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Pre-Conceptions in Action in the Construction of Semantic Networks

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ABSTRACT

This research concerns how people use their pre-existing knowledge to make sense of scientific information presented by the media. It describes a group interview study conducted with Brazilian secondary school students, who were asked to summarise their shared understandings of a text about radioactivity by constructing a semantic network. Proposed nodes included entities and events mentioned in the text while proposed links included class/subset links, activity links (describing actions performed or suffered by elements represented in the nodes) and influence links (describing more indirect interactions). Instructions given emphasised the need for an agreement of what should be represented in the net. The group discussion which accompanied the construction of the net, revealing students' attempts to make their views explicit along the debate, were tape-recorded and aided to clarify the meaning of links and associations made. The analysis proposed measurements of network structures and used a PROLOG program written to reveal which inferences were allowed by each net making a comparison between groups possible. Results show that students' prior conceptions (as assessed in a related study) influence associations made, mostly as long causal chains with few interconnections. Possibilities of using related activities in the classroom are also discussed.

OVERVIEW

This paper describes and discusses the results of an interview study conducted with groups of Brazilian secones the use of semantic networks with the purpose of both eliciting and representing knowledge (Norman & Rumelhart, 1985). It is part of a research project which investigated systematically how people use commonsense to make sense of scientific /

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technological information with public importance as it is presented in the media. The position adopted here privileges people's potential competencies of using their pre-existing knowledge to interpret scientific information over the mere exposure of the public's ignorance of specific bits of scientific information. This position will also be reflected by avoiding the confrontation of students' ideas explicitly with scientifically accepted ones.

In the study conducted, students were asked to read a text containing information about radioactivity, comment upon their difficulties in making sense of the information presented and summarise their shared understandings by constructing a semantic network. The construction of the semantic networks was proposed as a concrete activity which would stimulate students to make explicit some of their views on the subject, as well as to reveal strategies employed to interpret and make sense of the information, as the group tries to reach a consensus about essential information that should constitute the summary. At the same time it was hoped to benefit from the more specific nature of the associations which can be made in the semantic network to understand better some of the associations made in connection with radioactivity as assessed in related studies.

Data constituted of the actual networks mounted by students and of the transcripts of the group discussion which took place during the construction of the nets. The transcripts were used so as to understand better the meaning attributed to links in the network, to "fill in" more links, to characterise better the construction and evolution of an argument, and to identify previously detected patterns of responses.

Semantic networks were used as a way of exploring how students would organise and structure the information contained in a text. They also provided 'motivation' for a complementary discussion about their understandings of radioactivity. Underlying these two aspects is a primary concern with the kind of thinking involved in making use of previous knowledge in order to make sense of new related information. The discussion of students' understandings as shown by the nets was done with respect to both their difficulties in interpreting information contained by the text and how pre-conceptions may shape the understanding of new related information.

SAMPLE

Altogether, 13 groups of 4 were interviewed. Whenever possible the balance between the number of boys and girls in each group was kept. Groups were formed by students who belonged to the same class. All students participated in the study in a voluntary basis and were in their final year of secondary school.

THE TEXT AND STUDENTS' UNDERSTANDINGS

The text students were presented with contained information about the nature of radioactivity and its effects on matter. It begins with a description of radioactivity as a process which involves nuclear disintegration, energy release, formation of new atoms and emission of one or more types of radiation. It then presents comparisons between the power of penetration of different kinds of radiation and the potential damage caused by exposure to, inhalation and ingestion of radioactive material. Examples related to the Goiânia radiological accident[1] are given to illustrate these points. This is done in three paragraphs, which end with information about Caesium 137 transforming into Barium 137 after emitting one particle. The text goes on with a discussion of the transformations it causes in matter. Ionisation is described as a process in which electrons are removed having as an effect, changes in the characteristics of molecules which can be observed macroscopically. Such changes are also described for the case of interaction of radiation with living tissue. The consequences of exposure to radiation is either total destruction of or changes in the way cells reproduce. This explains why radiation is capable of both causing and help the treatment of cancer.

[1]In September 1987, a medical device was taken from an abandoned hospital and opened by force in Goiânia, an inland city in Brazil. The device, formely used for radiotherapy contained 28 g of Caesium chloride, which was separated into pieces after the lead shield was violated. The ignorance of the dangers of manipulating radioactive material caused several casualties. This event was widely covered by the media at the time it happened, and the text selected for this research is an example of many others published in connection with the accident.

Occurrence of cancer after exposure to radiation is described as a statistical probability. The last paragraph explains how radioactivity is measured and defines the Curie as the number of disintegrations of a given radioactive material per second. It also presents data about the activity of the teletherapy device involved at the accident of Goiânia. (see Appendix 1 for a transcription of the text).

Criticisms about the text concentrated on two related issues, namely the language used and the audience to which the text was supposedly addressed. It was considered by many students as too "*technical*", containing a lot of statistics. In addition, knowledge of chemistry and mathematics was thought to be required for its comprehension.

> ***A**: Well... I think I have learnt much more talking than reading this text because it's too technical, it has a lot of statistics and numbers... these numbers here at the end...I didn't understand this bit very well. I think that what really interests us is left behind.*
>
> *...*
>
> ***M**: The most important bit is that it modifies the atoms, when it passes through matter it modifies the atoms.*
>
> ***A**: OK., but for a person who has not studied physics or chemistry, a lay person ... for example this thing of 3.7 x 10 to the ... it interests us because we are at school and we know what it is. But a lay person, who doesn't know anything about it, will simply skip it.*
>
> ***A**: How it propagates, what it is, what can we do in case of contamination, these kinds of thing. How will it get you? How does it affect you? The ways it contaminates, what can you do to stop it...*

The nature of decay was clearly problematic for some students who appeared to have difficulties with this notion. That might have been reinforced by the way numerical information is presented in the text. Although the text did not present a qualitative explanation, the mere reference to rates of decay and simple proportion calculations were enough to provoke a negative reaction in some students. In fact, what a Curie represents, remained obscure for most students, even after reading the text. It was not understood properly as a unit of measurement and the closest they could get to understanding its meaning is exemplified below. This quotation may also suggest that, perhaps for some students, a meaningful unit is that which, perhaps, gives some indication of the "power of a radioactive material", maybe in terms of its effects (on matter) .

> "***R***: *I really didn't understand what a Curie is...*
>
> ***Ve***: *Curie is a measurement of the ... they've used it to... to explain... to determine the force of Caesium or of the radiation...*
>
> ***R***: *No... but, what's its consequence? I mean what is its power? For example... 1 Curie... what is its power?*
>
> ***R:*** *I mean... is it a lot... is it a little... what is it? We need more specific information here.* (NS3)

A few students suggested a possible comparison with energy in order to understand better the nature of radioactive decay. They would associate the radiotherapy device to a non-renewable source of energy (*"...if you've got a battery at home, it releases energy, it is used up, it hasn't got a way of using more energy ... to replace energy"* NS2) and propose analogies with known more familiar systems in order to explain how it might occur (*" ... if you picked up a light bulb and put it inside a black-box with only a small hole. Then you could control whether you wanted more or less light.* NS2). Despite being widely employed in students accounts, analogies and images of radiation were not depicted in the nets mounted by students mostly because of constraints imposed by the selection of nodes and links available (for an account of analogical type of explanation involving radioactivity related phenomena see Martins, 1992).

