because it has a wave nature and it behaves more like an electro magnet. Radiation consists of a charge that form electricity and magnetic field that alternates at about 90 from each other.	An electromagnetic wave
132	B	Radiation is harmful to the body so should consist of nuclear particles.	consist of nuclear particles
133	C	Radiation is the energy released from electromagnetic waves. Electromagnetic waves with high frequencies have more energy.	Energy released from electromagnetic waves.
134	A	While I am unsure about the idea of particles, I know that radiation consists of different waves of varying strength.	Consist of waves of varying strength
135	N	[No response]	[No answer]
136	A	[No answer]	No idea
137	C	Both are radiation. Particle-wave duality.	Particle - wave duality
138	C	I don't agree with either of student A or B's answer on their own. The reason is that Albert Einstein proved that radiation (or "light") behaves as both an electromagnetic wave and as a nuclear particle (photon). "Wave - Particle duality" of light / radiation.	<ul style="list-style-type: none"> • Wave-particle duality of light • Photon is a particle.
139	A	Radiation is part of electromagnetic waves because when light is emitted it radiates.	When light is emitted it radiates.

140	C	Radiation is energy released in the form of electromagnetic waves or particles.	Energy released from electromagnetic waves or particles
141	B	Radiation does consist of nuclear particles.	Consist of nuclear particles
142	A	The option is ambiguous but correct in one way - the 'radiation' that is usually spoken of like that is gamma-rays: a type of electromagnetic waves. However, all electromagnetic waves are 'radiation'.	Gamma rays are a type of EM waves.
143	C	I think that radiation is not a form of electromagnetic waves. Radiation consist of alpha- particles, beta -particles and gamma rays.	Consists of alpha-particles, beta particles and gamma rays.
144	A	Because the spectrum works with radiation so for someone to detect radiation he/ she needs to understand the forms of electromagnetic waves.	Form of EM waves
145	C	I think there are different types of radiation, there is a type that consist of nuclear particles and the type that consist of electromagnetic waves	Consist of nuclear particles and of EM waves.
146	A	Radiation is formed from the rapid acceleration of an electron caused by a gain in energy and when it loses this energy it appears in the form of electromagnetic radiation.	Formed from the rapid acceleration of an electron caused by a gain in energy.
147	C	Although my knowledge of radiation is limited, I believe it is the result of the decay of radioactive element, thus should consist of nuclear particles which could emit electromagnetic waves.	The result of the decay of radioactive element.
148	C	I don't know thoroughly about radiation to take either side.	[no idea expressed]
149	C	Particle-wave duality	Particle-wave duality
150	C	Radiation can be caused by either waves or particles.	<ul style="list-style-type: none"> • Waves • Particles
151	C	No prior knowledge of radiation.	[no idea expressed]
152	A	All radiation is made of electromagnetic waves.	EM waves

153	B	Not quite sure.	[no idea expressed]
154	C	Radiation can consist of either electromagnetic waves or nuclear particles. For instance, radiations like alpha and beta particles consist of nuclear particles, and x-rays and gamma radiation are electromagnetic waves.	Consist of either EM waves or nuclear particles/ Alpha and beta particles consist of nuclear particles, and x-rays and gamma radiation are electromagnetic wave
155	A	Student A is right. As far as I understand radiation it consists of photons (light) that is an electromagnetic wave. X-rays, gamma rays, etc are just photons in highly energised state. Photons are not nuclear particles (from the nucleus of an atom) therefore student B is wrong.	<ul style="list-style-type: none"> • Consists of photons (light) that is an EM wave/X-rays, gamma rays, etc are photons in highly energised state • Photons are not nuclear particles
156	A & B	Well both students A & B seem to be correct. There is nuclear radiation caused by the instability within the nucleus. The sun radiates a large variety of electromagnetic waves	<ul style="list-style-type: none"> • Nuclear radiation is caused by the instability within the nucleus • Sun radiates a large variety of EM waves.
157	C	Radiation is an electromagnetic wave and is emitted from radioactive particles.	<ul style="list-style-type: none"> • An EM wave • Emitted from radioactive particles
158	C	I believe that radiation is both. It is a form of electromagnetic waves and also consists of nuclear particles.	Both form of EM waves and consists of nuclear particles
159	A	I chose this because I read this somewhere and I'm sure I learnt this in physics.	Consists of nuclear particles
160	C	Radiation is what gives super hero's their powers i.e. hulk, Spiderman, etc.	What gives super hero's their powers
161	A	Because even though it consist of nuclear particles, it is still a form of electromagnetic	<ul style="list-style-type: none"> • Consists of nuclear particles

		waves since it has those electromagnetic waves like properties.	<ul style="list-style-type: none"> • Form of EM waves
162	C	Radiation in simple terms could be considered simply as emission of something. As such, not only electromagnetic waves are radiated. With this in mind, radiation does not have to consist of nuclear particles as taking an example of light from the sun which does not require particles to reach the earth.	<ul style="list-style-type: none"> • Emission of something • Both EM waves are radiated and particles e.g. sun
163	C	I believe it has been shown that radiation consists of both electromagnetic waves and nuclear particles.	Consists of both nuclear particles and EM waves.
164	A	[No answer]	No idea
165	A	[No answer]	No idea
166	C	Radiation is heat energy.	Heat energy
167	C	Radiation is a form of electromagnetic waves with an extremely high frequency.	Form of EM waves with an extremely high frequency.
168	B	I'm not sure between A and B but I would think closer to nuclear particles as there are different element in radiation although I do think electromagnetic waves play a part.	<ul style="list-style-type: none"> • Closer to nuclear particles as there are different element • EM waves play a part.
169	C	Radiation could be either one of those two. It depends what type of radiation we're talking about. Depends what type of radiation we're talking about.	<ul style="list-style-type: none"> • Could be either nuclear particles • Or EM waves
170	C	Different types of radiation.	Different types of radiation
171	C	Frankly I don't know much how radiation anymore.	No key idea about radiation
172	A	Radiation is a form of electromagnetic radiation.	Form of EM radiation.
173	A	Radiation comes from the sun and UV light is part of the electromagnetic waves scale.	Comes from the sun and UV light.
174	C	Solar radiation is a form of electromagnetic waves but I actually think it might consist of	<ul style="list-style-type: none"> • Solar radiation is a form of EM waves

		nuclear particles as well. So I guess they are all right?	<ul style="list-style-type: none"> • Consist of both nuclear particles and EM waves.
175	A	Radiation form part of electromagnetic waves since it can be used as magnetic radiations.	Form part of EM waves.
176	A	Am not sure about this one, but I do think radiation consists of nuclear particle and it is an electromagnetic wave, I would learn more towards A.	Consists of nuclear particle and is EM waves
177	A	The word 'Radiation' does not actually refer to nuclear particles, but also a lot of other thing, which a form electromagnetic waves.	Refer to EM waves
178	A	Radiation is a form of electromagnetic waves.	Form of EM waves.
179	C	It's both.	Both EM waves and nuclear particles.

6.3 Appendix C

Table 15 Numerical coding scheme of the inferred ideas from students' responses

codes	Nuclear Particles Category
100	Consists of nuclear particles/ alpha-particles, beta particles and gamma rays/can be nuclear particles (alpha-particles, beta particles)/ can be nuclear particles
110	Effect of energised particles on unenergised particles/ forcing electrons from metal surface
120	Caused by the instability within the nucleus
130	Formed from the rapid acceleration of an electron caused by a gain in energy
140	The result of the decay of radioactive element/ emitted from radioactive particles
150	Can cause cells to create cancerous cells/molecular disruption and radiated object/ harmful to the body.
160	Partially nuclear particles
codes	Electromagnetic waves Category
200	Part / Consists /form /Made/consequence of EM waves
205	Refer to / emission of EM waves
220	EM waves with high/different frequencies/strength
230	EM waves: gamma rays, x-rays, radio, light/wave nature/ consists of photons(light)
240	Sun radiates EM waves/Comes from sun and UV/when light is emitted it radiates/solar radiation is a form of EM wave
250	Travel/propagate through vacuum, space, air etc.
codes	Electromagnetic waves and nuclear particles Category
300	Both EM waves and nuclear particles/nuclear and EM radiation
305	Propagates as both EM waves and nuclear particles
310	Consists of /can be both EM waves and nuclear particles
315	Could be either EM waves and nuclear particles
320	Can be caused by either waves or particles
325	Can consist of either EM waves or nuclear particles
330	Can act as wave and particle, as can all EM-waves
335	Giving off waves, the waves can contain nuclear or just particles and electrons
350	Particle-wave duality

360	Light can act as both wave and particle
codes	Heat Category
400	Form of heat
405	Heat energy/heat transported through air as medium
410	Form of conduction
415	Emission of energy of any form, mostly heat
420	Release of heating
425	Energy is emitted from some source, travelling towards something/Energy released from EM waves
codes	Other Category
500	Emission from a focal point
510	What gives super hero's their power.
520	Emission of something
530	Different types of radiation.

6.4 Appendix D Sample of the probe for four scenarios

Student number:

Physics First Year Questionnaire (PFYQ)

Department of Physics
University of Cape Town
May 2013

Q1.

While sitting at the beach with your friend, your friend turns to you and asks, "What is radiation?"

How would you explain to your friend what radiation is?

Student number:

Physics First Year Questionnaire (PFYQ)

Department of Physics
University of Cape Town
May 2013

Q1.

While sitting on the bench at the dentist with your friend, your friend turns to you and asks, "What is radiation?"

How would you explain to your friend what radiation is?

Student number:

Physics First Year Questionnaire (PFYQ)

Department of Physics
University of Cape Town
May 2013

Q1.