On the other hand, the text was considered as containing lots of *"new important"* information about radioactivity, such as the existence of different types of radiation, how ionising radiation is used in Medicine and the definition of half-life. The way it affects the human body was also considered "well explained" and was carefully read by most students to whom it was a main concern.

Nevertheless when asked which was the main message of the text, nearly all students' responses contained some reference to the dangers associated with radioactivity and its applications. Some typical responses were "*to inform the population of the dangers that Caesium represents to mankind*" (NS2). However, some attenuated comments like, "*to warn people that Caesium is an element that can help as well as be harmful to people*" (NS4) were also made, though less frequently. This is consistent with the fact that, in a related questionnaire study (Martins, 1992) **danger** was the most significant and prevalent feature in students' responses to questions related to properties attributed to the concepts of radiation, radioactivity and radioactive material. This associations were also frequently found in the networks students constructed and illustrate how deeply rooted convictions found their way through the interpretation of the information from the text.

The credibility of the information conveyed in the text was raised as an issue for discussion by some students. Most of them thought that the information “must” be true, for two main reasons. One was that it came from an interview with a specialist and the other was that it would not have been accepted for publishing if it was not true or reliable. However, a point made by a few students was that, be it true or false, they, as lay people, would not have any other alternative but to believe in it as they had no means to either question the facts or verify the results presented. The quotation below illustrates this point.

> *“**AE**: I think the text is OK.. It’s well explained and so on. But if it wasn’t... I mean... there is no way to know. There’s no way I can tell. I would have to calculate if I want to know... if I want to be sure... I would have to have the equipment to detect... and that’s not possible for an ordinary person.”* (NS4)

This suggests that some people feel, in a sense, alienated from this kind of knowledge. In fact this raises the issue of how much or which kind of knowledge one should have in order to analyse information critically. It is often argued that, owing to their lack of knowledge, people ultimately rely on the opinion of experts. Although this may be the case for most people, a problem arises when two experts hold opposing views on the same subject and people have to analyse the two lines of argument and decide in favour of one. In that situation, the question arises of how much knowledge, or which kind of knowledge one would need to be able to follow an informed debate. Some students' opinions converge to a view where both information and knowledge required by people are, in general, dependent on the relevance they might have for the lay person in daily life situations. This is exemplified by the quotation shown next.

> ***A****: But this* [rates of decay] *is not so important in the daily life. The important thing is to know whether or not it is dangerous. You don't have to make calculations to know that.*
>
> ***Se****: But if there were no calculations... people need the calculations to know it is dangerous.*
>
> ***A****: I know. But what really interests people is whether or not it is dangerous, people don't need to do calculations, people just can't do it. Can you imagine if everybody had to make some sort of calculation to decide whether it is dangerous or not?* (NS2)

Aspects, such as those mentioned above, concerning ownership and credibility of information were not captured in the nets. Nevertheless they are mentioned here as a relevant dimension of analysis of students' understandings even though they will not be further discussed in this paper. One reason for that was the nature of the task (making a summary by means of a net) and the selection of the nodes and links available concerned the content of information rather than the contexts it may be conveyed.

THE CONSTRUCTION OF THE NETS: TASK ADMINISTRATION

Students were asked to read the text individually (which took them 12 minutes in average) and, later, to make a summary of what they considered to be the main ideas contained in the text, by means of constructing a semantic network. After having read the text, they were presented with twenty-six cards corresponding to a list of entities, processes, objects, etc., covering most of the concepts mentioned in the text, which were to be used as the nodes in the network.

Similarly, there were eleven cards representing the labelled directed relationships which should be used to link nodes in the diagram. Links could be the classic class/subset links (is a kind of, etc.) or activity links, denoting the effects nodes could have upon one another (creates, destroys, etc.). Links could also denote a more indirect influence of one concept upon the other (prevent or allow). Links might provide an indication of the kinds of causation involved. By contrast to links, which could be used as often as necessary, nodes could not be repeated. Nodes and links were fixed so as to allow comparability between the networks.

Students were allowed to consult the text whenever they judged necessary and were encouraged to discuss and justify their propositions. Instructions given also emphasised the need for an agreement on what should be represented in the net. No time was set in advance to complete the task. The average time spent by the groups was 30 minutes. The discussion which accompanied the mounting of the net was tape-recorded and transcribed, to clarify the meaning of links and associations. A list of all nodes and links is as follows:

NODES	LINKS
Radioactivity	is an example of
Nuclei	is a kind of
Atoms	is an amount of
Energy	is a part of
Radiation	creates
Rays	causes
Particles	provokes
Paper	produces
Person	destroys
Aluminium	prevents
Caesium 137	allows
Lead	
Barium 137	
Electrons	
Cells	
Cancer	
Time	
Probability	
Radium	
Disintegration	
Emission	
Penetration	
Substance	
Transformation	
Ionisation	
Curies	

Table 1: Nodes and Links allowed in the Semantic Networks.

DISCUSSION OF RESULTS

The table below shows the number of nodes and links used in each net. Totals and breakdowns for school are given. The figures in the table reveal that, on average, nets were constructed using 14 of the twenty six nodes provided connected by 15 links.

NODES		LINKS		
		Class/Subset	Activity	Total
MS1	14	2	15	17
MS2	14	7	9	13
MS3	17	3	14	17
MS4	16	6	12	18
MS5	13	4	9	13
MS6	20	4	17	21
MS7	12	4	9	13
NS1	16	6	11	17
NS2	15	3	10	13
NS3	13	3	11	14
NS4	17	5	14	19
NS5	14	4	10	14
NS6	8	2	4	6

Table 2: Numbers of nodes and links per net

The fact that nets were constructed using only half of the links provided suggests that students were quite selective in relation to the information they decided to include in their summaries. Table 3 contains information about frequency of use of each proposed node and link. It shows that the nodes radiation, lead and cancer were used in all nets. In fact, a closer examination of the nets reveals that references to *radiation / radioactivity / radioactive materials as able to cause cancer* and to *lead as capable of preventing them* are present in all the nets. Links such as 'cause', 'produces' and 'provokes' were used to express this idea. In the case of lead being capable of ‘preventing’ radiation / radioactivity / radioactive materials, the link ‘prevents’ meant essentially ‘prevents propagation’ or ‘blocks’. Other nodes used in most nets were energy, rays, particles, cells, transformation, Caesium

137, Barium 137. They were either connected among one another by links like ‘is a kind of’ (e.g. Caesium 137 - produces -> Barium 137) or by activity links such as ‘destroys’, ‘provokes’ or ‘produces’ (for example in Radiation (- is a kind of ->) Energy - destroys-> Cells, NS1; Radioactivity - produces -> Particles, NS3).

The table also shows that nodes such as Nuclei, Electrons, Probability and Radium as well as the link ‘is a part of’ were hardly ever used. It also shows that processes such as, Emission, Penetration and Ionisation, were mentioned less often than were physical entities.

The table also shows that ‘activity’ links were used much more often than class/subset links. ‘Destroys’, ‘produces’, ‘causes’ were often associated with negative effects of radiation, radioactivity and radioactive materials, and ‘prevent’ was used in connection with the idea of lead shielding. ‘Produces’ was used to denote the idea of generate whereas ‘causes’ was used to denote the idea of make happen. ‘Is an amount of’ was used nearly just to express the relationship between Radioactivity and the Curie. ‘Is an example of’ was regarded by students as giving an indication of strong similarity and, for this reason, was avoided many times, with ‘is a kind of’, to which a vaguer connotation was attributed, being preferred instead.

‘Allow’ was used to refer to an action which although necessary was not sufficient to cause a given effect. One example is Time - allows -> Ionisation (MS4). In general links are used to indicate ‘negative actions’. Examples of these are: Radiation - provokes -> Cancer (MS1), Radioactivity - causes -> Cancer (MS3) , Radioactivity - destroys -> Cells (MS2), Caesium 137 - destroys -> Person (MS1).

An overall view also suggests that, most nets, despite their diagrammatic arrangement, consist of linear ‘chains’ of nodes, with interconnections being, in fact, rare. This is illustrated by the contrast between figures 1 and 2.

NODES	MS	NS	Total	LINKS	MS	NS	Total
Radioactivity	5	5	10	is an example of	7	2	9
Nuclei	0	0	0	is a kind of	13	14	27
Atoms	4	3	7	is an amount of	6	7	13
Energy	6	6	12	is a part of	0	0	0
Radiation	7	6	13	creates	6	4	10
Rays	7	4	11	causes	12	9	21
Particles	6	6	12	provokes	12	7	19
Paper	2	2	4	produces	11	14	25
Person	3	3	6	destroys	13	13	26
Aluminium	2	2	4	prevents	10	11	21
Caesium 137	6	5	11	allows	6	1	7
Lead	7	6	13				
Barium 137	6	4	10				
Electrons	1	1	2				
Cells	5	6	11				
Cancer	7	6	13				
Time	3	1	4				
Probability	0	1	1				
Radium	1	0	1				
Disintegration	5	3	8				
Emission	5	0	5				
Penetration	2	3	5				
Substance	4	2	6				
Transformation	6	4	10				
Ionisation	3	2	5				
Curies	3	3	6				

Table 3: Frequencies of use of nodes and links in the semantic networks

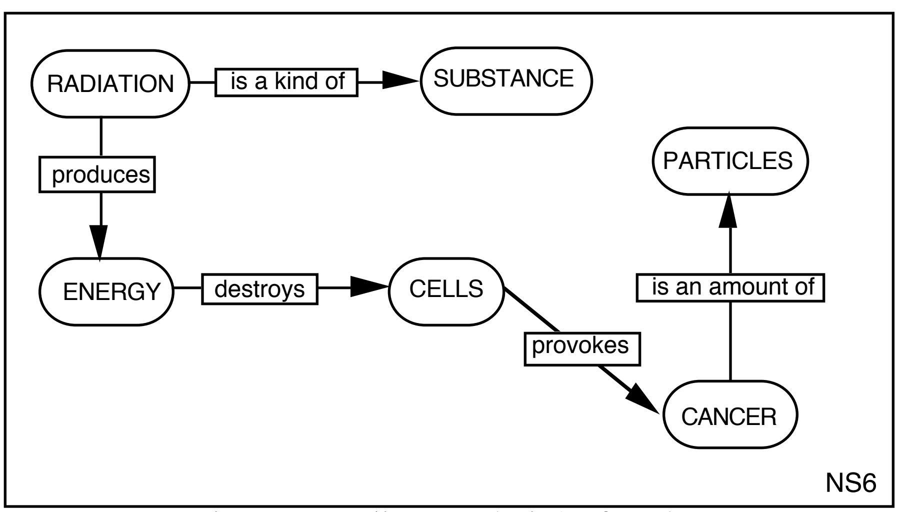

Figure 1: A linear ‘chain’ of nodes

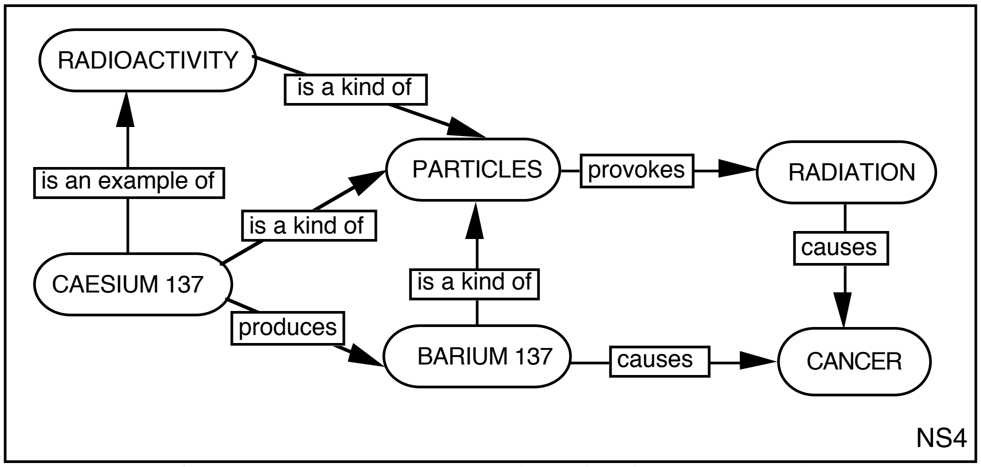

Figure 2: Interconnected nodes in a network

One indication of how structured a net is, is the ratio between of the number of links to the number of nodes. It is easy to see that the maximum ratio between links and nodes in a net which has *n* nodes (where each node is connected to one another) is (n-1)/2. The table below compares these numbers with the actual ratios, as calculated for each net.

	$\left(\frac{\text{links}}{\text{nodes}}\right)_{\text{máx}}$	$\frac{\text{links}}{\text{nodes}}$
MS1	6.5	1.2
MS2	6.5	1.1
MS3	8.0	1.0
MS4	7.5	1.1
MS5	6.0	1.0
MS6	9.5	1.1
MS7	5.5	1.1
NS1	7.5	1.1
NS2	7.0	0.9
NS3	6.0	1.1
NS4	8.0	1.1
NS5	6.5	1.0
NS6	3.5	1.3

Table 4: A measurement of net structure

This table also repeats, indirectly, the information about how many nodes were used to construct each net. On average, each net contained fourteen nodes. The ratio between links and nodes is in most cases slightly greater than one indicating that the number of links is approximately the same of that of nodes. This is consistent with the general view that diagrams set out by students were mainly chains of nodes.

A more sensitive measure of how structured a net is obtained by dividing the total number of links associated to each node (either "departing" from or "arriving" at each), by the total number of nodes. Theses figures, shown in Table 5, represent better the degree to which a net presents more or less connections. For example, in the case of nets NS4 and NS6, whereas the ratios of links to nodes differ by just 0.2, the ratio between the total of all links associated to each node to the total number of nodes differ by 0.9. In fact this quotient reveals differences which would not be noticed just by inspecting table 5, such as that between NS1 and MS6.

	all links/nodes
MS1	2.3
MS2	2.2
MS3	1.6
MS4	2.2
MS5	1.7
MS6	2.3
MS7	2.2
NS1	1.9
NS2	1.5
NS3	2.2
NS4	2.2
NS5	2.0
NS6	1.3

Table 5: Another measurement of network structure.