While visiting the nuclear power station at Koeberg with your friend, your friend turns to you and asks, "What is radiation?"

How would you explain to your friend what radiation is?

Student number:

Physics First Year Questionnaire (PFYQ)

Department of Physics
University of Cape Town
May 2013

Q1.

While sitting in the Physics class waiting for a lecture to start, your friend sitting next to you turns to you and asks, "What is radiation?"

How would you explain to your friend what radiation is?

6.5 Appendix E

Table 16 Typical Entries in the Spread Sheet used to capture the Results of the Analysis

RIN	Summarized student writing	Inferred idea
101	Radiation would be a transfer of heat through vacuum, meaning just as heat can be transferred through a metal or any other substance and when heat is transferred through particles, radiation is the transfer of heat through space.	Transfer of heat through vacuum
102	Well, radiation is the ability for an object to transmit heat to and from itself, in the absence of a medium (direct medium).	Ability of an object to transmit heat to and from itself without the direct medium

103	It is the heat energy transferred through the sun, rays to the environment e.g. human and the sun. Therefore this type of heat transfer is not due to molecules moving and passing the energy to the next molecule. I would tell them that it is the reason they feel warm while sitting on the beach.	Heat energy transferred through the sun, rays to the environment
104	Radiation refers to the transfer of heat energy between objects that are not in direct contact with each other (such as heat transfer through a vacuum).	The transfer of heat energy through vacuum
105	Radiation is the transmission of heat without a medium. It does this by means of electromagnetic waves of a certain wave length. The greatest example of this is the sun's UV radiation which travels from the sun to through space (a vacuum with no medium) to the earth's atmosphere.	The transmission of heat without a medium
106	Radiation refers to the transmission of heat without the use of a medium; therefore it can travel through space. A good example of this would be the transfer of 'heat' from the sun, through the vacuum of space, and also the earth's surface.	The transmission of heat without the use of a medium
107	An electromagnetic wave.	An EM wave
108	Radiation is heat or energy being transferred through space without a medium.	Heat or energy being transferred through space without a medium
109	I would say it's the energy the sun gives off and it reaches us as heat. Radiation may cause sunburn and it travels via waves. Radiation may be protected against, but more especially the UV rays, via sunscreen with a good SPF.	The energy given off by the sun which then reaches us as heat
110	Energy from the sun in the form of waves. Radiation can travel in a vacuum as we can see when the sun emits radiation. We end up getting some radiation on earth in the form of gamma, up etc.	Energy from the sun in the form of waves
111	Radiation is small particles emitted in the form of rays as the atoms change from the unstable states to the more stable state. The energy contained by these emitted particles differs in energy levels, some are extremely dangerous (gamma rays) can penetrate almost everything.	Small particles emitted in the form of rays as the atoms change from the unstable to the more stable state

112	Transfer of energy through waves. Radiation can best be described like sun rays as the heat energy from the sun moves through space by waves; it does not require a medium to move from one point to the next.	Transfer of energy through waves without a medium
113	Radiation is the electromagnetic waves that are emitted from mostly the sun to the earth surface.	Radiation is the electromagnetic waves that are emitted from mostly the sun to the earth surface.
114	Emission of absorbed energy to the external environment, e.g. terrestrial radiation, electromagnetic radiation etc. This energy can be propagated in either shortwave or long wave, radiation can alter the structural composition of matter, e.g. cell deterioration, mutations, etc.	Emission of absorbed energy to the external environment
115	Radiation is the emission of energy e.g. heat, light etc. from a source or system into the surroundings. This mostly due to the source having enough chemical energy which it emits as form of heat, light etc. which travels through air or space into the surroundings e.g. the sun's solar radiation.	The emission of energy e.g. heat , light from a source or a system into the surroundings
116	Radiation is the emission of energy from a molecule due to electromagnetic rays, it is advisable to stay away from radiation as it can cause damage to cells and tissues, cancer	The emission of energy from a molecule due to electromagnetic rays
117	Light and heat rays that are transmitted by a source and move from one medium to another medium e.g. your body loses heat into the surrounding air.	Light and heat rays that are transmitted by a source and move from one medium to another
118	A process in which energy particles travel through vacuum.	A process in which energy particles travel through vacuum
119	Energy emitted by the sun, travels as electromagnetic waves, and reaches earth in the form of heat.	Energy emitted by the sun which travels as electromagnetic waves, and reaches earth in the form of heat.
120	Radiation is the emission of heat or transfer of heat through a vacuum or without a medium. The heat is emitted from a source, for example the sun.	<ul style="list-style-type: none"> • The emission of heat from a source, e.g. sun