As further way looking at the nets, the computer language PROLOG was used to answer the question, " Given a net, how many inferences can be made from it ?". For example, given:

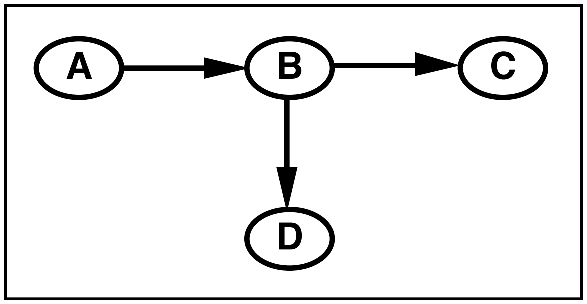

Figure 3: Scheme of an arbitrary net

If arrows are causes, it is possible to infer, besides A-->B, B-->C, B-->D, the more indirect inferences A-->C and A-->D. The same can be done for indirect inferences with ‘is a’ relationships.

PROLOG is a programming language adapted to logical inferences (Bratko, 1990). Each pair of two entities and a link from a semantic network are expressed in PROLOG as rules with the following general form: LINK(ENTITY 1, ENTITY 2). For instance, in the net of MS2 (shown in figure 4), the program is as follows:

PROLOG programme for MS2 Net

```
prevents(lead, radioactivity).
prevents(lead, caesium).
destroys(radioactivity,cells).
destroys(ionisation,cells).
produces(caesium,barium).
provokes(radioactivity,ionisation).
allows(atoms,cancer).
is_kind_of(caesium,substance).
is_kind_of(barium,radiation).
is_kind_of(radiation,energy).
is_kind_of(radiation,rays).
is_kind_of(radiation,rays).
is_kind_of(radiation,particles).
is_kind_of(radiation,atoms).
is_example_of(ionisation,transformation).
```

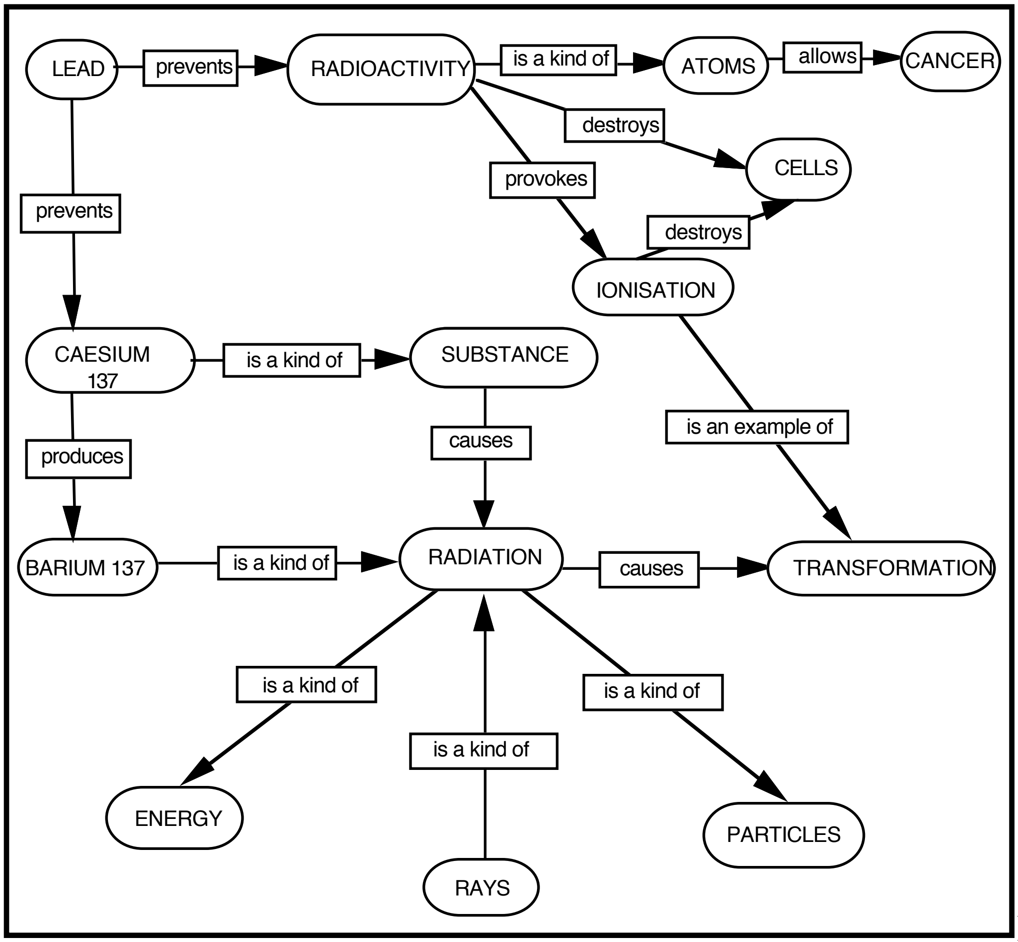

Figure 4: Semantic Network MS2

There are other facts, which, although not explicitly represented in the nets and therefore not stated as clauses in the programs, can be inferred from this net. For instance, from the following facts: (Lead - prevents -> Radioactivity) and (Radioactivity - provokes -> Ionisation), is possible to infer that (Lead - prevents -> Ionisation). Likewise, things which are seen as kinds of radiation, such as, for example, energy, rays and particles, can also be inferred to cause transformation, as radiation causes transformation[2].

Meta-rules were added to define sequences of links. An 'is a' chain was defined as any chain if 'is a' links. An 'activity chain' was defined as any chain containing causal links only, which could be of several kinds. A 'causal chain' was defined as any chain consisting of 'is a' links or causal links, but with at least one causal link.

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[2]This is actually a statement of the "inheritance" property of the semantic network.

A PROLOG programme works by answering queries. In the analysis, queries could ask how many links or chains there were of a given kind, or what they were, what links or chains led from or to a given node, or whether two given nodes were connected, directly or indirectly.

Questions about numbers of links or chains allow some comparability among the nets, giving an indication of the nature of the relationships between the entities chosen. Other questions allow the identification of particular relationships which may be of interest. For example one may want to know to what extent the concepts of radiation, radioactivity and radioactive material are seen as differentiated or not. A typical query aiming at listing all the case where some kind of class/subset relationship is obtained is :

Q: is_link(X,Y)
A: X,Y

In the case of MS2 net, the answers are:

radioactivity,atoms
barium,radiation
caesium,substance
radiation,energy
rays,radiation
radiation,particles
ionisation,transformation
barium,energy
barium,particles

The program works by searching for 'is a' links, as they were defined, and prints the cases which match the query, displaying the node at the beginning of the link (head) and the node at the end of the link (tail).

In this example, the nature of all is_a links indicate, once more, the confusion between the concepts of radioactivity, radiation and radioactive material (as exemplified by Caesium and Barium). It is possible to check whether this is a feature that appears in all nets by checking directly what the associations of the is_a type are for each of the concepts. This convenience makes easier the identification of well known misconceptions and also facilities the spotting of certain association. For example, in the case of radioactivity, this query would be:

Q: is_link(radioactivity,Y)

A: Y

It is also possible to search for causal chains with the following query:

Q: cause_chain(X,Y)

A: X,Y

For MS2, the answers are:

caesium,barium
radioactivity,ionisation
substance,radiation
radiation,transformation
ionisation,cells
radioactivity,cells
lead,radioactivity
lead,caesium
atoms,cancer
radioactivity,cancer
barium,transformation
caesium,radiation
caesium,radiation
caesium,energy
caesium ,particles
caesium,energy
caesium ,particles
radioactivity,transformation
substance,energy
substance,particles
lead,atoms
lead,substance
caesium,transformation
radioactivity,cells
substance,transformation
lead,ionisation
lead,cells
lead,cancer,
lead,transformation
lead,cells
lead,cancer
lead,transformation

lead,cells
lead barium,
lead,radiation -
lead,radiation
lead,energy
lead,particles
lead,energy
lead,particles
lead,transformation

Repeated pairs indicate that different paths were found linking them.

Combining these results with an inspection of the net, it is possible to see that out of the 44 causal associations allowed by the net, 9 involved the association of two nodes, 16 involve three nodes, 13 involve four nodes and 3 involve five nodes. They all have the form of ‘chains of activity’. For instance, Lead --prevents --> Caesium -- produces --> Barium -- is a kind of --> Radiation -- causes--> Transformation.

Some chains include both causal and ‘is a’ links, giving an indirect causal relation. Consider, for example, the case of the association between Rays and Transformation. The program takes into consideration the relationship Radiation -- is a kind of --> Rays and infer that a ray, as being a kind of radiation, which is associated to transformation, must be associated (may be causing) transformation too. In this net there are three cases of these more indirect inferences, namely that between Lead and Cancer and that between Lead and Radiation. As the nature of associations of this kind have to be guessed, they will not be discussed in this analysis.

A similar analysis was done for all the nets and table 6 summarises information concerning the number and the kinds of inferences allowed by each of the nets.

NETS	Inferences			Is_a	Amount_of	Causal				
	Direct	Indirect	Total			Direct	Indirect	Activity	Mixed	Total
MS1	17	15	32	2	0	15	15	21	9	30
MS2	16	33	49	9	0	9	31	24	16	40
MS3	17	16	33	0	3	14	16	30	0	30
MS4	18	22	40	5	2	12	21	26	7	33
MS5	13	8	21	3	1	9	8	15	2	17
MS6	19	31	50	0	3	16	31	47	0	47
MS7	13	5	18	4	0	9	5	12	2	14
NS1	16	24	40	4	2	10	24	13	21	34
NS2	13	25	38	2	1	10	25	15	20	35
NS3	13	14	27	3	1	10	13	20	3	23
NS4	18	35	53	6	1	13	33	28	18	46
NS5	14	30	44	4	1	10	29	26	13	39
NS6	6	3	9	1	1	4	3	7	0	7

Table 6: Number and types of inferences allowed by semantic networks.

From table 6 it is possible to see that there seems to be little difference between the two groups, in so far as the number of inferences allowed by the nets is concerned. Most of the links are causal and the majority of the causal associations correspond to causal chains which link at least three nodes. The only exceptions are nets MS7 and NS6 which do not allow as many inferences as the others.

Examples of parts of networks containing long chains of activity, or causal chains, are shown in figures 5 and 6. In most cases they include both positive and negative links. From an analysis of such causal links, it is possible to see that Radiation, Radioactivity, Caesium, Barium and Energy are seen as essentially active concepts, having in most cases more arrows either departing from or arriving to them than processes such as Ionisation, Penetration and Transformation have. Processes were not connected to many nodes either, with the possible exception of Disintegration which was more frequently associated to Atoms, Particles or to radioactive materials. One reason for this may be the stronger emphasis given to this process in the text. Cells, Particles, Substance, Atoms and Time are, on the other hand, examples of concepts which were not connected to as many nodes as those mentioned above.

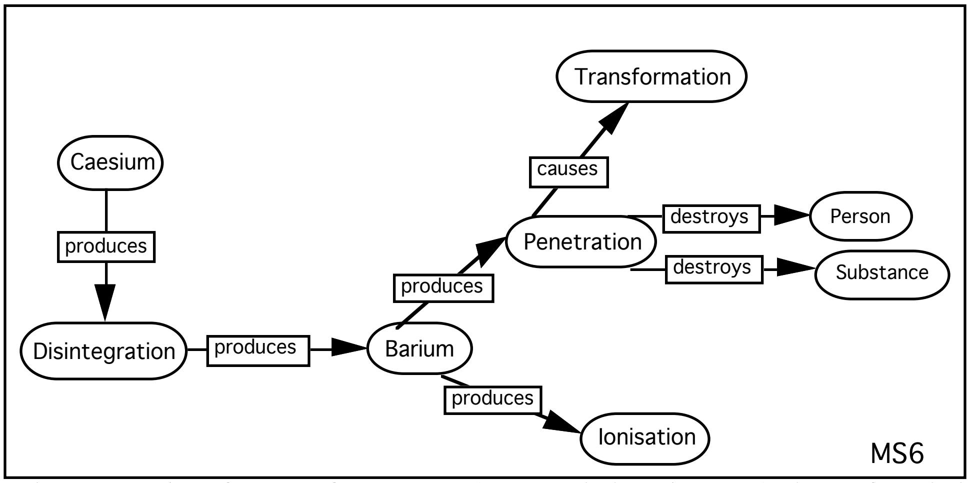

Figure 5: Example of part of a network containing long chains of activity (I).

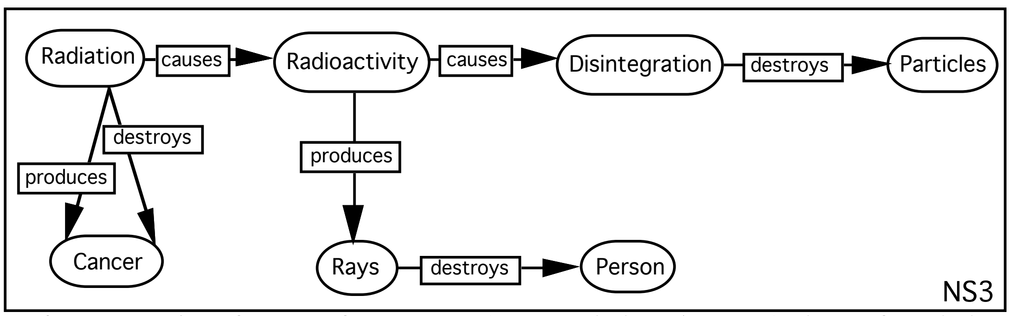

Figure 6: Example of part of a network containing long chains of activity (II).

Finally, instances of the confusion between substance and activity and substance, as observed earlier in media reports as well as in students' responses to a written questionnaire and interviews (Eijkelhof, 1990; Martins, 1992), were also observed in the networks. One example is from net NS4. The association Curies -- is an amount of --> Barium, together with Barium – is a kind of --> Particles, leads to Curies being associated with Particles.

THE NETS AS SUMMARIES OF THE TEXT

Since the networks were constructed by students with the objective of summarising the text, it is interesting to examine how far the information contained in the nets relates to the information contained in the text. An analysis of the nets in relation to the text will involve then looking for:

What is *in the text* and *in the net* ?
What is *in the text* and *not in the net* ?
What is *in the net* and *not in the text* ?