		<ul style="list-style-type: none"> • Transfer of heat through a vacuum or without a medium
121	The transfer of heat or energy in the absence of a medium.	The transfer of heat or energy in the absence of a medium
122	Heat that is emitted in all directions and it doesn't require a medium to travel through.	Heat that is emitted in all directions and it doesn't require a medium to travel through
123	Radiation is the transfer of heat through space between objects that are not in contact.	The transfer of heat through space between objects that are not in contact
124	Radiation is the transfer of energy in the form of electromagnetic waves.	The transfer of energy in the form of electromagnetic waves
125	The transfer of energy through electromagnetic waves (from the sun).	The transfer of energy through electromagnetic waves (from the sun)
126	The transfer of energy through electromagnetic waves.	The transfer of energy through electromagnetic waves
127	I would explain that it is the process where energy is transferred between objects through space without the need for medium.	The process where energy is transferred between objects through space without the need for medium.
128	It is energy that is transferred through electromagnetic waves i.e. it doesn't need a medium to travel or move through.	Energy that is transferred through electromagnetic waves i.e. it doesn't need a medium to travel or move through
129	Flow or movement of heat through space.	Flow or movement of heat through space

130	I am not too sure because I haven't thoroughly done my work. Electromagnetic waves propagating through air. It is energy from the sun	<ul style="list-style-type: none"> • Electromagnetic waves propagating through air • Energy from the sun
131	The process in which energy is transferred by means of electromagnetic waves.	The process in which energy is transferred by means of electromagnetic waves
132	I would say it is one of the methods heat is transferred. It is different to the other 2 methods as it doesn't need a medium. An example would be the heat from the sun. It travels through space, where there is no air, to the earth.	One of the methods by which heat is transferred without a medium
133	Radiation is energy emitted from an object. In fact when an object releases energy in the form of waves that need no medium to travel through.	Energy emitted from an object in the form of waves and need no medium to travel through
134	Radiation is the transfer of heat through EM waves (not fluids)	The transfer of heat through EM waves (not fluids)
135	It is a type of heat transfer	A type of heat transfer
136	It's a type of heat transfer.	A type of heat transfer
137	Radiation is form of heat transfer without a medium, so it is through a vacuum.	Form of heat transfer without a medium, i.e through a vacuum
138	Radiation consists of waves that cannot be seen, it's often a form of heat transfer. Radiation is also a carcinogen.	<ul style="list-style-type: none"> • Consists of waves that cannot be seen • A form of heat transfer
139	Electromagnetic waves that move in no medium of transportation in a vacuum.	Electromagnetic waves that move in no medium of transportation in a vacuum
140	Radiation is electromagnetic particles that travel in the form of waves. It may cause mutations in the genetic expression of a human which can cause cancer.	Electromagnetic particles that travel in the form of waves

141	Radiation is a method of how heat or energy can be transferred. It consists of electromagnetic rays and does not require a medium to transfer energy.	<ul style="list-style-type: none"> • A method of how heat or energy can be transferred • It consists of electromagnetic rays and does not require a medium to transfer energy
142	It is the transfer of energy through electromagnetic waves.	The transfer of energy through electromagnetic waves
143	The transfer of energy by means of electromagnetic waves.	The transfer of energy by means of electromagnetic waves
144	Heat transfer through electromagnetic waves, transfer which is not conduction or convection.	Heat transfer through electromagnetic waves, transfer which is not conduction or convection
145	Heat transfer through electromagnetic waves, without touching.	Heat transfer through electromagnetic waves , without touching
146	Radiation is the transfer of heat through electromagnetic field.	Radiation is the transfer of heat through electromagnetic field
147	Assuming my friend does physics: Radiation is energy transferred by electromagnetic waves, e.g. rays from the sun.	Energy transferred by electromagnetic waves, e.g. rays from the sun
148	It is the transfer of energy via electromagnetic waves, mate.	The transfer of energy through electromagnetic waves
149	Radiation is the movement of waves in space or in a vacuum and requires no medium.	The movement of waves in space or in a vacuum and requires no medium
150	It is the transfer of heat particles.	The transfer of heat particles
151	Radiation is the transmission of electromagnetic waves from particles.	The transmission of electromagnetic waves from

		particles
152	Radiation is a form of waves which have the potential to be harmful to living organisms.	A form of waves
153	Radiation is electromagnetic wave or energy that is transferred from one place to another in forms of waves.	<ul style="list-style-type: none"> • Electromagnetic wave that is transferred from one place to another • Energy that is transferred from one place to another in forms of waves
154	Radiation is a manner in which heat energy can be transmitted outwards from a central source. Thus comes the heat energy from one place to another in waves.	<ul style="list-style-type: none"> • A manner in which heat energy can be transmitted outwards from central source • The heat energy from one place to another in waves
155	Radiation is the transfer of heat through electromagnetic waves. That is waves that flow through vacuum. This is why we receive the sun's heat because it flows through the vacuum in space to heat the earth through radiation.	<ul style="list-style-type: none"> • The transfer of heat through electromagnetic waves • Waves that flow through vacuum
156	Radiation is transfer of heat particle through a vacuum. The heat particles are transferred via electromagnetic waves.	Transfer of heat particle through a vacuum or electromagnetic waves
157	Radiation is the transmission of heat over a period of time, through rays or waves. Transmission can be emission or absorption.	The transmission of heat over a period of time, through rays or waves
158	The transfer of energy through EM waves (can go through a vacuum)	The transfer of energy through EM waves (can go through a vacuum)