Table 7 shows which items of information were present in the text only, in the nets only or in both. The types of information listed in the first column correspond to the researcher's interpretation of the main ideas contained in each paragraph of the text and of some associations made by students.

	MENTIONED IN THE TEXT	*TEXT NOT NET*	*TEXT AND NET*	*NET NOT TEXT*
RY - disintegration - forms other atoms	✓	✓		
RN as emission of particles / rays	✓		✓	
Different power of penetration of α,β,γ particles	✓		✓	
Caesium 137 transforms into Barium 137	✓		✓	
Ionisation - changes in characteristics of molecules which constitute atoms	✓		✓	
Ionisation - changes in living tissue	✓		✓	
Radiation both helps treatment and increases chances of getting cancer	✓		✓	
Possibility of developing cancer is statistical probability	✓	✓		
Radioactivity is measured in Curies	✓		✓	
Activity decreases with time	✓	✓		
Relationships between RY, RN and RM				✓
Type relationships between atomic particles and radiations / Nature of radioactive elements				✓
Effects of cancer on people				✓

Table 7: The Nets as Summaries of the Text

It is possible to see that students rarely included information which was not in the text in the nets. In fact, in most groups, students tried to be as complete as possible, including all information available in the text that they could and avoiding interpretations of their own. One type of extra information they did mention was that about the type relationship between radioactive materials and atomic particles. When they did include information of this type, it was regarded by them as additional information that could be omitted without spoiling the meaning of the activity link. This is illustrated by figures 7, 8 and 9, where such extra information is shown in bold.

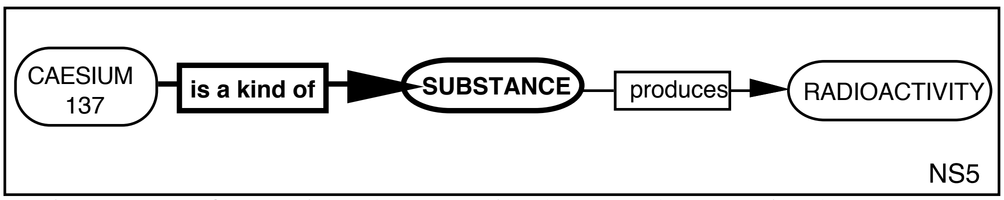

Figure 7: Information that was in the nets but not in the text (I).

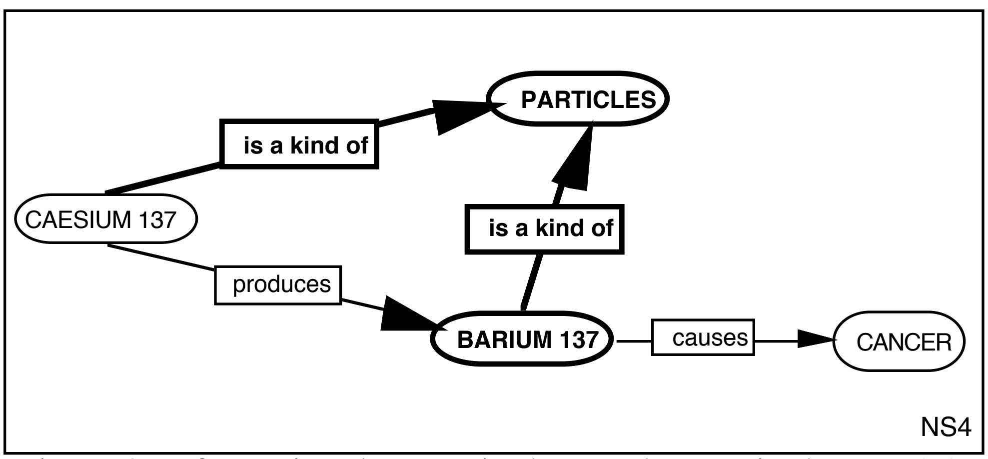

Figure 8: Information that was in the nets but not in the text (II).

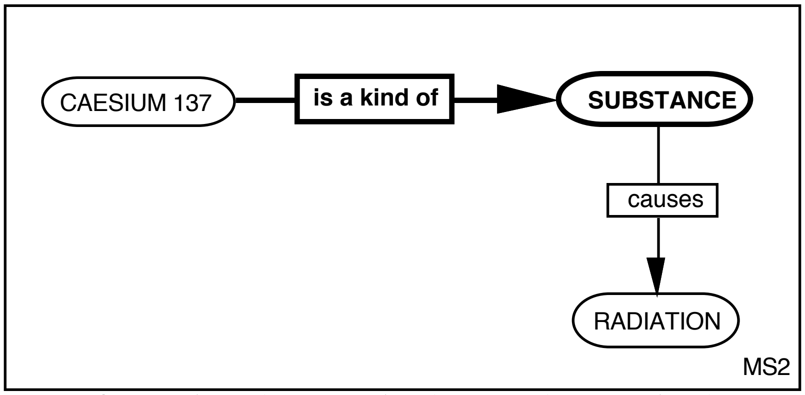

Figure 9: Information that was in the nets but not in the text (III).

The other type of information that students included in their nets, that was not explicitly mentioned in the text, related to their own knowledge about the effects of cancer on people. About half of the nets included information about people being ‘destroyed’ both directly and indirectly, by radiation, cancer or radioactive materials. In this case, the link ‘destroys’ was used as meaning ‘kills’.

Despite not being overtly discussed in the text, relationships between the concepts of radiation, radioactivity and radioactive material were made explicit by all but one group. Links attached to these concepts were both class/subset and activity links. A closer analysis of the class/subset links used reveals more about possible differentiations between them.

Radioactive materials were more often associated with particles, atoms and substance, though there were a few cases of links with rays and radiation too. Radioactivity was also associated with particles, atoms, radioactive materials and substance, but more often with radiation, energy and rays. Only once was it associated with a process, namely that of emission. Radiation was equally associated with particles, substance, atoms and radioactive materials, and with rays, radioactivity and energy.

Direct associations made between radiation and radioactivity were not as many as one might expect in view of the strong pattern of undifferentiation between these two concepts as suggested by a related questionnaire study results (Martins, 1992). Although the text does not contain an explicit discussion about the nature of these concepts, many students noticed that the words were used in two different contexts. That was revealed by hesitation in employing the two words as synonymous during the discussion of the net. That does not mean students were able to differentiate the concepts at all. In fact, the confusion between the concepts became hidden. The two examples shown in figures 10 and 11 are used to illustrate the points above.

In these nets, Caesium 137 is seen as able to create/produce/provoke both radiation and radioactivity. Radiation is also seen as a kind of energy and as able to provoke/cause cancer by both groups. Similarly, the information that radioactivity is measured in Curies was translated as ‘Radioactivity <-- is an amount of --> Curies’ by the two groups. It is also the case that in the two examples Radiation has more links attached to it, whilst Radioactivity is only associated to Curies. In the net shown in figure 11 it is Radioactivity (and not Radiation) which is seen as a kind of emission, denoting some confusion between the two concepts. For this reason, it is not possible to understand the different associations made with the concepts as an indication that students perceive a distinction between the two. In fact, that might be only related to an attempt to be faithful to the text.