159	Radiation is a form of electromagnetic wave. It has a relatively high frequency and so is damaging to the human body as it disrupts cellular function (due to the energy they transfer). Like all electromagnetic waves they can travel in a vacuum. They are often associated with x-rays (also have a high frequency).	A form of electromagnetic wave
160	The transfer of heat from a body of higher temperature to the surrounding which is of a lower temperature. This transfer of heat does not need a medium to be transmitted e.g. the sun's rays reach the earth by radiation. The heat is transferred from the sun by the sun's rays through space (which is a vacuum) i.e. no material is needed for the transfer of this heat.	The transfer of heat from a body of higher temperature to the surrounding which is of a lower temperature through vacuum
161	Radiation is a form of heat transfer which does not require a medium. An example of radiation is the heat of the sun travelling through space (a vacuum)	A form of heat transfer which does not require a medium
162	Heat energy which travels in rays, and doesn't need a medium to travel in, e.g. heat energy from the sun which travels to us through the vacuum of space.	Heat energy which travels in rays, and doesn't need a medium to travel in
163	Radiation is energy transferred by electromagnetic waves, meaning it can travel through a vacuum.	Energy transferred by electromagnetic waves
164	Transfer of heat from the sun to earth. This transfer requires no medium unlike conduction.	Transfer of heat from the sun to earth which requires no medium
165	Transfer of heat in absence of a medium.	Transfer of heat in absence of a medium
166	Radiation is a type of energy transfer through a wave. There are many different types of radiation like gamma radiation which is very dangerous or visible light which allows us to see. Radiation works through the propagation of waves and obeys a set of well-defined laws and definitions and formulae in physical science.	A type of energy transfer through a wave

167	Radiation is a silent killer. It looks in the shadows and grabs you when you least expect it. It's a wave of tiny particles moving chaotically in an invisible wave. It sinks into your cells and harasses every particle of your being. It can grab you at a hospital, on the phone and even when heating up a microwave meal. Beware of this radiation, it's not friendly.	It's a wave of tiny particles moving chaotically in an invisible wave
168	Radiation is the passing of energy from one thing as electromagnetic waves or as moving subatomic particles.	<ul style="list-style-type: none"> • The passing of energy from one place to another as electromagnetic waves • The passing of energy from one point to another as moving subatomic particles
169	Radiation is invisible. It's the "stuff" that radioactive substances give off. It's very toxic. Radioactive substances are a waste substance from the fission of uranium, I think to make energy. Exposure to radiation can cause cancer. It is why nuclear power plants (like Koeberg) have to be careful - radiation can kill.	The product that radioactive substances give off
170	I would say radiation is a type of energy transfer that does not need a medium to travel in (i.e air or a conductor). Energy can be transferred through a conductor, through convection etc. In radiation usually (if not all the time) involves the sun transferring heat to earth etc.	A type of energy transfer that does not need a medium to travel in
171	Radiation is a type of energy transfer which does not need a medium. An atom emits this energy by means of an electromagnetic wave.	A type of energy transfer which does not need a medium
172	Is the emission of rays. It involves the generating of electricity by using nuclear power. What I also know about nuclear power is that it is dangerous and the gases it emit are dangerous.	The emission of rays

173	Radiation is basically just the energy that a source emits or gives out. This energy then travels through a material or medium. There are different types of radiation such as light, heat and sound.	The energy that a source emits or gives out and it travels through a material or medium
174	Radiation is the process in which energetic particles or energetic waves travel through a vacuum, or through matter-containing media that are not required for their propagation.	<ul style="list-style-type: none"> • The process in which energetic particles travel through a vacuum, or through matter-containing media that are not required for their propagation • The process in which energetic waves travel through a vacuum, or through matter-containing media that are not required for their propagation
175	Basically, you get waves that are electrical and also magnetic (which exists between magnets and electron) and they act at 90° angles to one another. Radiation has waves like these and by means of these waves, energy is transferred over a specific distance. The trick in it, is that the waves don't need a medium to travel through. an example would be the sun, in space there is nothing, so no medium, yet we are able to feel the heat of the sun on earth.	Electromagnetic waves
176	Form of energy moving from one object to another. Energy is emitted in forms of waves. It is harmful to living organisms. Causes biological defects to infants if mother of an infant was exposed to radiation while they were pregnant. Kills people. It's dangerous.	Form of energy moving from one object to another and the energy is emitted in the form of waves