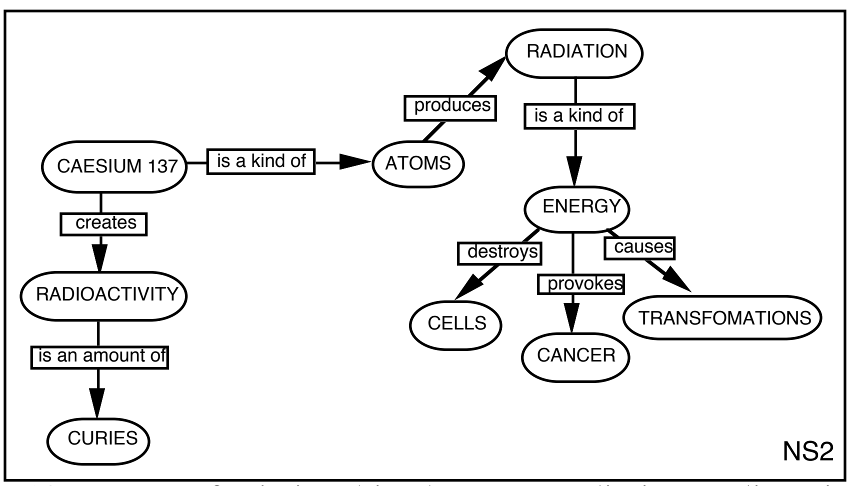

Figure 10: Nature of relationships between radiation, radioactivity and radioactive material (I)

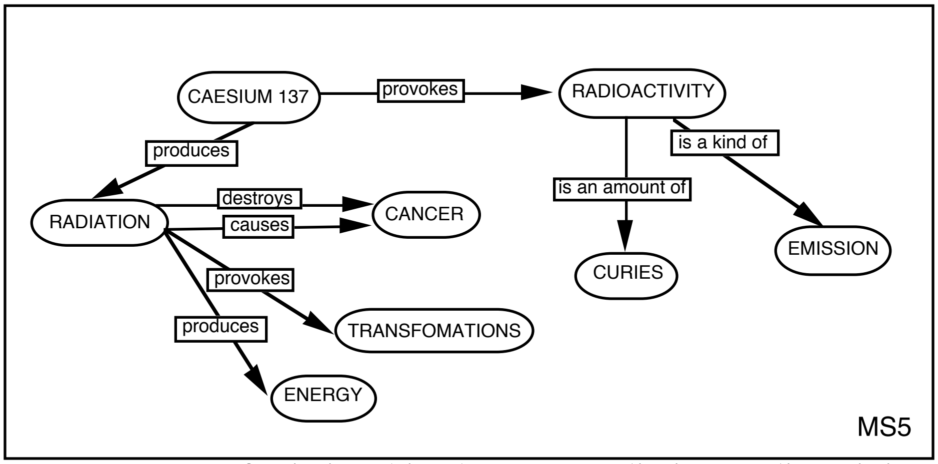

Figure 11: Nature of relationships between radiation, radioactivity and radioactive material (II)

All three concepts are seen as essentially active, in that the number of activity links which are associated to each of them usually outnumbers those of class/subset type. It was also possible to find in most nets 'chains of activity', that is, nodes connected by activity links only. Many of them emphasised the destructive character of radiation/radioactivity/radioactive material on matter.

Information which was both contained in the text and which appeared frequently in the nets related mainly to the effects of ionising radiation on living tissue. This links with the strong interest in knowing more about "how radiation affects both living and non-living things" as identified in a related quantitative study (see Martins, 1992). It relates also to the fact that most of the students considered the main message of the text to be "a warning of the possible dangers of radioactivity to mankind" as reported in the last section. Examples of that are shown below in figures 12 and 13.

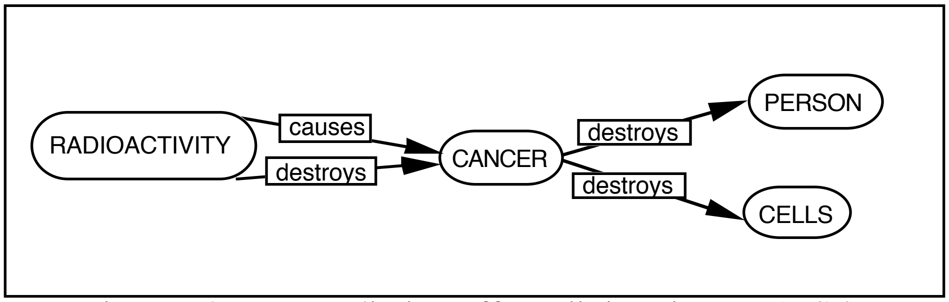

Figure 12: How radiation affects living tissue I (NS5)

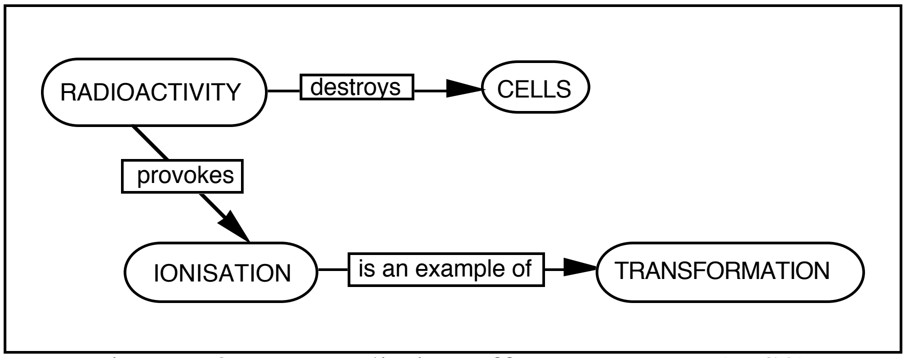

Figure 13: How radiation affects matter II (MS2)

In fact, all nets contained reference to damage caused by ionising radiation to cells and to it as causing cancer or destroying the person or cells. In half of the nets this view is more balanced, with students mentioning that radiation is also used to treat (destroy) cancer. This mainly 'negative' view of radiation is consistent with students' answers in a related questionnaire study, which were found to be related to a factor called danger (Martins, 1992).

Many nets contained references to the fact that radiation, radioactivity and radioactive materials can be seen as 'kinds of' as well as 'producing' particles and/or rays. Examples of this are shown in figure 14. Again, the similarity in the associations made in connection with any of the three concepts (radiation, radioactivity and radioactive material) seems to reinforce the argument for the undifferentiation among them.

Figure 14: The Undifferentiation of the Concepts.

There were three types of information which were left out in the construction of the nets. One was the characterisation of radioactivity in terms of the process of disintegration and the formation of new atoms, which appeared only in three out of the thirteen nets analysed. Another related to activity decreasing with time and the influence of time in the effects of exposure to ionising radiation. A third was that concerning the probabilistic effects of exposure to ionising radiation. In this case, however, it is not possible to determine to what extent this is due to constraints imposed by the nature of the links allowed or whether it reflects a deliberate choice of the students. Nevertheless, it can be argued that a similar problem of awkward representation could have also affected representing the idea of activity decreasing with time. Some students insisted on having this represented in the net, making it clear this is what they meant by links of the type 'Time – allows --> Disintegration' (MS3). "Allows" was, therefore, used to express "happens as time goes by'.

FINAL REMARKS

It was possible to see that pre-conceptions appear to influence students' understandings (as revealed and represented by the semantic networks they mounted), in as much as:

(a) Students were able to accommodate their pre-existing ideas into the network without worrying much about a final overall coherent structure. An example of this unproblematic juxtaposition of ideas is the idea that radiation 'is a kind of' or 'produces' energy. Although not present in the text, it could be found in many of the nets.

(b) Pre-conceptions also selected contexts of interest and topics to be represented. Studies about students' understandings of radioactivity (Eijkelhof, 1990; Martins, 1992) reveal that most of the information available comes embedded in a background of danger and the associations made with harm, destruction and risk are the most frequent. Furthermore, radioactive contamination and safety issues concerning exposure to ionising radiation are mentioned by students as a major concern. From this perspective, it is not surprising that associations involving radioactivity/radiation/radioactive materials with destruction, cancer, etc. are found in most nets. This kind of association is also such that very few groups bother to try and describe/explain how it happens, with only a few mentioning the process of ionisation. Another indication is that effects of cancer on people (Cancer – destroys --> People) are also included in the net.

(c) The nets show how radioactivity, radiation and radioactive materials are undifferentiated concepts in so far as they are ‘kinds of’ one another and that they do similar things. This undifferentiation is also widely reported in the literature (Eijkelhof, 1990; Martins, 1992).

(d) Part/whole relationships (as expressed by 'is a part of' link) were also seen as problematic and rarely used in the nets. One example of that is that atomic particles appear to be more often thought of as produced or created by radioactive materials than as being ‘a part of’ radioactive materials. Similarly, there is a disagreement as to whether Caesium 137 transforms into Barium 137 or whether Barium 137 is actually an example of Caesium 137.

(e) Students’ thinking tends to be structured in terms of linear chains of activity with few interconnections between concepts.

In so far as the use of the semantic networks as a complementary methodology for eliciting and representing knowledge is concerned, it is possible to say that:

(a) The engagement in the construction of the net provided a focus for the discussion, stimulated the debate between students (who had to make their views explicit and to persuade one another when negotiating a consensual view) and allowed an insight both on the content and structure of their ideas about radioactivity. The outcome corroborates information already found out about students’ ideas on radioactivity (e.g. undifferentiation of concepts) and highlights some new aspects of such ideas. (e.g. material/immaterial nature of radiation);

(b) The PROLOG programme allowed the identification of “indirect” inferences, that is, relationships that are not stated as clauses but which can be inferred from the net. It is interesting to point out that this feature can be of special help for students if, for example, they are given the chance to examine the output of the programme. It may be the case that by having their attention called to a specific indirect inference allowed by a given net, students are able to identify or to make explicit what may tacit assumptions. Similarly, it may help in making them aware of the full extent of the implications of some of their ideas. These two points may be of particular value within a constructivistic approach to teaching.

(c) In the case of radioactivity one of the most significant features of students' thinking is the use of analogies both in relation to its nature and to processes through which it acts. It is perhaps investigating to what extent, given a wider range of possibilities and contexts, whether it would be possible to capture criteria for judgements resting on similarities in which analogies would be ultimately be based upon.

(d) The nets alone do not provide a fair picture of students' actual use of prior knowledge when process of making sense of new information in as much as they provide a more static picture. It is the transcripts and the recording of successive stages of development of a net which provide some insight into this matter. Nonetheless the measurement of both the structure and 'activity' of a net and the identification of the kinds of inferences it allows gives a fair idea of knowledge that may not be explicit but which can be derived from students' associations. The nets might not however allow the representation of contracdictory information without spoiling the possibility of an interconnected structure. That may explain why, for many groups, the net resembled a linear chain of nodes linked by independent relationships.

ACKNOWLEDGEMENTS

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APPENDIX: Text read by students.

RADIATION LASTS FOR THREE CENTURIES

In 2300, atomic waste will still be emitting 1 curie.

Radioactivity is a natural process through which certain nuclei of atoms disintegrate, releasing energy and, forming, in general, new atoms. In this process, there is the emission of one or more types of radiation: the alpha and beta particles and the gamma rays.

The alpha particles have little power of penetration and can be stopped by a simple sheet of paper. It is worth mentioning that a person exposed to alpha radiation is caused damage only on her skin.

The beta particles are a bit more penetrating than the alpha particles. They are able to pass through a sheet of paper, but they do not pass through, for instance, a final foil of a light metal, like aluminium. For a person exposed to beta radiation, the damages caused go beyond the skin, but are not deep either, unless the person has ingested or inhaled a substance which emits beta radiation. In this case, the particles would provoke greater damage, because they would be emitted from inside the body. That was what happened with the girl Leide das Neves Ferreira, who ingested the caesium 137 together with a boiled egg. Caesium emits beta particles when it disintegrates.

The gamma rays are much more penetrating. Thick layers of lead are the only thing they cannot pass through (that's why the lead shielding in the coffins of the victims of Goiânia). Thus, a person exposed to gamma radiation, for a long time, is caused damages in inner tissues of her body. When it disintegrates, caesium 137 transforms into barium 137, which emits gamma rays. That is why the victims from Goiânia were exposed to two types of radiation - beta and gamma.

When radiation passes through any material, it modifies the atoms of this material. This modification is called ionisation, that is, radiation takes electrons out of the atoms, changing the characteristics of the molecules constituted by these atoms (there are industrial applications in which radiation is deliberately used to change a given material, making it, for example, harder or more flexible).

When radiation passes through living tissue, it ionises [the] atoms of the tissue as well.

The consequence is that the cells that form this tissue are either destroyed or start to reproduce in an abnormal way. Actually, this is the very reason why, radiation is used to treat cancer but it can cause cancer too. Applied with proper care, in scientifically calculated doses, during a calculated time as well, and directed only to the organ which needs treatment, radiation kills the cancered cells. Applied without control, it may turn healthy cells in cancered cells. The frequency of when the cancer could happen is a statistical probability, as emphasises the medical doctor, Luiz Renato Caldas, chief of Radiology Unit of the "Servidores do Estado" Hospital. It is not guarantied that an irradiated person will develop cancer, it's the probability that increases.

Radioactivity is measured in curies, as a tribute paid to the French-Polish researcher Marie Curie, who studies and clarified its mechanisms, having discovered, at the beginning of the century the element radium and, who died of cancer. As the physicist Aquilino Senra Martinez, from the Coppe/UFRJ (Co-ordination of Post Graduate Studies in Engineering of the Federal University of Rio de Janeiro), explains, one curie is equivalent to 3.7×10^{10} disintegrations per second. This means that one curie is equivalent to the radiation emitted by the disintegration of 37 billion of atoms per second. The CNEN (National Commission of Nuclear Energy) informs that medical device destroyed in Goiânia had, in 1971, when it was first made, a total activity of, 2000 curies. That is to say that, at that time, 74 trillion of atoms disintegrated (and, therefore, emitted radiation) in each second. When the caesium disintegrates it becomes barium. Because of that, last month, when the device was destroyed, there were less atoms inside it than in 1971 (the CNEN estimates that in September the activity of the device had already decreased to 1370 curies, that is, 50 trillion 690 billion of caesium atoms disintegrating per second).

Jornal do Brasil, 01.10.87