177	Charged particles emitted in nuclear reactions which have the potential to damage human DNA.	Charged particles emitted in nuclear reactions
178	Radiation is a type of energy transfer. It is a wave and is electromagnetic. This means the wave can be propagated through a vacuum or through a medium. This is the way in which the sun transfers its energy to be used by plants for photosynthesis. This radiation is useful in that it can ionise electrons and change the nature and structure of molecules.	<ul style="list-style-type: none"> • A type of energy transfer • An electromagnetic wave
179	Radiation is a type of energy transfer. It is a wave and is electromagnetic. This means the wave can be propagated through a vacuum or through a medium.	<ul style="list-style-type: none"> • A type of energy transfer • An electromagnetic wave
180	Radiation is the transfer of energy (heat) from one source to an object, and doesn't require a medium between the two.	<ul style="list-style-type: none"> • The transfer of energy from one source to an object, and doesn't require a medium between the two • The transfer of heat from one source to an object, and doesn't require a medium between the two
181	Radiation is heat energy that can be transmitted without the need of a medium to do so. An example of this is the heat from the sun that is transported through electromagnetic waves through a vacuum and heats up the earth.	Heat energy that can be transmitted without the need of a medium to do so
182	Radiation is the transfer of energy (heat) through rays which spread out in all directions. It usually carries an enormous amount of energy.	<ul style="list-style-type: none"> • The transfer of energy through rays which spread out in all directions • The transfer of heat through rays which spread out in all

		directions
183	I would say that radiation is just a process in which energy is transferred, without the use of a medium, like electromagnetic waves. Electromagnetic waves are waves consisting of an electricity component and magnetic component. Basically an electric field and magnetic field (vibrate) perpendicular to each other.	A process in which energy is transferred, without the use of a medium
184	Radiation is a type of energy transfer in the form of waves. One body emits energy in the form of a wave. This wave then travels through a medium or through space and it is absorbed by another body.	A type of energy transfer in the form of waves.
185	The energy that is given off by or emitted from an object in the form of waves. If given off with high energies it is able to destroy cells.	The energy that is given off by or emitted from an object in the form of waves
186	Radiation is a form of energy released in particles or waves which can take on the form of heat, light or both, it may be transferred without the use of a medium.	A form of energy released in particles or waves which might be transferred without the use of the medium
187	I would say that it is a process in which energy is transferred by means of electromagnetic waves in others it requires no medium to transfer energy.	A process in which energy is transferred by means of electromagnetic waves in others it requires no medium to transfer energy
188	It is energy that is transferred via electromagnetic waves. Close contact with it could cause damage to cells leading to cancer. Different sources can emit radiation e.g. sun emits UV radiation.	Energy that is transferred through electromagnetic waves
189	The energy emitted via radioactive materials through electromagnetic waves. It causes damage to tissues and other materials.	Energy emitted by radioactive materials through electromagnetic waves
190	Radiation is energy emitted from electromagnetic waves, which can vary from radio waves to gamma rays. Even light (UV) would be a form of radiation.	Energy emitted from electromagnetic waves, which varies from radio

		waves to gamma rays
191	Radiation is the transfer of heat (energy) through space or a vacuum. It is an electromagnetic wave which propagates in a vacuum at a high frequency (UV light). It can cause a lot of damage because of the high energy it transfers due to the high frequency.	<ul style="list-style-type: none"> • The transfer of heat through space or a vacuum • The transfer of energy through space or a vacuum • An electromagnetic wave which propagates in a vacuum at a high frequency (UV light)
192	It is a certain heat and light energy, in the form of electromagnetic waves that can be emitted by an object or substance. Its effects can be harmful causing things such as cancer. It is characteristic of a wave.	A certain heat and light energy, in the form of electromagnetic waves
193	Transfer of energy, can cause cancer.	Transfer of energy
194	Radiation is heat energy travels in electromagnetic waves and no medium is required.	Heat energy that travels in electromagnetic waves and no medium is required
195	Radiation is the energy which is emitted from a source into the environment. It is not visible but is able to penetrate the skin (pass through objects) and is harmful. It is able to destroy cellular material and cause mutations.	The energy which is emitted from a source into the environment
196	Radiation is a lot like light, except higher energy and invisible. It's a wave of high energy particles, the little invisible bullets full of energy. It's given off in nuclear reactions, and can harm you by causing mutations or damage to your cells.	A wave of high energy particles
197	Radiation is the transfer of energy through electromagnetic waves without particles or medium.	The transfer of energy through electromagnetic waves without particles or medium

198	Radiation is the emission of energy by a substance. It is a form of energy transfer which is directly linked to absorption. Heat transfer without a medium, heat other forms of energy.	<ul style="list-style-type: none"> • The emission of energy by a substance • A form of energy transfer which is directly linked to absorption • Heat transfer without a medium
199	Radiation is a process where energy will be transferred with no use of a medium. The energy is transferred by waves, known as electromagnetic waves. Electromagnetic waves consist out of an electric and magnetic fields which are perpendicular to each other.	A process where energy will be transferred with no use of a medium
200	Radiation is the heat energy that can be transmitted through space where there is no material. Also known as a vacuum.	The heat energy that can be transmitted through vacuum
201	Radiation is the transmission of energy (usually heat) from one point to another, without a medium, e.g. the heat you feel when you place your hands close to a beaker of boiling water without you touching the beaker. Heat is radiated from the beaker to your hands without direct contact.	The transmission of energy (usually heat) from one point to another, without a medium
202	Radiation is the movement or oscillation of electromagnetic waves. This is in dependence of wavelength and frequency. At different frequencies and wavelength they have unique properties.	The movement or oscillation of electromagnetic waves
203	Radiation is a form of energy. The electromagnetic spectrum covers all types of radiation and ranges from microwaves to gamma rays. These rays are self-propagating.	A form of energy
204	It's the transfer of energy using electromagnetic waves, that doesn't require a medium. Some of it is like radio waves, not tangible but still travels through space. Some radiation is made of small charged particles-bits of atoms-which disrupt tissues. It can't be seen, but it adds energy to other objects. The different types can penetrate-go through certain materials.	<ul style="list-style-type: none"> • The transfer of energy using electromagnetic waves, that doesn't require a medium • Made up of small charged particles of

		atoms
205	Radiation is the transfer of heat by electromagnetic waves.	The transfer of heat by electromagnetic waves
206	Radiation is the transfer of energy (in the form of heat) with no medium.	The transfer of energy (in the form of heat) with no medium
207	Radiation is a type of energy transfer that occurs between objects without any contact.	A type of energy transfer that occurs between objects without any contact
208	Radiation is a form of energy; it is also a way in which energy can be transferred.	<ul style="list-style-type: none"> • A form of energy • A way in which energy can be transferred
209	The transfer of heat through a vacuum.	The transfer of heat through a vacuum
210	Transfer of energy through vacuum, no medium required.	Transfer of energy through vacuum
211	The transfer of heat through a vacuum, no medium required.	The transfer of heat through a vacuum
212	Transfer of heat through electromagnetic waves. No medium is required.	Transfer of heat through electromagnetic waves
213	Radiation is when heat is transferred without a medium. It's kind of like "look Ma, no medium!" and what the sun does.	When heat is transferred without a medium
214	Radiation is heat that doesn't require a medium. Here's a joke. What did radiation say? "Look ma, no medium!" haha:)	Heat that doesn't require a medium
215	Radiation is a type of electromagnetic wave, which essentially consists of electric and magnetic fields that move through space like a wave. So it's like light, and a good example would be UV radiation from the sun.	A type of electromagnetic wave, which essentially consists of electric and magnetic fields that move through space like a wave

216	Radiation is energy emitted from a source in the form of waves that can travel through a medium or no medium and be absorbed by matter (increasing that matter's energy) e.g. the ion radiates heat to the earth, absorbed partially by atmosphere and rest by earth. None absorbed or lost to space.	Energy emitted from a source in the form of waves that can travel through a medium or no medium and be absorbed by matter
217	Radiation is electromagnetic waves that are emitted by source and can often be harmful to its targets. It can be caused by the sun or even active chemicals and can cause mutations in living organisms. It can penetrate almost all substances except lead.	Electromagnetic waves that are emitted by source
218	Heat that needs no medium to be transferred. So it is transferred via electromagnetic waves through a vacuum from the sun.	Heat that needs no medium to be transferred
219	Heat energy that can be transferred without a medium. Electromagnetic waves emitted from the sun	Heat energy that can be transferred without a medium
220	Transfer of energy, can cause and abnormal growth.	Transfer of energy
221	Radiation is a wave-an electromagnetic wave which does not need a medium for it to travel. It can cause the ejection of electrons from a metal surface, and it is potentially carcinogenic	An electromagnetic wave which does not need a medium for it to travel
222	Radiation is an electromagnetic wave which travels in a transverse wave pattern and can move in vacuum (requires no medium for propagation). It could be produced by the sun or radioactive decay substances.	An electromagnetic wave which travels in a transverse wave pattern and can move in vacuum
223	Radiation is energy that is transferred over long distances and does not require a medium.	Energy that is transferred over long distances and does not require a medium
224	Transfer of heat or energy, no medium. Sun.	Transfer of heat or energy, no medium
225	The movement of electromagnetic waves through mediums causing heat.	The movement of electromagnetic waves through mediums causing heat
226	Radiation is the transfer of energy through electromagnetic	The transfer of energy

	waves.	through electromagnetic waves
227	Radiation is the transfer of energy from a source.	The transfer of energy from a source
228	I would say: "Radiation is the gradual dissipation of energy from a molecule. It is the transfer of energy involving no contact."	<ul style="list-style-type: none"> • The gradual dissipation of energy from a molecule • The transfer of energy involving no contact
229	I would say that it is a form of energy transfer using waves. I would also tell him that there is a formula associated with it. That radiation is affected by nature of surface, can travel through vacuum.	A form of energy transfer using waves
230	The transfer of heat through waves, from a hot to cold object. Radiation is also to do with gamma waves, nuclear waves, deformities, etc.	.The transfer of heat through waves, from a hot to cold object .Gamma waves, nuclear waves
231	A type of heat conduction which does not need a medium to go through.	A type of heat conduction which does not need a medium to go through
232	It is an electromagnetic wave that doesn't need a medium. It is a form of heat.	<ul style="list-style-type: none"> • An electromagnetic wave that doesn't need a medium • A form of heat
233	The process of radiation is when particles or energy is transmitted without a medium. There is therefore no contact between the source and the receiver. That's why you can, for example feel the heat from an object when you stand close by, but you're not in contact with it.	<ul style="list-style-type: none"> • When particles are transmitted without a medium • When energy is transmitted without a medium
234	Radiation is the transmission of all electromagnetic waves due to perpendicular propagation of an electric field generating a magnetic field. Thereby it is continuously and does not require a medium.	The transmission of all electromagnetic waves due to perpendicular propagation of an electric

		field generating a magnetic field
235	Radiation is electromagnetic waves emitted from a source that doesn't need a medium to travel through and can cause changes in objects it encounters.	Electromagnetic waves emitted from a source that doesn't need a medium to travel through
236	Heat energy which travels in rays and does not require a medium. E.g. Heat of the sun moving through outer space (vacuum).	Heat energy which travels in rays and does not require a medium
237	Imagine a vacuum, for example space. Nothing makes up space. There is no medium. Just imagine. Now consider the fact that you can see stars. This is electromagnetic radiation, or light rays. They radiate through space (no medium). One can view radiation in terms of heat which passes from object to object without direct contact. So, which radiation are you asking me about?	<ul style="list-style-type: none"> • Electromagnetic radiation, or light rays • Heat which passes from one object to the other without direct contact
238	The movement of energy through electromagnetic radiation without the need of a medium.	The movement of energy through electromagnetic radiation without the need of a medium
239	The f*ck I know? B*tch. Go google that sh*t.	No main idea expressed
240	Radiation is a type of electromagnetic wave, a wave where the electric wave and magnetic wave oscillates at right angles to each other. They are of relatively high frequency and can travel in vacuum.	A type of electromagnetic wave, a wave where the electric wave and magnetic wave oscillates at right angles to each other

6.6 Appendix F

Table 17 Coding Scheme of the inferred ideas from the four scenarios

	Main Categories
CNMP	Heat

H100	Heat from the sun/stars
H101	Emission of heat
H102	Heat transported through air as medium
H103	Transfer/transmission of heat through vacuum/no medium
H104	Movement of heat through space
H105	Heat and light rays
H106	Heat emitted in all directions
H107	Transfer of heat energy through the sun rays
H108	Transfer of heat through EM waves
H109	Transfer of heat
H110	Transfer of heat through electromagnetic field
H111	Heat which does not require a medium
H112	Form of heat
CNMP	Waves
W200	Electromagnetic wave
W201	Electromagnetic waves that are transmitted/emitted from the sun
W202	consists of waves
W203	Movement of waves in space/vacuum/no medium
W204	Transmission of EM waves
W205	Form of waves/form of EM waves
W206	EM waves transferred from one place to another
W207	wave of tiny particles
W208	Energetic waves that travel through vacuum or matter/ EM waves propagating through air
W209	Wave of high energy particles
W210	Movement/oscillation of EM waves
W211	Movement of EM waves through mediums
W212	Gamma waves, nuclear waves
W213	EM wave that does not need medium

CNMP	Particles
P300	Particles from decaying atoms
P301	Particles of energy
P302	Electromagnetic particles
P303	Transfer of heat particles
P304	Transfer of heat particles through a vacuum
P305	Energetic particles that travel through vacuum or matter
P306	Charged particles emitted in nuclear reactions
P307	Made of small charged particles
P308	Transmission of particles without a medium
CNMP	Energy
E400	Emission of energy /Energy emitted/ Energy emitted from source
E401	Energy from the sun/Energy emitted by the sun/Energy from the sun in the form of waves
E402	Emission of energy by waves
E403	Emission of energy by EM rays
E404	Transfer of energy through vacuum/without medium
E405	Transfer of energy in the form of EM wave/waves
E406	Transfer of energy through EM waves/waves
E407	Energy emitted in the form of waves
E408	Transfer of energy
E409	Transmission of heat energy
E410	Heat energy which travels in rays and need no medium to travel
E411	Passing of energy as EM waves or as moving subatomic particles
E412	Energy that travels through a medium
E413	Energy released in particles or waves
E414	Energy emitted by radioactive materials through EM waves

E415	Energy emitted from EM waves
E416	Heat and light energy in the form of EM waves
E417	Heat energy that travels in EM waves
E418	Heat energy that can be transmitted through space where there is no material
E419	Form on Energy
E420	Emission of energy without medium
E421	Movement of energy through electromagnetic radiation without the need of a medium